Message

From: Johnson, Steffan [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=EBA5C0DFC5FC4593AFA62CE7C3DD6F02-JOHNSON, STEFFAN]
Sent: 3/24/2021 6:24:22 PM
To: Lisa Rector [lrector@nescaum.org]; gallen@nescaum.org
Subject: RE: IDC and TEOM sop version

Lisa,

Thank you. The QA/QC pieces remaining won't be answered until our ORD validation work gives us the answers, I believe. So we should put in some general language, or wider windows than we are expecting the validation work to eventually clarify, just so that there are ***some*** qa/qc requirements.

Is that helpful?

That said, moving forward it would be good to have those posted and static (until we have data to fill in some of the QA/QC bits).

Let me know if there are other questions that this raises.

Thanks very much!

Stef

From: Lisa Rector <lrector@nescaum.org>
Sent: Wednesday, March 24, 2021 1:28 PM
To: Johnson, Steffan <johnson.steffan@epa.gov>; gallen@nescaum.org
Subject: RE: IDC and TEOM sop version

Stef, we only have the filter version up on our website. We do not have the EPA research protocols posted, neither the IDC protocol or the dichot. Should those be posted? If so, we will need to finalize the dichot SOP. I believe that protocol still has remaining comments that are unaddressed. I believe George is waiting for input before he can finalize.

From: Johnson, Steffan <johnson.steffan@epa.gov>
Sent: Wednesday, March 24, 2021 1:22 PM
To: Lisa Rector <lrector@nescaum.org>; George Allen <gallen@nescaum.org>
Subject: IDC and TEOM sop version

Lisa and George,

Please see Ben's note below. I'd like to be able to point everyone to the correct, (and to a static) IDC and TEOM SOP.

I am not sure the version ben refers to is correct? Isn't this the filter based version we used for the Alaska IDC ATM?

Please advise and if you could provide links to the correct /current versions, it would be great to keep us all on the same page moving forward.

Thank you!

Stef

From: Alben T. Myren Jr <myren.ben@gmail.com>
Sent: Wednesday, March 24, 2021 12:51 PM
To: Johnson, Steffan <johnson.steffan@epa.gov>
Subject: INFO

Stef,

I am in receipt of your email dated 22 March 2021 which contains a discussion of EPA's past efforts and plans for the future. Given that there have been multiple different drafts of the IDC test method that have been circulated over the past few years, I want to ensure that the version I have is correct before I offer any comments on the latter The version I have obtained via the links provided in your letter has the following information, V7B_2.23.21 AK IDC, printed on the bottom left hand corner on each page. Is this version the current official EPA working copy of the IDC and have any changes/ updates been made since the approval date of 2.23.21?

Thank you in advance for your response. I look forward to your reply.

Regards,

Ben Myren

Message

From: Brashear, Angelina [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=053E2B97D3734721B14E0EE84E290E86-POE, ANGELI]
Sent: 8/11/2021 9:03:23 PM
To: George Allen [gallen@nescaum.org]
Subject: RE: Data Parameters Question

George,

I'll try to get in the lab and if I have other questions then I will reach back out to you and schedule a meeting.

Kind regards,
Alina

-----Original Message-----
From: George Allen <gallen@nescaum.org>
Sent: Wednesday, August 11, 2021 3:32 PM
To: Brashear, Angelina <Brashear.Angelina@epa.gov>
Subject: RE: Data Parameters Question

Sure. I'm around this week. Next week not Mon-Wed.

ORD [Amara] has a couple of these - maybe you could borrow one to play with in your office or a corner of a lab somewhere.
-- George

At 02:09 PM 8/11/2021, Brashear, Angelina wrote:
George,

I was wondering if you had time to meet with me to discuss some sections of the SOP, mostly for my clarification. I have not run the procedure yet so it would be good to get more context and have some questions answered.

Likely next week or thereafter, whatever works for your schedule just let me know some times and dates.

Kindest regards,
Alina

-----Original Message-----
From: George Allen <gallen@nescaum.org>
Sent: Wednesday, August 11, 2021 11:19 AM
To: Brashear, Angelina <Brashear.Angelina@epa.gov>
Subject: RE: Data Parameters Question

Yes they did -- same as what's in the SOP, yes?

At 11:07 AM 8/11/2021, you wrote:
Hey George,

Did my two tables send though in the email?

Kind regards,
Alina

-----Original Message-----
From: George Allen <gallen@nescaum.org>
Sent: Wednesday, August 11, 2021 11:03 AM
To: Brashear, Angelina <Brashear.Angelina@epa.gov>
Subject: Re: Data Parameters Question

Hi Alina - the tunnel Teom is a dichot. The lab air Teom is a single channel, thus there are fewer parameters to log.
-- George

At 11:00 AM 8/11/2021, Brashear, Angelina wrote:
Hello George,

I wanted to verify the differences in data parameters between the 1405-D tunnel TEOM and the lab air TEOM. I wanted to verify the differences between the two and make sure they were correct.

Message

From: Johnson, Steffan [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=EBA5C0DFC5FC4593AFA62CE7C3DD6F02-JOHNSON, STEFFAN]
Sent: 3/25/2021 2:05:47 PM
To: Lisa Rector [lrector@nescaum.org]
Subject: RE: NESCAUM DATA

Ok, got it. That puts us in a tight spot.

Please let me know what you hear from NYSERDA.

Thanks,

Stef

From: Lisa Rector <lrector@nescaum.org>
Sent: Thursday, March 25, 2021 9:35 AM
To: Johnson, Steffan <johnson.steffan@epa.gov>
Cc: Burkhard, Ellen G (NYSERDA) <Ellen.Burkhard@nyserda.ny.gov>; Paul Miller <pmiller@nescaum.org>; gallen@nescaum.org
Subject: RE: NESCAUM DATA

Stef, sorry I misspoke this morning. I cannot publicly post additional IDC protocols without NYSERDA approval. Stay tuned.

Lisa

From: Johnson, Steffan <johnson.steffan@epa.gov>
Sent: Thursday, March 25, 2021 8:55 AM
To: Alben T. Myren Jr <myren.ben@gmail.com>
Cc: Robert Ferguson <bob.fcllc@gmail.com>; John Crouch <crouch@hpba.org>; Toney, Mike <Toney.Mike@epa.gov>; Brashear, Angelina <Brashear.Angelina@epa.gov>; Lisa Rector <lrector@nescaum.org>; Burkhard, Ellen G (NYSERDA) <Ellen.Burkhard@nyserda.ny.gov>
Subject: RE: NESCAUM DATA

Hi Ben,

I did not see an attached memo, however here are all the publicly available data that I'm aware of from NYSERDA at this time:

https://www.nyserda.ny.gov/About/Publications/Research-and-Development-Technical-Reports/-/media/925394CA61C54492B91930A3B5881377.ashx

Regarding your earlier message about the correct protocol(s), I e-mailed Lisa Rector and asked that the NYSERDA IDC and TEOM protocols be publicly posted on the NESCAUM site, and she has agreed that she would do that. Those protocols will be used, with our Level 1 QAPP, moving forward to develop all data to be used for validation of the TEOM measurement approach for PM, and for the IDC protocol for wood heaters. I don't know for certain when she will be getting those posted, but I expect that would take only a couple of days to accomplish.

As I've mentioned to the Round Table members, ALL data developed by EPA will be made publicly available once it clears the QA/QC review. Also, ALL data we use to support validation work for any test method will be publicly available and will be subject to the same QAPP (QA/QC requirements) as any data EPA develops.

As of yet, EPA is not in receipt of any data from NYSERDA that would be used toward validation of the test method(s). The Agency is hopeful that outside parties would be willing to use the IDC and TEOM protocols, along with our QAPP to develop data in support of the effort, and that they would be willing to share those complete data sets with the Agency. Quite frankly, this is an expensive effort and we will not refuse assistance with respect to data that supports the validation work. 52 tests x 2 labs...just for wood heaters; this is not an inconsequential effort.

Please don't hesitate to reach back out to us with additional questions.

Also, glad to hear that SHASH is working out for you and Ilsa, it will be so nice to put COVID in the rear view.

Always my best,

Stef

From: Alben T. Myren Jr <myren.ben@gmail.com>
Sent: Wednesday, March 24, 2021 9:16 PM
To: Lisa Rector <lrector@nescaum.org>
Cc: Johnson, Steffan <johnson.steffan@epa.gov>; Robert Ferguson <bob.fcllc@gmail.com>; John Crouch <crouch@hpba.org>; Toney, Mike <Toney.Mike@epa.gov>
Subject: NESCAUM DATA

Hi,

Look at the attached memo. I am requesting that LIsa post all of her test data and supporting data/ info on her website so we review it.

Any questions, let me know.

Regards, Ben

Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 5/7/2021 12:56:48 PM
To: Strum, Madeleine [Strum.Madeleine@epa.gov]; George.Allen [George.Allen@fda.hhs.gov]
CC: Johnson, Steffan [johnson.steffan@epa.gov]; Toney, Mike [Toney.Mike@epa.gov]; Brashear, Angelina [Brashear.Angelina@epa.gov]
Subject: RE: follow up questions from webinar

Grab your coffee, it's going to be a fun Friday morning. Stef's joining the meeting. I invited Mike and Angelina as well.

-----Original Appointment-----
From: Strum, Madeleine <Strum.Madeleine@epa.gov>
Sent: Friday, May 7, 2021 8:16 AM
To: Strum, Madeleine; Lisa Rector; George.Allen
Subject: follow up questions from webinar
When: Friday, May 7, 2021 9:00 AM-10:00 AM (UTC-05:00) Eastern Time (US & Canada).
Where:

1. My question (or set of questions) was from one of the first few slides on test methods and have to do with condensible PM --- the dilution and filter temperature (70-90 F) is much higher than ambient but still you indicated that the PM measured would include condensible. Why not use a lower temperature for the dilution air/filter ? Wouldn't that be needed to capture all of the condensible that would condense under the real conditions? Does the IDC use this high dilution temperature as well? You noted Method 5H uses an ice bath – would that get a more complete picture of condensible that one would get for real world conditions? Related to that is that you indicated that the filter drying (to remove water) also removes some of the condensed SVOC. Is this not an issue with IDC because the TEOM is used (so no drying of filters)? If this is the case then how do you not count the condensed water as PM (can the TEOM distinguish the condensed organics vs the water).

2. Another question is related to the point you made on how different the devices / their use are in Northern(?) Europe and that is why you chose not to adopt BeReal. What about other countries like Portugal, Australia (they have a lot of studies of "real world" vs lab), New Zealand – do they use BeReal and are they closer to Northern Europe or U.S. stove use?

3. Finally, are there large differences in stove efficiencies with the IDC approach than compliance test approach?

4. Slides from webinar?

5. EF question

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Message

From: Johnson, Steffan [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=EBA5C0DFC5FC4593AFA62CE7C3DD6F02-JOHNSON, STEFFAN]
Sent: 5/28/2021 12:38:13 PM
To: Lisa Rector [lrector@nescaum.org]
Subject: RE: IDC protocol

Lisa,

This presents no issue for us. Thanks for asking!

Stef

From: Lisa Rector <lrector@nescaum.org>
Sent: Friday, May 28, 2021 8:10 AM
To: Johnson, Steffan <johnson.steffan@epa.gov>
Subject: IDC protocol

Hi Stef, fyi, I removed oak fuel from the protocol since it is now down to maple, doug fir, and birch for the EPA testing. Please let me know if this is an issue for you.

Lisa

NESCAUM

Lisa Rector, Policy and Program Director at **NESCAUM**
89 South Street, Suite 602, Boston, Massachusetts, 02111 | 802.899.5306| 617.259.2095 | Fax: 617.742.9162 | lrector@nescaum.org

Message

From: Johnson, Steffan [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=EBA5C0DFC5FC4593AFA62CE7C3DD6F02-JOHNSON, STEFFAN]
Sent: 7/7/2021 1:55:01 PM
To: Lisa Rector [lrector@nescaum.org]
CC: Toney, Mike [Toney.Mike@epa.gov]; Angelina Brashear (Brashear.Angelina@epa.gov) [Brashear.Angelina@epa.gov]
Subject: RE: IDC FUEL PIECE MOISTURE CONTENT MEASUREMENTS

Lisa,

We certainly can. First off though, are you thinking another IDC modification is in order? And, if so, anything changing the IDC/TEOM protocol should probably wait. Anything impacting ATM 140 or a hydronic IDC is fair game.

Thoughts on that?

Stef

From: Lisa Rector <lrector@nescaum.org>
Sent: Tuesday, July 6, 2021 1:38 PM
To: Johnson, Steffan <johnson.steffan@epa.gov>
Subject: FW: IDC FUEL PIECE MOISTURE CONTENT MEASUREMENTS

Stef, do you want to set up a call to discuss these items?

From: Alben T. Myren Jr <myren.ben@gmail.com>
Sent: Tuesday, July 6, 2021 12:55 PM
To: Sanchez, Rafael <sanchez.rafael@epa.gov>; Lischinsky, Robert <Lischinsky.Robert@epa.gov>; Aldridge, Amanda <Aldridge.Amanda@epa.gov>; Baumgart-Getz, Adam <Baumgart-Getz.Adam@epa.gov>; French, Chuck <French.Chuck@epa.gov>; Boyd, Rochelle <Boyd.Rochelle@epa.gov>; Lowe, Theresa <Lowe.Theresa@epa.gov>; Cozzie, David <Cozzie.David@epa.gov>; Jordan Scott <jordan.scott@epa.gov>; Wayland, Richard <Wayland.Richard@epa.gov>; Hemby, James <Hemby.James@epa.gov>; Yellin, Patrick <Yellin.Patrick@epa.gov>; Scinta, Robert <scinta.robert@epa.gov>; Danick Power (dpower@polytests.com) <dpower@polytests.com>; John Steinert <john.steinert@pfsteco.com>; Brian Ziegler Intertek <brian.ziegler@intertek.com>; Wayne Terpstra <WTerpstra@pfscorporation.com>; Atemboski Alan <A.Atemboski@travisindustries.com>; Ryan Carroll <carroll@hpba.org>; Rachel Feinstein <feinstein@hpba.org>; Jack Freeman <jack@kumastoves.com>; John Ackerly <jackerly@forgreenheat.org>; Jason Freeman <jason@kumastoves.com>; Sean Reilly <sreilly@eenews.net>; Segall, Martha <segall.martha@epa.gov>; Brashear, Angelina <Brashear.Angelina@epa.gov>; Scott Plageman <scott.plageman@appliedcatalysts.com>; Carroll, Allen <allen.carroll@appliedceramics.com>; Martin Morrill <martin.morrill@appliedcatalysts.com>; Marc-Antoine Cantin <macantin@sbi-international.com>; Paul Miller <pmiller@nescaum.org>; Paul Hodges <PHodges@napoleonproducts.com>; Rumens, Kurt <kurt@travisindustries.com>; Dan Henry <dan@5g3consulting.com>; Lorin Day <lorind@woodstove.com>; Louise Cleroux <lcleroux@icc-rsf.com>; Andre Bibaud <abibaud@icc-rsf.com>; Luc Gilbert <lgilbert@icc-rsf.com>; Chris Neufeld <cneufeld@blazeking.com>; Cindy Heil <Cindy.Heil@alaska.gov>; Edwards, Alice L S (DEC) <alice.edwards@alaska.gov>; Mendivil, Gary A (DEC) <gary.mendivil@alaska.gov>; Steve Hoke <steven.hoke@alaska.gov>; Lisa Rector <lrector@nescaum.org>; Herschberger, Lisa (MPCA) <lisa.herschberger@state.mn.us>; Chung, David <DChung@crowell.com>; David Grant (davg461@ECY.WA.GOV) <davg461@ecy.wa.gov>; Formanj@hearthnhome.com; Guillaume Thibodeau-Fortin <gthibodeaufortin@sbi-international.com>; Robert Ferguson <bob.fcllc@gmail.com>; Eric Schaefer <ericsschaefer82@gmail.com>; Haslam, Alex <A.Haslan@travisindustries.com>; Ken Morgan <kmorgan@omni-test.com>; Bruce Davis <bdavis@omni-test.com>; Alex Tiegs <atiegs@omni-test.com>; Tom Morrissey <tomm@woodstove.com>; Dane Myren <danemyren@gmail.com>; Steffan Johnson <johnson.steffan@epa.gov>; John

Crouch <crouch@hpba.org>; Toney, Mike <toney.mike@epa.gov>
Subject: IDC FUEL PIECE MOISTURE CONTENT MEASUREMENTS

All,

The attached memo explains in detail why the current approved version of the IDC (6.25.21 EPA letter) is wholly inadequate and sorely lacking in the details necessary to (1.) take accurate fuel piece moisture content measurements and (2.) make the necessary calculations to determine emission factors (g/kg), among other things.

ENJOY!

Ben

Ben Myren, President
Myren Consulting, Inc.
512 Williams Lake Road
Colville, WA 99114
Office: 509 684 1154
Lab: 509 685 9458
email; <myren.ben@gmail.com>

Message

From: Johnson, Steffan [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=EBA5C0DFC5FC4593AFA62CE7C3DD6F02-JOHNSON, STEFFAN]
Sent: 3/25/2021 11:47:59 AM
To: Lisa Rector [lrector@nescaum.org]; gallen@nescaum.org
CC: Graham Fitzsimons [gfitzsimons@scainc.com]
Subject: RE: IDC and TEOM sop version

Lisa,

Thank you! Is there any way you could post this as a pdf? I would like to be able to point to it for the round table folks to see.

Thank you!

Stef

From: Lisa Rector <lrector@nescaum.org>
Sent: Wednesday, March 24, 2021 2:56 PM
To: Johnson, Steffan <johnson.steffan@epa.gov>; gallen@nescaum.org
Cc: Graham Fitzsimons <gfitzsimons@scainc.com>
Subject: RE: IDC and TEOM sop version

Stef, I have attached the research protocol, which was revised after the review call on 2 8 21.

From: Johnson, Steffan <johnson.steffan@epa.gov>
Sent: Wednesday, March 24, 2021 2:24 PM
To: Lisa Rector <lrector@nescaum.org>; George Allen <gallen@nescaum.org>
Subject: RE: IDC and TEOM sop version

Lisa,

Thank you. The QA/QC pieces remaining won't be answered until our ORD validation work gives us the answers, I believe. So we should put in some general language, or wider windows than we are expecting the validation work to eventually clarify, just so that there are *__some__* qa/qc requirements.

Is that helpful?

That said, moving forward it would be good to have those posted and static (until we have data to fill in some of the QA/QC bits).

Let me know if there are other questions that this raises.

Thanks very much!

Stef

From: Lisa Rector <lrector@nescaum.org>
Sent: Wednesday, March 24, 2021 1:28 PM
To: Johnson, Steffan <johnson.steffan@epa.gov>; gallen@nescaum.org
Subject: RE: IDC and TEOM sop version

Stef, we only have the filter version up on our website. We do not have the EPA research protocols posted, neither the IDC protocol or the dichot. Should those be posted? If so, we will need to finalize the dichot SOP. I believe that protocol still has remaining comments that are unaddressed. I believe George is waiting for input before he can finalize.

From: Johnson, Steffan <johnson.steffan@epa.gov>
Sent: Wednesday, March 24, 2021 1:22 PM
To: Lisa Rector <lrector@nescaum.org>; George Allen <gallen@nescaum.org>
Subject: IDC and TEOM sop version

Lisa and George,

Please see Ben's note below. I'd like to be able to point everyone to the correct, (and to a static) IDC and TEOM SOP.

I am not sure the version ben refers to is correct? Isn't this the filter based version we used for the Alaska IDC ATM?

Please advise and if you could provide links to the correct /current versions, it would be great to keep us all on the same page moving forward.

Thank you!

Stef

From: Alben T. Myren Jr <myren.ben@gmail.com>
Sent: Wednesday, March 24, 2021 12:51 PM
To: Johnson, Steffan <johnson.steffan@epa.gov>
Subject: INFO

Stef,

I am in receipt of your email dated 22 March 2021 which contains a discussion of EPA's past efforts and plans for the future. Given that there have been multiple different drafts of the IDC test method that have been circulated over the past few years, I want to ensure that the version I have is correct before I offer any comments on the latter The version I have obtained via the links provided in your letter has the following information, V7B_2.23.21 AK IDC, printed on the bottom left hand corner on each page. Is this version the current official EPA working copy of the IDC and have any changes/ updates been made since the approval date of 2.23.21?

Thank you in advance for your response. I look forward to your reply.

Regards,

Ben Myren

Message

From: George Allen [gallen@nescaum.org]
Sent: 6/29/2020 1:07:46 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]; Lisa Rector [lrector@nescaum.org]
CC: Toney, Mike [Toney.Mike@epa.gov]; Brashear, Angelina [Brashear.Angelina@epa.gov]
Subject: Re: Latest version of the IDC protocol for wood heaters?

Hi Stef - Yes, there have been changes, and it's my understanding that the most recent draft was sent to Nyserda about 2 weeks ago. Ellen probably has that version if Lisa can't get back to you in time [she's on vaca to July 15].
George

At 08:49 AM 6/29/2020, Johnson, Steffan wrote:
Greetings Lisa!

You may know that I spoke with Ellen Burkhardt on Friday and she informed me that you folks have updated the IDC document a great deal in recent months.

We have recently opened a contract with a test lab to conduct some wood heater testing with the IDC in a Western Lab and so we would like to obtain the latest version for review and possible adaptation to an EPA method format.

Also, just FYI - at this time we are looking at Douglas Fir and Oregon White Oak (Quercus garryana) for the Western softwood/hardwood mix.

Thoughts on the hardwood selection accepted.

Thanks very much!

Stef

Message

From: Johnson, Steffan [johnson.steffan@epa.gov]
Sent: 2/4/2021 3:47:45 PM
To: Lisa Rector [lrector@nescaum.org]; Toney, Mike [Toney.Mike@epa.gov]; Brashear, Angelina [Brashear.Angelina@epa.gov]
Subject: RE: revised protocol

Lisa,

I am fine with the changes as listed, though I have a question about fuel shape.

Agreed that squares are out, and I like limiting trapezoids. We haven't discussed rectangular slabs. Such a fuel piece may be useful to allow when head space is slim and the density criteria are not yet met. I'm ok with allowing one, as I've seen wood 'find' that shape when being split. Typically I target these in my fuel pile for kindling stock (easy to nip off narrow pieces) but it makes some sense to me to allow a shape such as this in order to help a fuel load meet loading criteria.

Any thoughts on that?
Stef

From: Lisa Rector <lrector@nescaum.org>
Sent: Wednesday, February 3, 2021 4:22 PM
To: Johnson, Steffan <johnson.steffan@epa.gov>; Toney, Mike <Toney.Mike@epa.gov>; Brashear, Angelina <Brashear.Angelina@epa.gov>
Subject: revised protocol

Hi Stef, attached to this email is a revised protocol (one with track changes, one clean) based on our conversations last week for the research program effort. ATM version will have similar changes. Can you please review and confirm these reflect previous week's discussion?

Lisa

NESCAUM

Lisa Rector, Policy and Program Director at **NESCAUM**
89 South Street, Suite 602, Boston, Massachusetts, 02111 | 802.899.5306| 617.259.2095 | Fax: 617.742.9162
| lrector@nescaum.org

Message

From: Johnson, Steffan [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=EBA5C0DFC5FC4593AFA62CE7C3DD6F02-JOHNSON, STEFFAN]
Sent: 11/19/2020 8:53:42 PM
To: Lisa Rector [lrector@nescaum.org]
CC: Toney, Mike [Toney.Mike@epa.gov]; Angelina Brashear (Brashear.Angelina@epa.gov) [Brashear.Angelina@epa.gov]
Subject: Eastern Softwood?

Lisa,

We have selected Douglas fir and white Oak (quercus garryana) for our West coast IDC fuels. I know that you have data that shows that red maple would be an Eastern hardwood of choice, but I'm wondering if you have any information supporting an Eastern softwood? I recall discussing Southern pine, or Eastern white pine?

Or do you feel that there isn't enough softwood being burned in the East to justify adding a second hardwood fuel instead of a softwood fuel?

Are you aware of any resources that show how common what fuels are in the East/West?

Stef

Steffan M Johnson | Leader – Measurement Technology Group | US EPA Office of Air Quality Planning and Standards | Air Quality Assessment Division | 109 T.W. Alexander Drive, RTP, NC 27710 | Mail Drop: E-143-02 | Phone: (919) 541-4790 | Cell: (919) 698-5096

Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 3/30/2021 4:44:44 PM
To: cindy.heil@alaska.gov; Johnson, Steffan [johnson.steffan@epa.gov]; Toney, Mike [Toney.Mike@epa.gov]; Brashear, Angelina [Brashear.Angelina@epa.gov]
Subject: revised protocol
Attachments: NYSERDA IDC Stove Protocol ATM revised 3 30 21.pdf

Hi everyone, my apologies, the ATM has been revised to reflect the IDCs as run for our research, which is 75% of the fuel pieces must have bark. The previous version had a typo that said 5%.

NESCAUM

Lisa Rector, Policy and Program Director at **NESCAUM**
89 South Street, Suite 602, Boston, Massachusetts, 02111 | 802.899.5306| 617.259.2095 | Fax: 617.742.9162 | lrector@nescaum.org

Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 11/19/2020 9:33:49 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
CC: Toney, Mike [Toney.Mike@epa.gov]; Brashear, Angelina [Brashear.Angelina@epa.gov]
Subject: RE: Eastern Softwood?

Stef, off the top of my head the only thing that comes to mind is the Minnesota survey data. On page 30 you can see the species use trends from 1988-2014. (https://www.pca.state.mn.us/sites/default/files/aq-ei4-46.pdf). I will reach out to my forestry friends to see if they have any other data. Thanks!

From: Johnson, Steffan <johnson.steffan@epa.gov>
Sent: Thursday, November 19, 2020 3:54 PM
To: Lisa Rector <lrector@nescaum.org>
Cc: Toney, Mike <Toney.Mike@epa.gov>; Brashear, Angelina <Brashear.Angelina@epa.gov>
Subject: Eastern Softwood?

Lisa,

We have selected Douglas fir and white Oak (quercus garryana) for our West coast IDC fuels. I know that you have data that shows that red maple would be an Eastern hardwood of choice, but I'm wondering if you have any information supporting an Eastern softwood? I recall discussing Southern pine, or Eastern white pine?

Or do you feel that there isn't enough softwood being burned in the East to justify adding a second hardwood fuel instead of a softwood fuel?

Are you aware of any resources that show how common what fuels are in the East/West?

Stef

Steffan M Johnson | Leader – Measurement Technology Group | US EPA Office of Air Quality Planning and Standards | Air Quality Assessment Division | 109 T.W. Alexander Drive, RTP, NC 27710 | Mail Drop: E-143-02 | Phone: (919) 541-4790 | Cell: (919) 698-5096

Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 3/25/2021 12:35:13 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
Subject: FYI

Stef, a small request…moving forward please refer to the IDC protocol's as NYSERDA test protocols, not NESCAUM. The data and protocols are the property of NYSERDA, and we are just the developer. Thanks!

NESCAUM

Lisa Rector, Policy and Program Director at **NESCAUM**
89 South Street, Suite 602, Boston, Massachusetts, 02111 | 802.899.5306| 617.259.2095 | Fax: 617.742.9162 | lrector@nescaum.org

Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 2/2/2021 4:53:11 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
Subject: RE: Reminder: Teom SOP review comments this week

I think this is a new issue that we didn't have on the books yet, squared or smooth elbows?

-----Original Message-----
From: Johnson, Steffan <johnson.steffan@epa.gov>
Sent: Tuesday, February 2, 2021 11:32 AM
To: George Allen <gallen@nescaum.org>; Holder, Amara <holder.amara@epa.gov>; Brashear, Angelina <Brashear.Angelina@epa.gov>; Toney, Mike <Toney.Mike@epa.gov>; Garnett, Kim <Garnett.Kim@epa.gov>; Nash, Dave <Nash.Dave@epa.gov>
Cc: Lisa Rector <lrector@nescaum.org>
Subject: RE: Reminder: Teom SOP review comments this week

George,

Didn't we finish this on the phone the other day, or am I missing something?

Stef

-----Original Message-----
From: George Allen <gallen@nescaum.org>
Sent: Monday, February 1, 2021 12:51 PM
To: Johnson, Steffan <johnson.steffan@epa.gov>; Holder, Amara <holder.amara@epa.gov>; Brashear, Angelina <Brashear.Angelina@epa.gov>; Toney, Mike <Toney.Mike@epa.gov>; Garnett, Kim <Garnett.Kim@epa.gov>; Nash, Dave <Nash.Dave@epa.gov>
Cc: lrector@nescaum.org
Subject: Reminder: Teom SOP review comments this week

Hi folks - this is a gentle reminder to get me comments on the revised draft I sent out last Tuesday. On the call we suggested a 1 week turnaround, but any time this week is greatly appreciated. I called out some areas that might need additional discussion in comments or highlighting. We are leaving the section on criteria for agreement between the 2 Teom channels for later.
Thanks very much -- George

On 1/26 I wrote:
Hi everyone - thanks to those on the call today - we're getting closer, having resolved the big issues. The attached version has notes/comments that Lisa made during our call that I will implement later.

There are many comments I've made to call out parts that may need attention [some are just clarifying background info]; please go thru them and note your preferences. Feel free to comment on other parts as needed. I'd like to get that input, incorporate it as much as practical, and then maybe schedule another call to review the result.

The short-term goal is to get a working SOP for use by ORD and then by PFS-TECO. The format and structure required for a regulatory method comes later once we get the content agreed on.
Thanks again! George

Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 1/25/2021 4:15:16 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
CC: Brashear, Angelina [Brashear.Angelina@epa.gov]; Toney, Mike [Toney.Mike@epa.gov]
Subject: RE: Can you give us some background for the thurs IDC meeting? Thank you! <end>

PFS review of the protocol raised several issues requiring your input to determine if we need to modify the protocol.

- Target tunnel flows for research
- Tunnel temperature requirements for protocol and research
- Piece shape configuration
    - Use of trapezoidal shapes L1 rules, L2-4 rules
    - How to define piece shape when two ends differ
- Rules for fuel adjustments
- Location specifications for TEOM
- Video requirements for testing
- Testing with or without fan
- TEOM use
- Filter requirements – we may not need this after tomorrow's call with on teom protocol.

From: Johnson, Steffan <johnson.steffan@epa.gov>
Sent: Monday, January 25, 2021 11:00 AM
To: Lisa Rector <lrector@nescaum.org>
Cc: Brashear, Angelina <Brashear.Angelina@epa.gov>; Toney, Mike <Toney.Mike@epa.gov>
Subject: Can you give us some background for the thurs IDC meeting? Thank you! <end>

Steffan M Johnson | Leader – Measurement Technology Group | US EPA Office of Air Quality Planning and Standards | Air Quality Assessment Division | 109 T.W. Alexander Drive, RTP, NC 27710 | Mail Drop: E-143-02 | Phone: (919) 541-4790 | Cell: (919) 698-5096

Message

From: Johnson, Steffan [johnson.steffan@epa.gov]
Sent: 10/6/2020 3:16:38 PM
To: Burkhard, Ellen G (NYSERDA) [Ellen.Burkhard@nyserda.ny.gov]
CC: Wayland, Richard [Wayland.Richard@epa.gov]; Koerber, Mike [Koerber.Mike@epa.gov]; Lisa Rector [lrector@nescaum.org]; gallen@nescaum.org
Subject: Data needs for IDC protocol method validation effort
Attachments: EPA_TEOM and IDC Validation and Supporting Data Needs.xlsx

Dear Ellen,

First off, I hope that his finds you and your family doing well, staying COVID free, and enjoying a lovely New York autumn.

As we have now left the goal of using a Dekati dilution system behind, it seemed prudent to revise our spreadsheet that lays out data needs for IDC /TEOM method validation work. That revised spreadsheet is attached to this e-mail.

You will note that the first two items on the "Overall" tab refer to data that support "feasibility" of the measurement approach(es). I thought I would explain in more specific detail what we are hoping for here, as some of these data we expect could be provided by NYSERDA through your contract efforts.

Primarily, we will need to docket data involving EPA Step 1 or Step 2 certified appliances that support broad acceptance of an IDC protocol, in other words, we have to show that the test works well on a wide variety of appliance types and models. To that end, we are interested in any/all data developed with a recent version of the IDC, using a TEOM as a measurement tool. Also, wherever such data have been collected along side ASTM E-2515 data, not to PROVE equivalence, but to demonstrate compatible results such that we can demonstrate the PM measurement approach with a TEOM is not a wide departure from the existing PM measurement approach. We are not interested in validating the TEOM measurement vs the ASTM E2515 as it's akin to comparing the handling of a 1964 Impala vs a 2019 Tesla. There is much more variability in the existing approach than we expect in the TEOM measurement, and so we just want to be able to demonstrate that the measurement approach is comparable; then we'll develop TEOM and IDC precision data that will let the methodology stand on its own. Also note that in docketing these data we are not only showing the IDC /TEOM combination to be feasible, but also demonstrating the fueling calculator portion of this to be workable for all these appliance types/models as well. It is important to demonstrate this as the fueling calculator makes a good deal of the operation protocol prescriptive and will eliminate a good bit of subjectivity from the testing. We really like this idea, but we also need supporting data to show that it doesn't force any appliance model outside the 'normal' operating 'box'.

Additionally, data that NYSERDA may have that demonstrates paired TEOM agreement, appropriate operating ranges for dilution tunnel velocity, or dilution tunnel Relative Humidity are desirable as well, as these are all key changes in the IDC, and those concepts would be best supported by a good deal of data.

We are not interested in any data comparing the IDC to ASTM (insert test method number here) as those are apples to potato comparisons and are not useful to EPA in terms of validating the IDC or a TEOM measurement approach. Nor are we interested in data where TEOM v Filter methods are used to evaluate g/hr data (though we would be interested in those same data if g/kg fuel were available), but again only from an IDC test.

We understand fully that NYSERDA owns and controls the data referenced above and we also know that NYSERDA has goals of publishing those data and would like to hold them until such time that publication has been made. I assure you, that is not an issue for us. Yes, we were hoping to be able to share those earlier, but having them in hand to discuss with stakeholders and to substantiate the docket at such time that the TEOM and IDC methods are ready for EPA promulgation is absolutely sufficient for our needs. We just need to be able to openly demonstrate to all stakeholders

that this measurement approach is workable across a wide variety of appliance categories and models, and that we have every expectation that the existing data indicate expected success with other models/types not yet tested.

FYI - EPA intends to conduct PM measurement validation work using a pair of dichot TEOM devices on a single pellet fired heater here in our RTP laboratory. Those data will be used to develop precision data for the TEOM measurement approach, and we will also conduct ruggedness testing with which to bound TEOM operation during any test.

We are also contracting with a Western US laboratory to begin testing with the IDC on paired appliances, each mounted with a dichot TEOM for PM measurement. These paired analysis are required by EPA's Environmental Measurement Forum guidance, developed over the past few decades and used across EPA for determining precision of repeatability (same lab) and reproducibility (across labs) such that we know that a given measurement technique will demonstrate compliance with an emission limit and that compliance issues aren't caused by measurement variability. I know from past discussion that you are uncertain as to the need for paired measurement, so let me try to illustrate that anecdotally with the goal of hopefully providing you a better picture as to why we do this.

Consider a regulation dartboard, and two players each with seven darts. Player 1 throws seven darts at the bullseye, and the standard deviation of that grouping in terms of distance from the bullseye gives us an idea of how good Player 1 is at hitting what they aim at. Player 2 throws seven darts at the bullseye and, likewise, we learn about player 2's abilities at throwing darts as well. Neither of these players results, taken individually, tell us much about the variability of the game of darts, but when we compare the precision of each player versus the other, we can start to learn about the precision involved in the game of darts and not just about a single player's capabilities. The key takeaway here is that there is variability in every measurement, and with a set of measurements those variabilities all stack up behind the reported result. Only by comparing two independent groupings of these variabilities can we truly learn about the overall variability of the measurement approach. I hope this is helpful, because this is the key underpinning of our method validation work, and it is upon this foundation that we intend...or rather that we NEED to build the future of wood burning appliance measurement upon. Knowing the capabilities of the measurement approach is absolutely key to making sound regulatory and policy decisions upon the resultant data.

Ok, with that said, I'll give you some time to review and consider what I've laid out here.

Thank you for your time, and for your support in improving EPA's wood fired appliance compliance efforts.

Very sincerely,

Stef

Steffan M Johnson | Leader – Measurement Technology Group | US EPA Office of Air Quality Planning and Standards | Air Quality Assessment Division | 109 T.W. Alexander Drive, RTP, NC 27710 | Mail Drop: E-143-02 | Phone: (919) 541-4790 | Cell: (919) 698-5096

EPA Wood Heater Method Validation Overview

Data Needs:

IDC Feasibility	Multiple Appliance types - Preference for multiple tests per appliance model, and /or multpile appliance types (cat, non-cat, hybrid, hydronic heater, etc.) to demonstrate feasibility and fueling calculator	Done by NESCAUM? (we are hopeful for such data)
TEOM Feasibility	Any Appliance type - 7 test runs minimum - TEOM vs ASTM 2515	Done by NESCAUM? (we are hopeful for such data)
TEOM Validation	Pellet and cord wood appliances -70 test runs (some done concurrent with IDC validation) - Varied fuels. Ruggedness done in RTP	Done to demonstrate equivalence of PM measurement - provides confidence in the measurement approach Done in ORD and in EPA Approved Labs
Wood Heaters	52 Paired tests	Validation of PM measurement precision and ruggedness determination of Dichot TEOM PM measurement Done in East/West coast labs Small non-cat, medium non-cat, large cat stoves, western and eastern hardwood and softwood. Validation of IDC operation precision inter-lab and intra-lab, various fuels
Hydronic Heaters	52 Paired tests	Done in East/West coast labs No thermal storage, partial thermal storage and pellet hydronic heaters, western and eastern hardwood and softwood. Validation of IDC operation precision inter-lab and intra-lab, various fuels
Forced Air Furnaces	28 Paired tests	Done in East/West coast labs Small FAF - Paired appliance comparison - 14 Eastern / 14 Western (7 test runs per fuel type, 4 fuel types). Validation of IDC operation precision inter-lab and intra-lab, various fuels
	12 Solo tests	Large FAF (if needed)

NOTES:

We assume that an IDC for pellet stoves is not needed at this time
We assume that a large forced air furnace would be needed for the category, though no one has come forward with a step 2 appliance in this category
We assume that paired TEOM can be done while a third TEOM arrangement measures a paired IDC (EPA could possibly share equipment for this)
7 Test runs is the minimum for reasonable student T value with M301 validation work

This is a Method 301 validation between the IDC with Dekati/TEOM PM measurement and IDC with ASTM E2515 PM m

Appliance type

Wood heater

ıeasurement

The purpose is to demonstrate equivalence between Dekati/TEOM measurement and ASTM E2515 measurement

End metrics for comparative purposes should be g/kg fuel vs g/kg fuel

EPA anticipates that NYSERDA/NESCAUM already have data that suits these parameters

This work does not need to be performed in an EPA approved wood heater test lab, but should be done under a level 2 Q

Opt.

Opt.

Opt.

APP*

(type of appliance is optional for this work, but EPA recognizes wood heaters to be the normal emissions type)

7
7
7
7

test runs with dual Dekati TEOM and dual ASTM E2515 PM measurement, with an IDC operating test being conducted

test runs with dual Dekati TEOM and dual ASTM E2515 PM measurement, with an IDC operating test being conducted - C

test runs with dual Dekati TEOM and dual ASTM E2515 PM measurement, with an IDC operating test being conducted - H

test runs with dual Dekati TEOM and dual ASTM E2515 PM measurement, with an IDC operating test being conducted - D

NOTES:

atalytic unit
ybrid unit
ifferent fuel species

7 test runs is the minimum for a Method 301 validation. Additional test runs of the same configuration help (somewhat)

Optional testing provides additional context for the validation work and shows robustness of the measurement method,

improve the Student T factor and are welcome
but more than 12 runs is typically superflous.
especially a second fuel species.

(minimum data set)

Nice to have

Ancillary, but more is better.

Would very much like to have

TEOM /DEKATI Diluter Validation Study

Appliance type

Pellet Stove	7
Pellet Stove	7
Pellet Stove	14
Wood Heater - Cordwood	7
Wood Heater - Cordwood	7
Wood Heater - Catalytic Cordwood	7
Wood Heater - Catalytic Cordwood	7
	56

TEOM - ASTM E1169: Ruggedness parameters to be evaluated:

IDC - ASTM E1169: Ruggedness parameters to be evaluated:

Test Runs to determine precision of paired TEOM arrangements
Test Runs to determine precision of paired TEOM arrangements
Test runs to determine ruggedness of TEOM sampling

Test Runs to determine precision of paired TEOM arrangements
Test Runs to determine precision of paired TEOM arrangements

Test Runs to determine precision of paired TEOM arrangements
Test Runs to determine precision of paired TEOM arrangements

Total test runs

Sampling rate
Filter temperature
TEOM Filter Change
Probe length

Tunnel flow
Tunnel R.H.
Tunnel induced draft

[redacted]

(28 of which will be accomplished concurrently with other validation testing)

Condition High	Condition Low	Reference
2 lpm	0.5 lpm	1 lpm
33 C	27 C	30 C
120%	100%	110%
20"	10"	14"

Condition High	Condition Low	Reference
700 fpm	400 fpm	500 fpm
75%	25%	50%
0.008" H2O	0.001" H2O	0.004" H2O

To be conducted at ORD RTP
To be conducted at ORD RTP - Different fuel
To be conducted at ORD RTP

To coinncide with IDC Stove validation work in EPA Approved lab
To coinncide with IDC Stove validation work in EPA Approved lab - Different fuel

To coinncide with IDC Stove validation work in EPA Approved lab
To coinncide with IDC Stove validation work in EPA Approved lab - Different fuel

Appliance type

Small non-cat

Medium non-cat

Large cat

EPA Expects that each appliance type listed here will operate within the Wood Heater IDC protocol.
These tests must be done with a Level 1 QAPP in an EPA Approved laboratory (QAPP starts out sub level 1 and is modifiec
QAPP Developed by EPA/Contractor

d as end test goals emerge)

	Test Runs	Where?
Paired (side by side)*	3	East Coast
Paired (side by side)	3	East Coast
Paired (side by side)	3	West Coast
Paired (side by side)	3	West Coast
Paired (side by side)	7	East Coast
Paired (side by side)	7	East Coast
Paired (side by side)	7	West Coast
Paired (side by side)	7	West Coast
Paired (side by side)	3	East Coast
Paired (side by side)	3	East Coast
Paired (side by side)	3	West Coast
Paired (side by side)	3	West Coast
Pairs of tests =	**52**	
		NOTES:

Overarching project description
TEOM v Filter manuscript
IDC v Filterable manuscript
Pellet results w startup
IDC pellet boiler
Startup of testing comparisons across methods
Impact of wood species on emissions outcomes

Fuel

Hard wood
Soft wood
Hard wood
Soft wood

Hard wood
Soft wood
Hard wood
Soft wood

Hard wood
Soft wood
Hard wood
Soft wood

Eastern and western fuel types should be static for all cordwood testing
Paired dichot TEOM data needed for 28 Eastern or Western cord wood tests to augment pellet fired TEOM Validation stu
Appliances swapped from coast to coast after testing done in one location
IF a pellet stove IDC is needed - would this be a separate IDC or Appendix to wood heater IDC?
Ruggedness testing of the IDC
All starts a bottom up start.

Denotes existing EPA Task Order work

Maple	Paired Dichot TEOM	
Pine?	Paired Dichot TEOM	
White Oak	Paired Dichot TEOM	
D. Fir	Paired Dichot TEOM	
Maple	Paired Dichot TEOM	Ruggedness
Pine?	Paired Dichot TEOM	Ruggedness
White Oak	Paired Dichot TEOM	
D. Fir	Paired Dichot TEOM	
Maple	Paired Dichot TEOM	
Pine?	Paired Dichot TEOM	
White Oak	Paired Dichot TEOM	
D. Fir	Paired Dichot TEOM	

dy

Nescaum #	candidates	size	
15	Jotul F682	0.8	
7	Hearthstsone casselton	2.1	
17	FPI Regency	3.04	hybrid

Appliance type

Hydronic Heater - no thermal storage

Hydronic Heater- Partial thermal storage

Pellet hydronic

EPA Expects that Hydronic heaters will have a separate IDC protocol. Perhaps with different sections for different techno
These tests must be done with a Level 1 QAPP in an EPA Approved laboratory
EPA or EPA Contractor to create QAPP

logies? Or appendicies of a master IDC for hydronics?

	Test Runs	Where?
Paired	3	East Coast
Paired	3	East Coast
Paired	3	West Coast
Paired	3	West Coast
Solo	7	East Coast
Solo	7	East Coast
Solo	7	West Coast
Solo	7	West Coast
Solo	3	East Coast
Solo	3	East Coast
Solo	3	West Coast
Solo	3	West Coast
Pairs of tests =	**52**	

NOTES:

,

Fuel	
Hard wood	Maple
Soft wood	Pine
Hard wood	W. Oak
Soft wood	D. Fir
Hard wood	Maple
Soft wood	Pine
Hard wood	W. Oak
Soft wood	D. Fir
Hard wood	TBD
Soft wood	TBD
Hard wood	TBD
Soft wood	TBD

Appliances swapped from coast to coast after testing done in one location
Pellet fuels should be specific to area (east/west)
All cord wood starts a bottom up start

	Candidate Model
	CB 560
	CB 560
	CB 560
	CB 560
	Froeling
<<< Likely pellet hydronic	
Eastern brand pellet	Winhauger?
Eastern brand pellet	
Western brand pellet	
Western brand pellet	

IDC Forced Air Furnace Heater Validation Study

Appliance type

Forced Air Furnace - Small	
	Paired (side by side)
	Paired (side by side)
	Paired (side by side)
	Paired (side by side)
Forced Air Furnace - Lg	
	Solo
	Solo
	Solo
	Solo

These tests must be done with a Level 1 QAPP in an EPA Approved laboratory
EPA or EPA Contractor to create QAPP

7	East Coast
7	East Coast
7	West Coast
7	West Coast
3	East Coast
3	East Coast
3	West Coast
3	West Coast

28 Pairs of tests
12 Solo tests

SBI?
Lamppa?
Hy-C?

Hard wood	Maple
Soft wood	Pine
Hard wood	W. Oak
Soft wood	D. Fir

Currently no appliances in this category

Hard wood	Maple
Soft wood	Pine
Hard wood	W. Oak
Soft wood	D. Fir

(small FAF only)
If large FAF is needed

Message

From: George Allen [gallen@nescaum.org]
Sent: 12/28/2020 10:20:22 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]; Tony.Mike@epa.gov; Brashear, Angelina [Brashear.Angelina@epa.gov]
CC: lrector@nescaum.org; Garnett, Kim [Garnett.Kim@epa.gov]; Nash, Dave [Nash.Dave@epa.gov]
Subject: Dichot TEOM dilution tunnel SOP revisions
Attachments: NESCAUM SOP TEOM 1405-Dichot markup 20-12-28_GA.docx

Flag: Follow up

Hi everyone -- the current revision to this SOP is attached. It is based on the clean version I sent out on 9/18 that incorporated earlier MTG comments.

This is reasonably complete, but there are a few unresolved items noted. I made some executive decisions for this version, including using wet flow for Teom and tunnel flows instead of dry for both [this is (a) simpler and (b) more accurate than current practice]. Everything is now 20C and 1 atm standard conditions.

It needs some formatting cleanup and structure to make it a regulatory method, but most of the vague language has been made explicit.

We should schedule a tele-meeting to go over this once everyone has had a chance to go through it.

Happy New Year... George

Appendix A.

Standard Operation Procedures for Thermo Scientific™ 1405-D TEOM™® for use in a dilution tunnel
DRAFT Dec. 28, 2020, using Sept. 18 clean version , 2020as the source
Based on single SOP Version from August 17, 2020 with MTG comments, incorporating 20-09-15 discussion comments.

Section 1. Introduction

This document covers operation concepts and procedures for use of the Thermo -Scientific model 1405-D TEOM to measure and report continuous particulate matter (PM) measurements in an EPA Method 5G dilution tunnel or equivalent dilution method. The TEOM is designed for ambient real-time PM measurements. It is an inertial microbalance - a true continuous mass measurement method with resolution of 0.01 µg (0.00001 mg). The TEOM is highly configurable, allowing the instrument to be configured to best meet the needs of a specific application. The version of the TEOM used here is the "Dichotomous" (Dichot) 2-channel configuration (1405D-ANF-special), without any inlet hardware, virtual impactor, flow splitter, or sample conditioning options such as "FDMS". For this application, the TEOM flows, temperatures, and timing settings are changed from the normal ambient settings, and the second ("coarse mass") channel is used as a co-located PM measurement. Configuration settings are the same for each channel. There are no hardware modifications needed. Instrument manuals, Microsoft Windows instrument software, and related support information are available from the Thermo web site.[1]

Commented [GA1]: special p/n without virtual impactor, flow splitter, etc, TBD

The TEOM configuration used here allows for fast filter changes with minimal data loss (typically four to five minutes). Key instrument parameters are stored with the concentration data and are used to perform quality control of the data during review and processing according to this protocol.

Instrument Software
Thermo provides two Microsoft Windows programs for the TEOM that can be obtained from the 1405 web page. "RPComm" (the serial port interface program) can be used to display the last 15 minutes of data on a graph, download data, and read all key operating parameters easily during a test run. It is also used to document the instrument settings. "ePort" (the ethernet interface program) is used to control the instrument remotely and to download data. Both programs can be used at the same time, and are available on the Thermo 1405 web page. Instrument operation and control can be accessed remotely using programs that provide remote PC access.

Instrument Installation.
The TEOM should be positioned as close to the dilution tunnel sample port location as possible. Two short pieces of 1/4 or 3/8 inch aluminum or stainless steel tubing are used to sample from the center of the dilution tunnel, similar to how a Method 5G or ASTM-2515 sample line is used.

1 The TEOM manual is referenced in this SOP, and is available here: [HYPERLINK "https://www.thermofisher.com/order/catalog/product/TEOM1405"]D

ED_005942D_00000023-00001

It is also possible to use short pieces of conductive flexible tubing with 3/8 inch OD and 1/4 inch ID with a short piece of ¼" metal tubing for insertion into the tunnel. Inlet tubing should be replaced or cleaned after every series of tests.

Supplies and Parts needed for TEOM operation:
Teom filters (typically 2 to 4 per test, ordered from Thermo)
Black sample filter change tool (supplied with the TEOM)
Red calibration filter change tool (ordered from Thermo, p/n 55-002013-0002)
(2) Triple-weighed Teom filters [~ 95 mg] for transducer calibrations, to at least 0.1 mg resolution, weighed on a NIST-traceable balance (this can be ordered from Thermo and comes with the red filter change tool)
Particle filter for zero-air tests and transducer calibration
Vacuum pump for 2 lpm at 20" vacuum (connects to TEOM with 3/8" plastic tubing)
3/8" or 1/4" conductive tubing (metal or conductive plastic)
(2) 1/2" to 3/8" or 1/4" swage SS reducing union for inlet tubing
NIST-traceable flowmeter for 1 to 3 lpm at 20C and 1 Atm, accuracy of 2% or better.
Laptop or desktop Windows PC for RPComm (needs a USB to serial port adaptor) and EPort (ethernet connection)

Formatted: Underline

Lab air PM is also measured with a TEOM without any particle size cut, with the inlet of the probe located within 10 feet of the bottom of the tunnel's hood. This TEOM can be a single channel TEOM (1405), and is run the same way as the dilution tunnel TEOM except for the following settings to increase sensitivity:
Inlet flow = 3 lpm
MRMC and MassAVG times set to 120 seconds

Commented [GA2]: Can we allow a 5 ft length of inlet tubing to be used here?

Lab air PM concentrations are subtracted from tunnel PM concentrations before any other calculations are performed.

Section 2. Routine Operation Procedures for Thermo 1405-D TEOM

This section is a summary of routine operating procedures.

A. *Quality Assurance checks to be completed before and after each set of test runs:*

1. Modify system settings as detailed in Section 8 (initial installation only).
2. Perform K0 mass transducer verification checks on both channels as detailed in Section 4 of this procedure.
3. Document the system settings listed below with a computer "screen shot" as shown here, using the Thermo RPComm program to display their values. Instrument time (PRC90) is in Unix Epoch format (seconds since 1/1/70, valid through 2037). This example is at 2020-09-16 at 15:15:14 (instrument clock time, not UTC). TEOMA (left sensor) is PM2.5 and TEOMB (right sensor) is PM-coarse. K0 values are specific to each of the two TEOM mass transducers.

Commented [GA3]: Do we need a "dynamic zero" overnight test to be performed here? To measure noise and identify leaks.

Commented [GA4]: 21 params max. Room for one more.

PRC	Name	Value
1	serial number	1405A201940805
2	instrument firmware version	1.74
3	instrument model	TEOM 1405-D
28	system wait time	0
35	mass average time	30
74	average temperature set point	21.100000
75	standard temperature set point	21.100000
76	average pressure set point	1.000000
77	standard pressure set point	1.000000
78	volumetric flow control	1
79	mass conc reporting	1
91	bypass flow mass set point	0.000000
259	TEOMA K0	14523.000000
343	TEOMB K0	15625.000000
390	instrument time	1600269314
392	MRMC average time	30
407	TEOMA mass constant A	0.000000
408	TEOMA mass constant B	1.000000
409	TEOMB mass constant A	0.000000
410	TEOMB mass constant B	1.000000

PRC	Name	Value
1	serial number	1405A201940805
2	instrument firmware version	1.74
3	instrument model	TEOM 1405-D
28	system wait time	0
35	mass average time	30
74	average temperature set point	20.000000
75	standard temperature set point	20.000000
76	average pressure set point	1.000000
77	standard pressure set point	1.000000
78	volumetric flow control	1
79	mass conc reporting	1
91	bypass flow mass set point	0.000000
259	TEOMA K0	14523.000000
343	TEOMB K0	15625.000000
390	instrument time	1609163566
392	MRMC average time	30
407	TEOMA mass constant A	0.000000
408	TEOMA mass constant B	1.000000
409	TEOMB mass constant A	0.000000
410	TEOMB mass constant B	1.000000

Other key instrument operating parameters are always recorded in the data file and thus are not listed here, since there is a limit of 21 parameters for this list.

B. Routine procedures before every test run to be conducted 1-2 hours prior to testing.

1. Check the TEOM time and set as needed to be within 5 seconds of laboratory time. Changing the time causes an instrument reboot and loss of up to an hour of data. See notes section below.

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2.

~~B~~Before installing new~~a new~~ filters, perform a leak test and flow check on both TEOM channels per section 3. The leak test results shall be no greater than 0.05 lpm. The flow checks ~~is~~are performed with a traceable calibration standard. If either~~the~~ measured flow is greater than 2% different than the reported flow, a flow calibration shall be performed.

~~3.~~ 3. Initial filter change. Using the "Advanced" filter change mode, install a clean filter for each channel before each run and put 2 clean filters on the storage pins inside the sensor. Proper operation of the TEOM must always be confirmed after a filter change, and if necessary the filters should be re-seated. Both TEOM frequencies should be greater than 200 Hz. For the PM2.5 channel, the RPComm PM plot can be used; there should not be excessive noise or large and erratic negative data. For the PM-coarse channel, verify that after five minutes ~~After 10 minutes, if~~ the TEOM "noise" parameter shown on the TEOM display for ~~either~~ both channels are~~is~~ ~~greater~~ no higher than 0.2 µg., ~~the TEOM filter shall be reseated~~.

Commented [GA5]: 0.2 ug is ONLY for when pm is very low or zero.

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C. Operation During Testing

1. Before initiating the test, run the TEOM while sampling dilution tunnel air (with tunnel flow) for at least 10 minutes. The change of pressure in the tunnel can cause a large transient TEOM response which would invalidate the data for several minutes.

2. TEOM filter changes during a test run are done when any of the~~as~~ following conditions are met~~s~~, using the "Advanced" filter change mode. Filters for both channels are always changed at the same time ~~when any of the following conditions are met~~. Note that filter "plugging" does not end the test run – it triggers a filter change and the run continues.
   a. Percent loading reaches 115~~20~~ % for either TEOM channel
   b. When the sample flow drops more than 5% of the flow setpoint for either channel.
   c. Near the end of burn phases 1, 2, and 3 but sufficiently in advance of loading the next fuel charge to allow the TEOM to stabilize for at least 10 minutes after completion of the filter change procedure. This ensures that ~~so~~ valid data are available when the next fuel charge is loaded.

   Proper operation of the TEOM must always be confirmed after a filter change. TEOM frequencies for both channels must be greater than 200 Hz. For the PM2.5 channel, the RPComm PM plot can be used; there should not be excessive noise or large and erratic negative data. For the PM-coarse channel, verify that after five minutes the "Noise" values for both channels should either be small (< 2 ug) or if large, similar.

   Commented [GA6]: I know… this is fuzzy. It's a placeholder for when thermo gives is noise info.

   Note that if the flow starts to drop from the setpoint before 1~~2~~15~~0~~% is reached, that is an indication of a vacuum pump problem. Vacuum is usually ~~no higher than~~between 0.20 and 0.30 atm as read on the "System Status" TEOM display screen, and if it exceeds 0.50 atm, the pump should be serviced.

Detailed information on performing filter changes during testing is provided in Section 5 of this document. Note that the TEOM does NOT have any clear visual warning that the filter needs changing due to loading, but it is possible to use the TEOM digital outputs (relay contact closures) to trigger an external alarm at any desired filter loading ~~or other parameter~~, as shown here. Alarm 1 (PM2.5 channel) and Alarm 2 (PM-Coarse channel are both set to trigger when filter loading > 115% in this example, since flows do not start to drop until loading is above this value. ~~-~~Under Settings, Analog & Digital Outputs, Contact Closure:

	Instrument Variable:	Compare Operator:	Compare Value:
#1:	PM 2.5 TEOM filter load	>	115.00
#2:	PM-Coarse TEOM filter load	>	115.00

3. At the end of the test, perform external leak and flow checks on both channels as detailed in Section 3 and record the results. For valid results, leak checks shall be no more than 0.05 lpm, and flow checks shall be within 2.0 % of the TEOM flow reading.

Commented [GA7]: Do we need a section on cleaning of the sample tubing and the Teom downtube?

4. Download the test data using either the Thermo ePort software (preferred), RPComm, or to a USB thumb drive. Note: the data format may be different depending on how the data are downloaded.

Notes:

Commented [GA8]: This could be moved somewhere else. Not sure where it belongs. Maybe it needs to be broken up, with notes next to appropriate content.

- The instrument "Status" code is not normally used for data validation. If the ambient T/RH sensors are not used, a status code of 8 will be present. Other than status codes of 134,217,728 (TeomA) and 524,288 (TeomB) when the % loading is greater than 90%, ~~T8his~~ is normally the only allowable "warning" status once the system is warmed up and is in use for testing.

Commented [GA9]: This is not a typo…

- When the TEOM is first turned on or rebooted, no data are recorded until the top of the next hour. Other than after a reboot, data will be recorded even when no concentration data is displayed on the screen.

- **After EVERY instrument ~~power on~~~~Boot~~ or Reboot:** confirm data are being recorded after the top of the hour. Occasionally the TEOM doesn't store any data after a reboot, even though all operational parameters are normal and concentrations are reported to RPComm and the TEOM display. If this occurs, Stop and Start the instrument to start data storage. A filter change using the Wizard is a Stop and Start cycle.

- When the time is changed, the instrument reboots (after many seconds of being hung, with no information on the screen). When it reboots, no data are recorded until after the

top of the next hour (see above).

- TEOM PM concentrations are in micrograms per cubic meter, at EPA STP (20~~1.10~~C and 1.00 atmosphere) with the instrument configuration used in this procedure. Filter mass loading is reported in micrograms, with a resolution of 0.01 micrograms (10^{-8} grams).

Section 3. Leak and Flow Checks and Flow Calibration for the 1405-D TEOM

A traceable flow standard capable of displaying flow at standard conditions of 20~~1.10~~ C and 1.00 atm shall be used for all flow checks and flow calibrations. Facing the front of the TEOM, the left channel is PM2.5 and the right channel is PM-coarse.

Leak Checks
A leak test measures the flow as reported by the TEOM's flow sensors with no flow~~the inlet closed off~~. Leak checks shall be done for both channels before the start and after the end of every test run. The TEOM leak test flow measurements must be corrected for the TEOM flowmeter's zero offsets. To conduct a flow check, follow the procedures below for each channel:

1. With the TEOM warmed up for at least 30 minutes, read the TEOM reported flow for both channels with the pump turned off or with the TEOM in Stop mode. ~~or with the sample flow set to 0 lpm.~~ This is the flowmeter zero reading.
2. Close off the inlets to the TEOM sample train ~~with a swage cap~~.
3. Turn on the TEOM pump, or set the ~~flow back to its nominal value~~TEOM to Run mode.
4. Wait one minute and read the flows reported by the TEOM.
5. The leak test values ~~is~~are the difference between the reading without and with ~~the pump~~flow ~~on~~.
6. The leak tests should be no greater than 0.05 lpm (net value).
7. ~~Remove the brass swage cap from~~Open the inlet to the TEOM ~~inlet~~sample train.

Flow Checks.
~~Leak checks shall be done before the start and after the end of every test run.~~ The TEOM sample flows for each channel shall be set to 1.00 lpm (at 20.0~~1.1~~ C and 1.00 atm). The TEOM should be warmed up for at least 30 minutes before checking or adjusting the sample flows. The sample flows must be measured at the sample train inlet with an external NIST-traceable flow meter that reads in STP (20~~1.10~~ C and 1.00 atm); measured flows must be within 2.0 % of the flow as indicated on the TEOM display for each of the two channels.

Flow Calibrations.
Flows are calibrated for each channel with a NIST-traceable flowmeter that reads STP flow at 20.0 C and 1.00 Atm, using the TEOM wizard at Service, Calibration, Flow Calibration (page 5-41 of the Dichot TEOM manual); select "Direct Flow Device" (not FTS). A Flow Check shall be performed immediately after every flow calibration.

NOTE: In buildings where heavy electrical equipment is operated, the actual TEOM flows might be unstable even though the reported flow appears to be stable. This can cause erratic and poor

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agreement in the PM between the two TEOM channels. For that reason it is recommended to use a constant voltage power supply for this instrument rather than a direct 120vac wall outlet.

Commented [GA10]: This text could be added somewhere if needed:
Flow troubleshooting [when flow zero is elevated - > .05? or any kind of flow issue]:
use RPComm to report the "flow offset" and "flow span" parameters [PRC 228, 229 for TeomA, and PRC 312, 313 for TeomB]. Then reset the instrument's flow calibration to 0 and 1 by doing a flow cal routine but just hit "next" without entering any flows. Once that is reset, perform a normal flow calibration and then record the new parameters.

Section 4. TEOM Mass Transducer K0 Check Procedure for the 1405-D TEOM

The mass transducer K0 checks described here are done before and after each set of test runs for both TEOM channels.

K0 Checks

K0 checks confirm the calibration factor for the tapered element mass transducer by weighing a clean TEOM filter of known mass (nominally 0.09 grams). These checks are done before and after every set of test runs using the K0 Wizard. See page 5-53 of the Dichot TEOM manual and the results screenshot below. The calibration filter should only be handled with the red filter change tool. The black filter change tool should never be used with the calibration filter.

Commented [GA11]: Do we need to include some info on documentation of this cal filter? They can be ordered from Thermo, but are trivial to make yourself with a 0.1 mg balance. We could include a procedure for doing that.

Document K0 checks with a screenshot of the result as shown below. If results are greater than 2% different from the values being used by the TEOM~~noted on the transducers~~, repeat the check. If repeated checks are greater than 2%, repeat the check with a second calibration filter. If the difference persists, the K0 value in the instrument may need to be changed, but this should ~~almost never need to~~ not be done without clear and robust evidence that the K0 value is wrong.

Commented [GA12]: Documented with a screenshot of the final wizard screen.

Commented [GA13]: Usually the same K0 as noted on the transducers.

Commented [GA14]: We could trigger this with a persistent error < 2%. – this would tighten up the agreement between 2 channels. Thermo spec is 2.5% but that allows a 5% diff between them, which is a lot. <1% would be very tight but can be achieved with care. Another quality metric could be the spread between the 2 results, since they are done with the same cal filter. For matching the PM from the 2 channels, the spread is the more important metric.

K0 Verification Results

The K0 Verification Wizard has completed successfully. The instrument will be put in Run mode when this wizard is finished.

PM-2.5 (left) TEOM:
K0: 14523.0 Audit K0: 14592.7
Percent difference: 0.48
Initial frequency: 344.8019
Final frequency: 248.8712

PM-Coarse (right) TEOM:
K0: 15825.0 Audit K0: 15871.9
Percent difference: 0.30
Initial frequency: 384.9188
Final frequency: 280.5874

Section 5. Filter Change Procedure for the 1405-D TEOM

The TEOM measures the pressure drop across the filter as % of maximum (115~~20~~%), and is shown on the instrument display screen. A clean filter has a loading of about 5 % at 1.00 lpm~~LPM~~. Filter lifetime will vary widely depending on the PM concentrations being sampled. At very high PM concentrations (several hundred mg/m^3), filter lifetime may be less than 30 minutes. Under typical sampling conditions, lifetime is an hour or more with concentrations in the 20 to 50 mg/m^3 range. With care, filter changes can be done such that only a few minutes of data are lost.

Filter change procedure.

The following are filter handling procedures that shall be followed:

A. Unused clean filters should be stored in the original box, with the silica gel desiccant.
B. Two clean filters should be stored in the mass transducer on the posts provided.
C. Filters must only be handled with the black filter change tool that is stored inside the TEOM cabinet.

The Dichot TEOM manual has illustrated procedures for filter changes starting on page 5-6. Minimize the time the mass transducer is open to reduce the time needed to re-stabilize temperatures after the filter change.

1. The filter change menu can be located by choosing Service, Maintenance, Replace Filter. Select the "Advanced" option, and then Next to proceed. This turns off the oscillating element which makes filter seating easier.

2. Open the TEOM cabinet door, open the box of clean filters, and open the mass transducer. Remove the old filter by sliding the filter tool onto the filter and pulling straight out. Do not twist the tool (to prevent damage to the glass tapered element).

3. For each channel, pick up a new filter that has been stored inside the mass transducer with the tool. Position it directly over the tapered element and push the filter on gently. Once the filter is on, remove the tool from the filter and fully seat the filter by pushing firmly straight down on the filter with the bottom of the tool (see the TEOM manual for more information). The filter should have a small amount of horizontal play when this is done; if not, the filter may be wedged between the tapered element and the side of the opening for the element. Store two~~another~~ new filters in the mass transducer.

4. Close the mass transducer, replace the filter box cover, and close the cabinet door. Restart the TEOM by completing the filter change wizard with Next, Finish. The TEOM is not restarted until the Wizard is closed with Finish, and the Maintenance screen is shown.

5. If the PM concentrations for both channels ~~as read on the RPComm graph~~ haven't stabilized within 5 minutes, or if either channel's frequency is less than 200 Hz, the filter may need to be reseated or is defective, or the sensor latch may not be closed properly. Repeat the filter change "advanced" procedure and take the filter off and re-seat it. Push it on firmly with the back of the filter tool and make sure the sensor is properly closed and latched. If the problem persists after another 5 minutes, restart the procedure with another new filter.

Commented [GA15]: This won't work for PM-C since output is 10x too low.

Commented [GA16]: as read on the RPComm graph – can't do this for the coarse channel since it reads 17 times too low.

Commented [GA17]: Raw Noise values can't be used here because PM may be high. The Wizard suggests looking at the Frequencies post-change and that they should be stable to the 3rd decimal place. But that's only updated every 10-seconds.

Note: the PM concentrations on the TEOM display will read 0.0 after a filter change until the top of the next hour. When valid data are being collected, the RPComm graph will indicate the concentrations, and the "Total Mass" on the TEOM display will read something other than "0.00" for both channels.

Commented [GA18]: Well… it does that for PM2.5 but not for PM-C. It's a feature, not a bug…

Section 6: Data Storage and Download

The TEOM shall be set to store data every 60 seconds. There is storage for more than a year of data at this storage interval. Data can be downloaded while the TEOM is running.

Data are usually downloaded with the ePort software but if needed can also be downloaded to a USB thumb drive or with the RPComm TEOM software. The data file is in .CSV format for importing into a spreadsheet.

The TEOM shall be configured to record data parameters as follows. There is a limit of 20 parameters (not including the Date and Time, which are always recorded).

~~1.~~ 0. Date, Time
~~2.~~1. Operating mode
~~3.~~2. PM-2.5 raw MC
3. PM-Coarse raw MC
4. PM-2.5 total mass
5. PM-Coarse total mass
6. Case temperature
7. Cap temperature
~~5.~~8. PM-2.5 flow rate
9. PM-2.5 air tube temperature
~~6.~~10. PM-2.5 TEOM filter load
~~7.~~11. PM-2.5 TEOM filter pressure
~~8.~~12. PM-2.5 TEOM noise
~~9.~~13. PM-2.5 TEOM frequency
~~10.1. PM-Coarse raw MC~~
~~11. PM-Coarse total mass~~
~~12.~~14. PM-Coarse flow rate
15. PM-Coarse air tube temperature
~~13.~~16. PM-Coarse filter load
~~14.~~17. PM-Coarse TEOM noise
~~15.~~18. PM-Coarse TEOM frequency
~~16.1. Case temperature~~
~~17.1. Cap temperature~~
~~18. PM-2.5 air tube temperature~~
~~19. PM-Coarse air tube temperature~~
~~20.~~19. Vacuum pump pressure
~~21.~~20. System status

Commented [GA19]: PM-c filter P is not recorded.

The key parameters for data validation and analysis are:

1. Date and Time – reported as the end of the average interval
2. PM2.5 raw and PM-Coarse raw Mass Concentration ~~—~~ ~~PM2.5 raw~~these are ~~is~~ always reported even when the instrument status is invalid. This minimizes loss of data after a filter change but also requires manual ~~editing~~ QC of the data file to remove invalid PM concentrations based on review of the data and critical parameters listed below. Concentration is in $\mu g/m^3$. A zero value ~~for Mass Conc~~or a repeating value for Mass

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Conc indicates no data.

3. PM2.5 and PM-Coarse total mass - the mass loading on the TEOM filter in µg since the last instrument reset, filter change, or Stop/Start cycle. A zero indicates no data.
4. PM2.5 and PM-Coarse flow rate - Flow is lpm at 20~~1.1~~0 C and 1.00 atm.
5. PM2.5 and PM-coarse TEOM filter load - filter loading as % of maximum.
6. Case temperature, in degrees C.
7. Noise is a mass transducer stability metric and should normally be less than 0.20 µg when PM concentrations are low or zero.
7.

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Section 7. Data Validation and Calculations

TEOM data are recorded every 60 seconds. Data validation and conversion to PM rate (g/h) is performed on the 60 second data. PM rate data are averaged up to longer intervals for reporting use as required.

Calculations for the ~~second~~ "PM-Coarse" (TeomB) channel PM concentrations.
The 1405-D TEOM does not report the actual PM-coarse channel (TeomB) concentration, since it is designed for use with a dichotomous sampler virtual impactor inlet system. The PM concentrations for this channel ~~must be~~are calculated ~~from …… TBD xxxx~~as follows: (16.67/PM-Coarse flow) * PM-Coarse raw MC. For 1.00 lpm flow, the calculation is:

PM-Coarse channel (ug/m3) = 16.67 * PM-Coarse raw MC.

One-minute TEOM PM concentration data for each channel are valid only when ~~all five parameters below are within these specified ranges~~ all of the following parameters are met:~~:~~

1. Flow reported by the instrument is within 5% of the flow setpoint (between 0.950 and 1.050 lpm)
2. Operating mode (not system status): 3 or 4
3. Noise: some form of concentration normalized noise goes here, in µg
4. Case~~All~~ temperatures~~:~~ +/- 0.1~~3~~0 C of setpoint (32.9 to 33.1 C)
5. ~~PM2.5~~ Concentration is not 0.0~~0~~
6. Total Mass for ~~both channels~~ is not 0.0~~0~~
7. Concentration is different from the preceding interval.
~~6.~~8. Lab air PM data are available and valid.

Xxxx PLACEHOLDER xxxx for validation based on how well the 2 channels agree with each other, TBD later.

Since the "wait time" is set to 0 to minimize data loss during a filter change, the TEOM never invalidates any data. Thus the data must always be reviewed and validated manually using the criteria above. 1-minute intervals during the test run that do not have valid data are represented using empty spreadsheet cells for those intervals. Any longer interval calculated from the 1-minute data must have 75% of the possible 1-minute values. Example: a 10-minute interval must have at least 8 minutes of valid data to be valid.

The output of the TEOM is PM concentration in µg/m^3 at 20.0~~1.1~~ C and 1.00 Atmosphere (29.92 inches Hg) pressure. ~~To correct TEOM data to dry flow conditions, the dilution tunnel dewpoint data shall be used. NEED TO ADD HOW here. XXXX runavg DP value or at 1-minute intervals? If 1-minute, will need a spreadsheet template~~ The TEOM flow is "wet" e.g., not dried, and the tunnel flow used here is also "wet", without any water vapor correction.

The 1-minute net (tunnel minus lab air) ~~dry~~ TEOM PM concentrations are converted into grams/hour using the tunnel flow as follows:

g/h = 0.000001699 * tunnel flow (in wet~~dry~~ CFM) * PM concentration (in µg/m^3)

Commented [GA20]: They are validated separately.

Commented [GA21]: Waiting for Thermo information.

Commented [GA22]: Case T is the critical one. See [9/23/20 HLS warmup data example]. There is only one Case T [it's common to both channels]. If case T is ok, air tube and cap T are always ok also. Thermo T spec is "2%", which is garbage.

Commented [GA23]: Covers "filled in missing data" during a filter change.

Commented [GA24]: Stef: This effectively fills in missing data from filter changes with the run avg value - is that what we want? **There is no way around some kind of data "fill-in" for missing data!!!!** Filling it in with best estimate from adjacent values is better than filling in with the run avg value.

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Commented [GA25]: STOP the presses! No water vapor correction is needed if the tunnel flow is not corrected.

Commented [GA26]: For examples of various ways to calc this, see: [HYPERLINK "https://www.wpc.ncep.noaa.gov/html/dewrh.shtml"] [HYPERLINK "https://www.decatur.de/javascript/dew/about.html" \l "InterpolationFormulas"] [HYPERLINK "http://www.dew-point.com/dew-point_calculator.asp"] [HYPERLINK "http://bmcnoldy.rsmas.miami.edu/Humidity.html"] [HYPERLINK "http://go.vaisala.com/humiditycalculator/5.0/help/index.html" \l "about"] and [HYPERLINK "http://www.michell.com/us/calculator/faq.html" \l "hc_formula"] which notes: "The most widely used formula is the Sonntag formula, found in BS1339-1, but other formula such as those by Hardy and Wexler are also. The uncertainties between the different formula are similar, and no formula is "more valid" than another."

Commented [GA27]: This *is* valid, and simpler than current practice!

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The values used for tunnel flow must be the actual (wet) measured values, at intervals of no greater than 10 minutes, except as follows. If the range of 10 minute tunnel flow measurements (100*(Max - Min) / average) is no greater than 5.0% of the run-average tunnel flow, the run average tunnel flow can be used for these calculations.

For calculation of lbs/mmbtu, total grams PM emitted is calculated by multiplying the average g/h rate for the test period of interest times the duration (in~~number of~~ hours) of that test period. Grams are converted to lbs by dividing grams by 453.6.

Section 8: TEOM Configuration Changes for Fast Response and High PM Concentrations, and List of TEOM Parameter Configuration Values.

These settings are for the 1405-D TEOM as used in this application that are different from instrument default settings. See the 1405-D manual for detailed information on how to change these values.

1. For both channels (TEOMA and TEOMB), ~~remove~~ confirm that all of the "Mass Constants" A and B factors ~~[+3 and x1.03] that are used for PM10 FEM status.~~ are set as follows: The 3 "Mass Constant A" values are~~is~~ set to 0.0~~zero~~, and the 3 "Mass Constant B" values are~~is~~ set to 1.00.

2. Change system signal filtering and wait time settings:
~~TM (Total~~ Mass Avg time~~)~~ from 300 to 30 seconds
MR-MC (Mass Rate/Mass Conc) Avg time~~)~~ from 300 to 30 seconds
System Wait Time from 1800 to 0 seconds (disabled)

3. Change the sample flow from 3.00 to 1.00 lpm for the PM2.5 channel, and from 1.67 to 1.00 lpm for the PM-Coarse channel. Change the bypass flow to 0.00.

4. Change all four temperature zones [Case, Cap, PM2.5 Air, and PM-Coarse Air] to 33 C.

5. Set the Flow Control to Passive, and Reporting conditions to Standard. Change T/P to 20~~1.1~~0 C and 1 atm as shown below.

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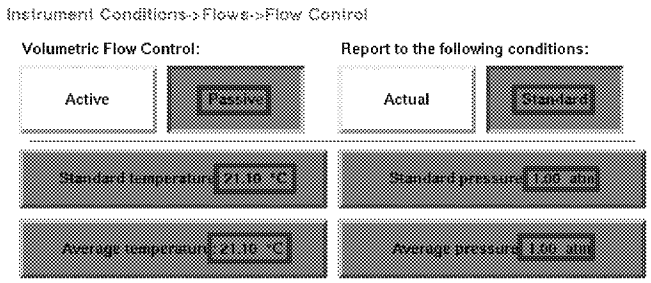

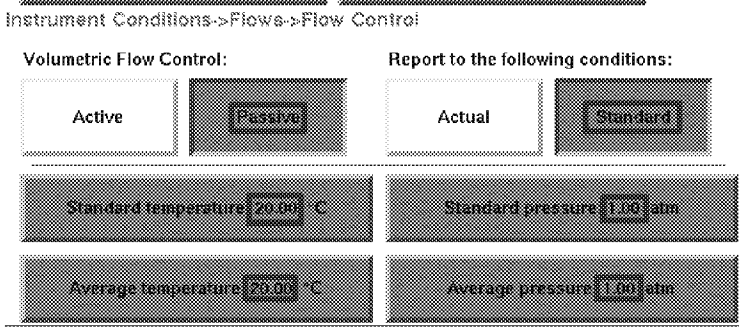

6. Change the Data Storage interval to 60 seconds.

A complete list of 1405-D TEOM Settings that are modified from instrument defaults are shown ~~listed~~ below. TEOMA is the PM2.5 (left) channel, and TEOMB is the "Coarse PM" (right) channel.

PRC*	Description	Value	Unit	Notes
12	storage interval	60	sec	
28	system wait time	0	sec	Always reports data
35	mass average time	30	sec	See also PRC392 (MRMC Avg)
48	case T	33.00	C	
59	cap T	33.00	C	
74	average T	20~~1~~.0~~1~~	C	For reporting PM at 2~~7~~0 ~~F~~C
75	standard T	20~~1~~.0~~1~~	C	For reporting PM at 2~~7~~0 C~~F~~
76	average P	1.00	ATM	For reporting PM at 29.92 "Hg
77	standard P	1.00	ATM	For reporting PM at 29.92 "Hg
115	TEOMA air tube T	33.00	C	~~Higher as needed for stable case T~~
225	TEOMA flow rate	1.00	lpm	
309	TEOMB flow rate	1.00	lpm	
321	TEOMB air tube T	33.00	C	
392	MRMC average time	30	sec	See also PRC35 (Mass Avg)

407	TEOMA mass constant A	0.0	µg	Intercept
408	TEOMA mass constant B	1.00		Slope
409	TEOMB mass constant A	0.0	µg	Intercept
410	TEOMB mass constant B	1.00		Slope

*TEOM Program Register Code

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Message

From: Johnson, Steffan [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=EBA5C0DFC5FC4593AFA62CE7C3DD6F02-JOHNSON, STEFFAN]
Sent: 9/8/2021 1:10:50 PM
To: Lisa Rector [lrector@nescaum.org]
CC: gallen@nescaum.org
Subject: RE: TEOM Ruggedness parameters

Lisa,

EPA will be assessing some ruggedness criteria of the TEOM's in ORD, and of the IDC at PFS.

The QAPP for the ORD work is not yet final, but I can tell you the ruggedness criteria will be those that are specific to changes of the TEOM equipment and/or sampling line/probe. Think TEOM filter temp, sampling rate, and rinse of sampling line vs non-rinse as well as precision with each being rinsed.

We do not yet have a quote for ruggedness work we intend to do at PFS, however we expect one soon. Those ruggedness tests will be pointed at changes to the operation of the IDC (fuel moisture, tunnel flow/temp, draft, etc).

Happy to discuss in more detail. Is there a day that works best for you? I have time this Friday at 2pm, or Monday at 3pm?

Stef

From: Lisa Rector <lrector@nescaum.org>
Sent: Wednesday, September 8, 2021 8:37 AM
To: Johnson, Steffan <johnson.steffan@epa.gov>
Cc: gallen@nescaum.org
Subject: TEOM Ruggedness parameters

Stef, I am looking at the EPA testing overview spreadsheet because we have some questions about EPA's TEOM ruggedness assessment. Does EPA still plan to assess the ruggedness parameters for the TEOM below (taken from the EPA spreadsheet-TEOM validation tab)? Are you planning any tests at PFS with cordwood for TEOM ruggedness parameters, or will that work be done solely at ORD? For the CS work, we are contemplating some additional measurements to obtain data for TEOM ruggedness if that would be useful for EPA assessment work. Can we set up a time next week to discuss this work? Thanks!

1	**TEOM /DEKATI Diluter Validation Study**		
2			
3	**Appliance type**		
4			
5	Pellet Stove	7 Test Runs to determine precision of paired diluter/teom arrangements	To be conducted at ORD RTP
6	Pellet Stove	7 Test Runs to determine precision of paired diluter/teom arrangements	To be conducted at ORD RTP - Different fuel
7	Pellet Stove	14 Test runs to determine ruggedness of diluter/teom arrangments*	To be conducted at ORD RTP
8			
9	Wood Heater - Cordwood	7 Test Runs to determine precision of paired diluter/teom arrangements	To coinncide with IDC Stove validation work in EPA Approved lab
10	Wood Heater - Cordwood	7 Test Runs to determine precision of paired diluter/teom arrangements	To coinncide with IDC Stove validation work in EPA Approved lab - Different fuel
11	Wood Heater - Cordwood	14 Test runs to determine ruggedness of diluter/teom arrangments*	To coinncide with IDC Stove validation work in EPA Approved lab
12			
13	Wood Heater - Catalytic Cordwood	7 Test Runs to determine precision of paired diluter/teom arrangements	To coinncide with IDC Stove validation work in EPA Approved lab
14	Wood Heater - Catalytic Cordwood	7 Test Runs to determine precision of paired diluter/teom arrangements	To coinncide with IDC Stove validation work in EPA Approved lab
15			
16		70 **Total test runs** (Many may be accomplished concurrently with other validation testing)	
17			
18			

19	**ASTM E1169:**	**Ruggedness parameters to be evaluated:**	**Condition High**	**Condition Low**	**Reference**
20		Dilution temperature	+50 deg F	-50 deg F	TBD
21		Dilution ratio	+30%	-10%	TBD
22		Sampling rate	+20%	-20%	TBD
23		Dilution Air	HEPA	Room	Quartz filter
24		Dilution moisture	Room	NAFION	Drierite
25		Filter temperature	95	75	85 deg F
26		TEOM Filter Change	3 hrs	dP trip	As needed

NESCAUM

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Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 7/6/2021 5:37:56 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
Subject: FW: IDC FUEL PIECE MOISTURE CONTENT MEASUREMENTS
Attachments: WOOD MOISTURE MEMO 6.26.21.doc

Stef, do you want to set up a call to discuss these items?

From: Alben T. Myren Jr <myren.ben@gmail.com>
Sent: Tuesday, July 6, 2021 12:55 PM
To: Sanchez, Rafael <sanchez.rafael@epa.gov>; Lischinsky, Robert <Lischinsky.Robert@epa.gov>; Aldridge, Amanda <Aldridge.Amanda@epa.gov>; Baumgart-Getz, Adam <Baumgart-Getz.Adam@epa.gov>; French, Chuck <French.Chuck@epa.gov>; Boyd, Rochelle <Boyd.Rochelle@epa.gov>; Lowe, Theresa <Lowe.Theresa@epa.gov>; Cozzie, David <Cozzie.David@epa.gov>; Jordan Scott <jordan.scott@epa.gov>; Wayland, Richard <Wayland.Richard@epa.gov>; Hemby, James <Hemby.James@epa.gov>; Yellin, Patrick <Yellin.Patrick@epa.gov>; Scinta, Robert <scinta.robert@epa.gov>; Danick Power (dpower@polytests.com) <dpower@polytests.com>; John Steinert <john.steinert@pfsteco.com>; Brian Ziegler Intertek <brian.ziegler@intertek.com>; Wayne Terpstra <WTerpstra@pfscorporation.com>; Atemboski Alan <A.Atemboski@travisindustries.com>; Ryan Carroll <carroll@hpba.org>; Rachel Feinstein <feinstein@hpba.org>; Jack Freeman <jack@kumastoves.com>; John Ackerly <jackerly@forgreenheat.org>; Jason Freeman <jason@kumastoves.com>; Sean Reilly <sreilly@eenews.net>; Segall, Martha <segall.martha@epa.gov>; Brashear, Angelina <Brashear.Angelina@epa.gov>; Scott Plageman <scott.plageman@appliedcatalysts.com>; Carroll, Allen <allen.carroll@appliedceramics.com>; Martin Morrill <martin.morrill@appliedcatalysts.com>; Marc-Antoine Cantin <macantin@sbi-international.com>; Paul Miller <pmiller@nescaum.org>; Paul Hodges <PHodges@napoleonproducts.com>; Rumens, Kurt <kurt@travisindustries.com>; Dan Henry <dan@5g3consulting.com>; Lorin Day <lorind@woodstove.com>; Louise Cleroux <lcleroux@icc-rsf.com>; Andre Bibaud <abibaud@icc-rsf.com>; Luc Gilbert <lgilbert@icc-rsf.com>; Chris Neufeld <cneufeld@blazeking.com>; Cindy Heil <Cindy.Heil@alaska.gov>; Edwards, Alice L S (DEC) <alice.edwards@alaska.gov>; Mendivil, Gary A (DEC) <gary.mendivil@alaska.gov>; Steve Hoke <steven.hoke@alaska.gov>; Lisa Rector <lrector@nescaum.org>; Herschberger, Lisa (MPCA) <lisa.herschberger@state.mn.us>; Chung, David <DChung@crowell.com>; David Grant (davg461@ECY.WA.GOV) <davg461@ecy.wa.gov>; Formanj@hearthnhome.com; Guillaume Thibodeau-Fortin <gthibodeaufortin@sbi-international.com>; Robert Ferguson <bob.fcllc@gmail.com>; Eric Schaefer <ericsschaefer82@gmail.com>; Haslam, Alex <A.Haslan@travisindustries.com>; Ken Morgan <kmorgan@omni-test.com>; Bruce Davis <bdavis@omni-test.com>; Alex Tiegs <atiegs@omni-test.com>; Tom Morrissey <tomm@woodstove.com>; Dane Myren <danemyren@gmail.com>; Steffan Johnson <johnson.steffan@epa.gov>; John Crouch <crouch@hpba.org>; Toney, Mike <toney.mike@epa.gov>
Subject: IDC FUEL PIECE MOISTURE CONTENT MEASUREMENTS

All,

The attached memo explains in detail why the current approved version of the IDC (6.25.21 EPA letter) is wholly inadequate and sorely lacking in the details necessary to (1.) take accurate fuel piece moisture content measurements and (2.) make the necessary calculations to determine emission factors (g/kg), among other things.

ENJOY!

Ben

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Date: 26 June 2021

To: Stef Johnson, EPA/OAQPS/AQAD;

CC:Mike Toney, EPA/OAQPS/AQAD; Richard Wayland, EPA/OAQPS/AQAD; Rochelle Boyd, EPA/OAQPS/SPPD
Robert Scinta, EPA/OECA; Angelina Brashear, EPA/OAQPS/AQAD; Chuck French, EPA/OAQPS/SPPD; Patrick Lessard, EPA/OAQPS/SPPD; Thersa Lowe, EPA/OAQPS/SPPD; Rafael Sanchez, EPA/OECA; Adam Bumgart-Getz, EPA/OAQPS

CC: A List of Other Recipients Is Attached

From: Ben Myren

RE: REVIEW OF TEST METHOD FUEL PIECE MOISTURE CONTENT MEASUREMENT PROCEDURES

EXECUTIVE SUMMARY

This review finds that the ASTM E3053 test method provides the most thorough, detailed procedures for measuring fuel piece moisture content and the NYSERDA IDC test method provides the fewest criteria for measuring fuel piece moisture content measurement of any of the test methods that have been used since 1984. Table 1 on page 13 summarizes these procedures in a test method by test method basis. The accuracy of fuel piece moisture content measurements is very important because fuel moisture content is known to be one of the key variables that significantly effects stove performance. Thus, this substantial difference in the procedures specified for fuel piece moisture content measurement will impact many different test results, e.g. emission factors (g/kg), emission rates (g/h), dry burn rates (DBRs) and overall efficiency (%OE) because drier wood tends to burn faster and cleaner.

The lack of detail in the procedures used to determine fuel piece moisture content is further compounded by the fact that the NYSERDA IDC has a number of substantial, significant errors, omissions and contradictions that make the test method unusable as presently written, e.g., the equation given for calculating emissions factors (g/kg) is wrong and generates an obvious incorrect answer. (See pp. 7-9.)

There are two suggestions provided as a way forward in the short term: (1.) EPA issue a new approval letter which clearly specifies the

procedures to be used to determine fuel piece moisture contents in the TEOM testing that is presently taking place and (2.) EPA rescind its approval of the IDC test method until ALL of the known deficiencies described in this memo and reported elsewhere in the IDC are resolved.

REVIEW OF TEST METHOD FUEL PIECE MOISTURE CONTENT MEASUREMENT PROCEDURES

In an effort to understand and be able to accurately conduct test runs using the recently EPA approved version of a test method titled "*NYSERDA Integrated Duty Cycle Test Method for Certification of Wood-Fired Stoves Using Cordwood: Measurement of Particulate Matter (PM) and Carbon Monoxide (CO) Emissions and Heating Efficiency*" (IDC test method or IDC), I am now raising some questions about the procedures specified in the latest EPA approved version (June 25, 2021) of the IDC that are to be used when taking fuel piece moisture content readings. This method was approved in an EPA (Stef Johnson) letter dated 6/25/2021 to Ms. Alice Edwards of the Air Quality Division of the Alaska Department of Environmental Conservation (ADEC).

In the above cited approved version of the IDC, Section 11.3.2.1 states:

> "…Determine fuel moisture for each fuel piece by averaging four moisture readings, one from each of three sides, measured parallel to the grain…"

That is all of the direction that is given!

Question: Just how does one do that exactly, i.e., take four readings from three sides?

Now for some history to demonstrate just how grossly deficient this section (and the IDC) is. It is grossly deficient because (1.) fuel moisture content is known as one of the key variables that can significantly impact stove particulate (PM) and Carbon Monoxide (CO) emissions, among other things and (2.) the lack of specifics about how to take fuel piece moisture content readings introduces an unnecessary and significantly large (huge) variable in obtaining consistent test results. The following discussion examines the fuel piece moisture content measurement procedures in all of the test methods that preceded the present approved version of the IDC and the current IDC version itself.

A. Oregon Method Seven:

Oregon Method Seven (OM7 or more simply M7) was promulgated by the State of Oregon's Department of Environmental Quality (DEQ) on July 8, 1984. It is the original wood stove test method. When EPA promulgated the first NSPS in 1988, OM7 was broken into two parts, EPA M5H and EPA M28. The latter became the operating and fueling protocol for all EPA certification testing until ASTM E2780 was approved. ASTM E2780 is a direct offshoot of M28 and improves upon the fuel piece

moisture content measurement process. ASTM E3053 followed ASTM E2780 and further refined those fuel piece moisture content measurement procedures. Thus, the initial fuel piece moisture content measurement criteria were in OM7. Here note that OM7, EPA M28/M28R and ASTM E2780 use crib fuel loads assembled from 2x4 and 4x4 dimensional lumber, while ASTM E3053 and the IDC use cordwood fuel pieces.

Section 4.1.2 in OM7 reads as follows:

> "…The test fuel shall have a moisture content range between 16% and 20% on a wet basis (19-25% dry basis). Moisture content shall be determined by measurements made with a calibrated electrical resistance type moisture meter or other equivalent performance type meter. Note: to convert moisture meter readings from the dry basis to the wet basis: (100)(%dry reading) ÷ (100 + % dry reading)…"

Section 4.1.4 in OM7 reads as follows:

> "…Moisture content determination per load shall be an average of a minimum of three readings for each fuel piece measured parallel to the grain of the wood on three sides (end readings excluded). If an electrical resistance type meter is used, electrode penetration shall be to a one inch depth using insulated pins. Moisture content measurements shall be made within a four hour period prior to testing, and the test fuel shall be at room temperature…"

Notes in the margins of my copy of OM7 state that (1.) that the average of the 3 readings for each fuel piece must be within the specified range of 19-25% DB, (2.) the fuel piece spacers were to be checked to insure they were within range but the fuel piece spacer moisture content was not to be included in the test load average and (3.) we were to read the (analogue!) moisture meter at 0.25%.

Comments:

1. A specific depth is specified for all fuel piece moisture content measurements.
2. Three readings per piece are required.
3. Spacer moisture content is checked but not included in the average fuel load moisture content calculation.
4. Simple averaging works reasonably well for determining the average fuel load moisture content for fuel loads that are all 2x4's and 4x4's. However, when a mix of 2x4's and 4x4's are required, this simple averaging can skew the overall fuel load moisture content because 4x4's typically weigh twice what a 2x4 of the same length weighs.
5. Note that no specific location is provided on each fuel piece for where the moisture readings should be taken.

<u>B. EPA M28/M28R:</u>

Section 6.2.5 in EPA 28 in the 1988 NSPS states in part as shown below. This section was carried forward into EPA M28R in the 2015 NSPS. Remember this is for 2x4 and 4x4 crib fuel pieces with (nominal) standardized depths (2x4 = 1.5″, 4x4 = 3.5″). Thus, with simple depth gauges this is easy to do.

> "…Test Fuel Charge. Prepare the test fuel pieces in accordance with the specifications in Section 4.3. Determine the fuel moisture content with a calibrated electrical resistance meter or other equivalent performance meter. (To convert moisture readings from the dry basis to the wet basis: (100)(percent dry reading)÷(100 + percent dry reading) = percent moisture wet basis.) Determine fuel moisture by averaging at least three moisture readings, one from each of three sides, measured parallel to the wood grain. Average all of the readings for all of the fuel pieces in the test fuel charge. If an electrical resistance type meter is used, penetration of the insulated electrodes shall be one fourth the thickness of the test fuel piece or 19 mm (0.75″), whichever is greater…"

Comments:

1. Note that specific depths are specified for each fuel piece size.
2. Note that no specific location is specified on each fuel piece for where the moisture readings should be taken.
3. No moisture readings were required for the test fuel piece spacers.
4. Again, simple averaging works reasonably well for determining the average fuel load moisture content for fuel loads that are all 2x4's and 4x4's. However, when a mix of 2x4's and 4x4's are required, this simple averaging can skew the overall fuel load moisture content because 4x4's typically weigh twice what a 2x4 of the same length weighs.

C. ASTM E2780:

Section 9.4.1.2(1) in ASTM E2780 adopts much of the language in M28 Section 6.2.5 and reads in part:

> "…*Test Fuel Piece Moisture* – Determine the fuel moisture for each fuel piece used for the test fuel crib by averaging at least three fuel moisture readings, one from each of three sides, measured parallel to the wood grain. If an electrical resistance type fuel moisture meter is used, penetration of insulated electrodes shall be 1/4 the thickness of the fuel piece or 19mm (0.75″), whichever is greater…"

In addition, Section 9.4.1.(2) in ASTM E2780 requires at least one moisture content reading from each test fuel spacer and requires the moisture content to be measured at 1/4 the thickness of the spacers, i.e., at 3/16″. Average all of the readings for the test fuel spacers to determine the average test fuel spacer moisture content. Here again a simple depth gauge makes this easy to do.

ASTM E2780 Section 10.2 *Nomenclature,* Eqn. 1 provides the calculation to determine the dry weight of the test fuel spacers. Eqn. 2 provides the calculation to determine the dry weight of each of the test fuel pieces in the test fuel crib. These weights are then added together to determine a total dry fuel weight of the test fuel crib and that weight is then used to determine the dry burn rate (DBR) in Eqn 5.

Comments:

1. Note that specific depths are given for the moisture content readings for each test fuel piece size and the spacers.
2. Spacer moisture content is now measured.
3. By determining the dry weight of each fuel piece in a crib fuel load and then combining that dry weigh with the spacer dry weight, any skewing of average moisture contents due to piece weights is eliminated, thus producing a much more accurate average fuel moisture content, emission factor and DBR.
4. A specific location for each moisture content reading is still missing.
5. Also missing is a procedure to calculate an average composite wet basis fuel load moisture content for use in CSA B415-1.

D. ASTM E3053:

ASTM E3053 Section 8.4.2.2 "*Test Fuel Load Moisture Content*" reads in part as follows:

> "…Using a fuel moisture meter as specified in 6.1 of the test method, determine the fuel moisture content for each fuel piece used for the test fuel load by averaging at least three fuel moisture meter readings measured parallel to the wood grain for each test fuel piece. One measurement each from two different sides shall be made at approximately 3 in. (75 mm) from opposite ends of the fuel piece. One additional reading shall be made at approximately the center of the third side. Penetration of the moisture meter insulated electrodes shall be 1/5 to 1/4 the thickness of the fuel piece. For fuel pieces with tightly adhered bark (defined as more than 1/8″ (3.2 mm) thick), the thickness of the bark shall be added to the electrode penetration depth or the bark shall be locally removed in the area where the moisture readings are taken. If more than three moisture readings are taken on any test fuel piece, the additional readings shall be dispersed as evenly as practicable among all the fuel piece sides and in proportion to the locations of the three required readings. Holes for the moisture meter pins may be pre-drilled to the measurement depth minus at least 1/4″ (6.4 mm). For half round pieces, the curved side shall be considered to be comprised of two equal sides and moisture readings taken accordingly. For fuel pieces with geometries that do not directly allow application of the measurement location criteria, measurements should be taken at locations that best meet the intent of this section. The average moisture content for each

fuel piece shall be in the range of 18-28 % on a dry basis. The average moisture content of the test fuel load shall be in the range of 19.0 to 25.0 % on a dry basis…"

Equations in Section 9.2 *Nomenclature* in ASTM E3053 provide the calculations necessary to determine the overall dry weight of the fuel pieces in the different fuel loads which are then used to determine DBRs and PM emission factors for each test run. The equations vary because the ASTM E3053 high burn test is ended when 90% of the wet fuel weight has been burnt. The ASTM E3053 Medium and Low burn tests end when 100% of the wet fuel load weight has been burned.

Comments:

1. Specific criteria are given for the location of fuel piece moisture content measurement readings.
2. Specific criteria are given for the depth of the fuel piece moisture content measurement readings.
3. Specific procedures are given for sides with bark.
4. Specific procedures are given for unusual shapes (half rounds) and other odd shaped pieces.
5. By determining the dry weight of each fuel piece, there is no skewing of data due to pieces with different weights and moisture contents because the sum of the dry fuel piece weights is used in all DBR and emission factor calculations.
6. A calculation for determining the average fuel moisture content on a wet basis (MC_{Wb}) is not provided, yet this value is necessary for use in CSA B415-1 overall efficiency (%OE) calculations. A weight based composite wet fuel moisture content can be determined by multiplying the average fuel piece moisture content by the fuel piece weight and then summing those values and dividing it by the total wet fuel load weight. This is what Myren Consulting has been doing when using CSA B415-1 to determine the overall efficiencies (%OE's) that are required to be reported in the 2015 NSPS. See example below.
7. The following suggestions have been made to improve the fuel piece moisture content measurement accuracy:
   (a.) require that the center of piece reading be made on the side with bark, if there is a side with bark.
   (b.) take the minimum required three readings on the three sides with the largest cross-sectional areas if a piece has more than 3 sides.
8. Based upon research done by Rick Curceet, the choice of the 1/5-1/4 depth requirement in the ASTM 3053 test method was based upon research done by Delmhorst in conjunction with the UF Forest Service where they wanted to be able to determine an average fuel piece moisture content by measuring the moisture content at a specific depth. (Delmhorst manufactures moisture meters.)

<u>E. IDC (Latest EPA approved version - on 6/25/2021):</u>

Section 11.3.2.1 in the current approved version of the IDC states:

"…Determine fuel moisture for each fuel piece by averaging four moisture readings, one from each of three sides, measured parallel to the grain…"

Comments:

1. Yes, that is it! This language has not changed since EPA issued its first alternative test method (ATM) approval letter for the IDC on 2.24.2021 (ALT-140). Since then EPA has issued four additional approval letters (3/09/2021, 3/30/2021, 4/9/2021 and 6/25/2021) with each letter superseding the preceding approval letter. These new approval letters were necessary because of changes made to the IDC.
2. No measurement depths are specified.
3. No measurement locations are specified.
4. Left unexplained is how does one, exactly, take four readings from three sides.
5. What does one do if a piece has more than 3 sides? Trapezoidal pieces are allowed. See Sections 11.3.6.3 and 11.3.6.4.
6. What does one do if a piece is half round? Or has a non-conforming geometry?
7. What does one do if there is bark present? Note that IDC Section 3.29 reads in part as follows:

   "…Test fuel charge – the collection of test fuel pieces used in each of the four phases of the test run. L1, L2, L3, and L4 require that at least 75% of the individual pieces with at least 80% bark on one side of the fuel piece…"

8. Fuel piece moisture content is determined by averaging the four readings taken from the three sides. Equation 2 in Section 13.6.1 calls for a W_{fuel}, (Fuel charge weight in pounds (kg)), and then provides the equation below for determining an emission factor. However, no criteria or equation(s) are provided for determining an average fuel load moisture content, i.e., a simple arithmetic average or a weight based composite average as is calculated in D. ASTM E3053 above where the dry weight of each fuel piece is determined. Given the wide difference in fuel piece weights specified by the Fuel Load Calculator (FLC), a weight based composite average fuel piece moisture calculation would be a much more accurate way to determine either an average dry basis ($\%M_d$) or wet basis ($\%M_w$) fuel load moisture content, as the following example will show.

IDC Section 14.4 Equation 2

$E_{g/kg} = E_T/(W_{fuel}/(1+M\%M_d/100))$, g/dry kg

Where

$E_{g/kg}$ = PM Emissions factor in grams per kilogram of dry fuel burned

E_T = Total particulate emissions for the full test run in grams

W_{fuel} = Fuel charge weight in pounds (kg) - Wet weight?

M%M_d = A typo? I think this should be %M_d. If so, %M_d = Fuel moisture content, dry basis, percent

Example Data Set: Based upon an IDC low burn fuel load with 3 large pieces and 2 small pieces:

Wet Pc. Wt.	%M_d
5.4 lbs.	24.5
5.3	23.0
5.0	20.5
3.2	19.5
2.9	20.0
21.8 lbs.	107.5 ÷ 5 = 21.5% Avg. %M_d

9.8884 kg (wet)

Assume E_T = 15.0 g

$E_{g/kg}$ = 15.0g/(9.8884kg/(1+.215 %M_d)/100)

= 15.0/(9.8884/(1.215/100))

= 15.0/(9.8884/.01215)

= 15.0/813.860

= 0.01843 g/kg Which is nonsense!

Using the same data set and the calculations specified in ASTM E3053, one gets the following answer:

Wet Pc Weight	Avg. %M_d	ASTM Section 9.2 Eqn. 1	Piece Dry Weight (lbs.)
5.4 lbs.	24.5	(5.4)(100)/(100+24.5) =	4.337
5.3	23.0	(5.3)(100)/(100+23.0) =	4.309
5.0	20.5	(5.0)(100)/(100+20.5) =	4.149
3.2	19.5	(3.2)(100)/(100+19.5) =	2.678
2.9	20.0	(2.9)(100)/(100+20.0) =	2.417
21.8 lbs.	107.5		17.890 lbs.

A weight based composite average fuel load moisture content calculation for the above data set would be:

Wet Weight (lbs.)		Avg. $\%M_d$		Pc Contribution
5.4	X	24.5	=	132.3
5.3	X	23.0	=	121.9
5.0	X	20.5	=	102.5
3.2	X	19.5	=	62.4
2.9	X	20.0	=	58.0
21.8				477.1

Composite weight based average $\%M_d$ = 477.1 ÷ 21.8 = 21.885%
= 17.956 $\%M_w$

Compare that to what the IDC requires (?):

$\%M_d$ = 107.5 ÷ 5 = 21.500%

so there is an "instant difference" in $\%M_d$ of 0.385%.

Using the ASTM equation for emission factors

ASTM $E_{g/kg}$ = 15.0 g(17.890 lbs. of dry fuel burnt/2.2046 lbs./ kg)

= 1.848 g/kg - versus IDC value of 0.01843 g/kg

IDC - If one were to use the "correct" equation in Section 14.4.1 for determining emission factors

IDC $E_{g/kg} = E_T/(((W_{fuel})(100)/(1+\%M_d))/2.2046)$, g/dry kg

= 15/(((21.8)(100)/(100+21.5))/2.2046)

= 15/8.1386

= 1.843 g/kg much closer to the ASTM value of 1.848 g/kg

So the Equation given for determining emission factors in the current approved version of the IDC is obviously wrong. As is the definition given in Section 3.6 for Emission Factor which states:

> "…the emission of a pollutant expressed in mass per unit of energy (typically) output from the appliance…"

It should read:

> "… The emissions of a pollutant in mass (g) per unit (mass) of (dry) fuel burnt…" (g/kg)

I should point out here that the first equation in IDC Section 14.4 is for determining g/Mj which must be reported. (See Section 15.2.2) However, there is no equation for determining PM emissions in pounds

per million British Thermal Units (Btu) heat output which is also required. (See IDC Sections 13.1 and 13.3.2.) So this Section needs to be revisited and revised.

9. Also note that Section 13.5 requires that burn rates be reported as wet burn rates (WBRs), yet no provision(s) is/are made for adjusting weight of the fuel burnt and the fuel left in the stove at the end of each phase when the fuel has been in a hot stove for perhaps hours. Are we supposed to assume that the fuel left in the stove at the end of a burn phase still has moisture left in it even when firebox temperatures are over 212° F and have been that way for long periods of time? If so, that seriously skews the wet burn rates (WBRs). I would like to point out here that none of the above test methods that preceded the IDC report WBRs, i.e., all burn rates are reported as dry burn rates (DBRs). This overturns a longstanding precedent. Why?

The last sentence in ASTM E3053 Section 8.5.9.8 states;

> "…For the purposes of this test method, the moisture content of the remaining fuel at the end of the (high burn) test run shall be assumed to be 0% …". (Words in parenthesis added for content clarity.)

The ASTM E3053 high burn test ends when 90% of the test fuel load has been burnt, just like in the IDC where the High, Medium and Low burn tests all end when 90% of each of the three test fuel loads have been burnt.

It would be very simple to adjust the pounds of fuel burnt using the format found in ASTM E3053. As noted, the equations given in IDC Section 13.5 make no such determination. Again, why? This whole section needs to be revisited and revised.

F. EARLIER VERSIONS OF THE IDC: (V1.07.20)

Earlier versions of the IDC had much more detailed criteria for taking fuel piece moisture content readings. For example, Section 8.10.2 in version V1.07.20 which was distributed right before the meeting on 1/15/2020 at EPA in RTP reads as follows:

> "…Determine the test fuel moisture content with a calibrated electrical resistance meter or other equivalent performance meters (meter), as defined in Section 6.6. If necessary, convert fuel moisture content values from dry basis (%Md) to wet basis (%Mw). Determine fuel moisture for each fuel piece by averaging four moisture meter readings, one from each of three sides, measured parallel to the wood grain. Moisture readings will include two core measurements and two shell measurements. One of the core measurements and one of the shell measurements shall be made at the center of the length of each piece. The second core measurement and second shell

measurement shall be made approximately one inch from one end of each piece. Either end may be selected for this measurement. The shell measurements shall be made with this (the) moisture meter insulated electrodes (pins) of 1/4 inch (at a depth of 1/4"). The core measurements shall be mode (made) with a penetration of a (the) moisture meter insulated electrodes (pins) to the center of the piece or a distance of 1.125 inch, whichever is less. For core measurements, a pilot hole is drilled to a distance of not greater than 1/4 inch less than the target penetration distance. Each individual moisture content reading shall be in the range of 10-35% MC on a dry basis - average all of the readings for all of the fuel pieces in the test fuel charge…".

Comments:

1. I have no idea why the more detailed procedures were abandoned and replaced. Since the December 17-18, 2017 Denver meeting with EPA and others, industry folks have been totally frozen out of the IDC development process.
2. Called out typos are in the draft as shown. Suggested revisions for the typos are in parenthesis.
3. Note that Section 6.6 is for Humidity gauges. It should read Section 6.8.
4. Words are being used interchangeably in this section that shouldn't be. Noted in Red. The entire slide hammer assembly with attached pins is called an "electrode". The pins used are called "insulated contact pins". See attached Delmhorst parts list. This has been on-going issue in the earlier test methods as well. Thought it time to call-out this issue and correct it.
5. Again, we have the issue of taking 4 readings from 3 sides, especially given the specifics of taking core and shell measurements. Again, how does one exactly do that?
6. Limiting moisture readings to 1.125 inches deep would grossly under report the fuel moisture content, especially for large fuel pieces, so we would be testing with much wetter wood than we would be with either ASTM E3053 or EPA M28. We routinely are measuring fuel piece moisture contents at depths >1.125" when using the 1/5 to 1/4 the depth criteria in ASTM E3053. Delmhorst makes both 3.0" (Part # 608) and 6.0" (Part #608/001) insulated pins that are to be used with the 18-ES electrode that comes with a built-in 0-4.0" depth gauge with 1/8" increments. So there is absolutely no reason for taking readings this way. Myren Consulting has been using this equipment for years.
7. Averaging all of the moisture readings for all of the fuel pieces in a test fuel charge will again skew the moisture content, resulting in inaccurate DBR and emission factors. This is especially true of the Low burn where there are 3 large pieces and 2 small pieces. All fuel load moisture contents

should be determined by using the weight based composite average moisture content described above in D. ASTM E3053 (#5). Again this is what we have doing because it provides more accurate data for use in CSA B415-1. See example calculations in E. IDC (#8) above.

8. Given the moisture content criteria in Sections 11.3.2.2 and 11.3.2.3 in the recently approved version (6/25/2021) of the IDC, I think the shell/ core criteria shown above are no longer what are intended to be used.

   Section 11.3.2.2 reads;

   "…The test fuel load shall have an average moisture content from 19% to 25%, dry basis…"

   and

   Section 11.3.2.3 reads:

   "…Average individual piece moisture content shall have an average moisture content (from) 18% to 27%, dry basis.

   Word in parenthesis added for clarity. It follows what is Section 11.3.2.2.

Those values are significantly different from what is required in Section 8.10.2 in the earlier version of the IDC mentioned above (V1.07.20), i.e., where each individual piece moisture content shall be in the range of 10-35% MC on a dry basis and the fuel load average moisture content is the average of all of the individual fuel piece moisture readings.

So is my assumption correct that what is in Section 8.10.2 is no longer what we use in terms of location and depth? And if the answer to that question is "YES", then just what is it we are supposed to be doing?

G. IDC EPA TEOM RUGGEDNESS TESTING:

This version of the IDC has the following at the bottom of each page:

"…NYSERDA IDC STOVE PROTOCOL FOR EPA Research, Draft May 28, 2021…". ("TEOM version")

Section 11.3.2.1 in the "TEOM version" reads exactly the same as Section 11.3.2.1 in the current EPA approved version:

"…Determine fuel moisture for each fuel piece by averaging four moisture readings, one from each of three sides, measured parallel to the grain…".

The same is true of the equations in Section 13.7.1. Note here that the numbering in Section 13 has been revised in the TEOM version and what was Section 13.6.1 in the EPA approved version dated

4.09.2021 is now Section 13.7.1 in the TEOM version. That numbering sequence has again changed in the latest approved version of the IDC (6.25.2021) and Section 13.6.1 (or 13.7.1) is now Section 14.4.1. Confusing? You bet!

Therefore, all of the issues raised above in E. IDC about the language in Sections 11.3.2.1 and 13.7.1 in the current EPA approved version of the IDC also apply to this special research "TEOM version". Given that this project has a Level 1 QAPP plan, these issues need to be addressed and corrected ASAP. I contacted PFS (one of the labs doing this testing for EPA) to see what they were doing and to date I have not received a response. Yet I know they have started testing, so, once again, just what is being done?

The following Table summarizes the fuel piece moisture content measurement criteria found in each test method that have been discussed above.

TABLE 1
TEST METHOD FUEL PIECE MOISTURE MEASUREMENT CRITERIA

	OM7	EPA M28	ASTM 2780	ASTM 3053	4.09.21 IDC	TEOM IDC
Depth Specified	Y	Y	Y	Y	N	N
Location Specified	N	N	N	Y	N	N
Bark Criteria	N/A	N/A	N/A	Y	N	N
Non Conforming Pcs.	N/A	N/A	N/A	Y	N	N
Spacers Measured	N	N	Y	N/A	N/A	N/A
# of Readings	3	3	3	3	4	4
Fuel Piece Avg.	19-25	19-25	19-25	18-28	18-27	18-27
Fuel Load Avg.	N	N	N	19.0-25.0	19-25	19-25
Weight Based Composite Avg. Dry Fuel Load Wt.	N	N	Y	Y	N	N

As Table 1 shows ASTM E3053 is a much more rigorous, robust and accurate test in terms of the criteria used to determine fuel piece moisture content. In as much as moisture content is known to be one of the key variables that effect stove performance, that alone should make ASTM E3053 the preferred test method.

Here I would suggest that EPA issue another approval letter for the "TEOM" version and stipulate in the caveats in that letter exactly what EPA wants done during the TEOM testing in terms of fuel piece moisture content measurement.

While NESCAUM/ NYSERDA/ ADEC raise a number of other issues in the two documents titled

(1.) Interim Report: Development of an Integrated Duty-Cycle Test Method for Cordwood Stoves NYSEDA Report 21-02 December 2020

(2.) Assessment of EPA's Residential Wood Heater Certification Program Test report Review: Stoves and Central Heaters. NESCAUM report dated March 2021

those organizations never once question the validity of any of the fuel piece moisture content readings taken during testing with ASTM E3053. So, given all of the other issues these organizations raised in these two reports, is it reasonable to assume that these organizations really do not have a major issue with the ASTM E3053 fuel piece moisture content measurement procedures? Thus, the wholesale adoption of the procedures in ASTM E3053 by EPA would eliminate this problem. This was discussed at the 12/17-18, 2017 Denver meeting with EPA and I can not remember any objections when Dr. Adam Bumgart-Getz (EPA) asked if the use of the ASTM E3053 fuel piece moisture content measurement procedures were acceptable to those at the meeting. Yet here we are, still dealing with these fuel piece moisture content measurement issues.

The more recent versions of the IDC are clearly labeled as the proprietary property of NYSERDA. I am not hopeful that NYSERDA will acknowledge these comments or issue a revision that corrects these obvious problems because on April 14, 2021 I sent a 12 page memo to Stef Johnson at EPA/OAQPS/AQAD about some of my concerns about what was in the approved version of the IDC at that time. We also had about a 30-45 minute phone conversation about the contents of that memo which he then forwarded to Dr. Ellen Burkhard at NYSERDA because NYSERDA owns the method and is responsible for all revisions. To date I have not received any communications from NYSERDA about the contents of my memo and I just checked the NESACUM website (6/25/2021) and the April 09, 2021 version of the IDC is still what is on the website. So, even though there is a new approved EPA version of the IDC, nothing obvious has been done. Now compare this to the NESCAUM/ NYSERDA reaction when they found a typo in Section 3.29 of the EPA 2.23.2021 approved version of the IDC which read in part:

"… L2, L3, and L4 require that at least 5% of the individual pieces with at least 80% bark on one side…"

The typo "5%" was quickly revised and by 3.30.21 a revised version had been approved by EPA which read:

"…L2, L3, and L4 require at least 75% of the individual pieces with at least 80% bark on one side of the fuel piece…"

So it is pretty obvious that NESCAUM/ NYSERDA can quickly get things changed if it is in their interest to do so. I'll let you draw your own conclusions about why they haven't responded to the issues in

my memo, at least one of which, the need to report PM emissions in lbs./ MM Btu's was raised in my 4/14/2021 memo.

And that brings me to another question. Given that determining the fuel piece and fuel load moisture contents has obviously changed, just what was used during all of the testing done by NYSERDA/ NESCAUM/ ADEC that is reported in the following three documents? By reading and comparing the texts of these two different versions (ID's of *1.07.2020* found in bottom of each page in that version and *NYSERDA IDC TEST METHOD FOR CERTIFICATION OF CORDWOOD STOVEs FILTER USE, June 10, 2021* found at center bottom of each page in that version. (Note: The *STOVEs* is not a typo. That is what is in the copy I downloaded.), we know that changes were made in the IDC between 1.07.2020 and 2.24.2021 when EPA issued its first approval letter and then again between 2.23.2021 and 6.25.2021. So even after the initial EPA approval of the IDC on 2/24/2021, changes continue to be made in the IDC. How can an EPA approved Alternative Test Method (ATM) continually be changed? That means we are "trying to hit a moving target". And it also seems like a trap. Reviewers could come back and say that you didn't do it "right", even when the test method did not provide specifics, much like the "*ex post facto* issue" that has arisen about what constitutes a "representative" ASTM E3053 medium burn rate, i.e., the moisture measurement locations and depths you used are not "representative" and this finding could then be used to reject a test report as has happened in the ADEC's review of EPA test reports where the stove was tested with cordwood, i.e., legal Medium test runs were declared "non representative" and that became a deficiency in the ADEC's Summary of Review for that stove.

Given the total lack of transparency in the last two years of the IDC development process, nobody outside the NSCAUM/ NYSERDA/ ADEC group knows when or why these changes to the fuel piece moisture content measurement criteria and other criteria were made. There is one admitted change in fueling procedures in one of the documents (Reports of Interest) cited below, but that is a topic for another time and memo. This question is especially pertinent since none of the test data supporting the conclusions in the reports cited below has been made available for public review. And there is no supporting data for the wholesale changes made to the IDC made in the EPA approved versions of the IDC. It is my understanding that even EPA does not have the NYSEDA data. I have personally filed a Freedom of Information Act (FOIA) request with the State of New York to get this data. If I do get it, I will share it with all.

And even if the data does become available it may be impossible to determine what was done when the fuel piece moisture content measurements were taken because of the way the data was recorded, i.e., since no specific depths and locations are given in the test method, no specific depths and locations may be recorded on the data sheets. Compare this total *carte blanche*, *laissez faire* attitude about the way to obtain fuel piece moisture content readings in the

IDC and with what is required in ASTM E3053. A sample ASTM data sheet is attached. The data sheet shows exactly what was done to obtain each moisture measurement. First, the depth of one side was measured on one end of the piece. Then the depth of a second side was measured on the other end of the piece. Then these two depths were averaged to determine the depth at the center of the piece. Once these depths were determined, the 1/5 to 1/4 depth measurement was determined and the three moisture readings were taken at those depths.

Reports of Interest:

1. ClearStaK Report - The Efficacy of the ESP on Cordwood Stoves, Alaska Department of Environmental Conservation Report Dated July 17, 2020

2. Interim Report: Development of an Integrated Duty-Cycle Test Method for Cordwood Stoves NYSEDA Report 21-02 December 2020.

3. Assessment of EPA's Residential Wood Heater Certification Program Test report Review: Stoves and Central Heaters. NESCAUM report dated March 2021.

If certain parties had been able to find comparable types of errors, omissions and contradictions in ASTM E3053 that have been pointed out in the IDC in this memo, e.g., the PM emission factor equation that is totally wrong, they would be screaming and pounding on the table for EPA to rescind its approval of the ASTM E3053 test method. As it is, they have already orchestrated a repeal/ rescind effort substantially based upon *ex post facto,* non-representative criteria. But nothing where they have been able show where an equation used to calculate results is totally wrong. So turn about is fair play and given the egregious errors, omissions and contradictions in the last approved version (6/25/2021) of the IDC pointed out in this memo - and this memo is just a start, I hereby formally and respectfully request that EPA rescind its approval of any/ all versions of the IDC except for the "TEOM version" until ALL of these errors, omissions and contradictions are resolved. And the "TEOM version would only be good for the TEOM testing research project.

I thank you for your consideration of the issues I have raised in this memo and look forward to your thoughts, comments, ideas and revisions. As has repeatedly been said, " We need to get this right." because the next generation of stoves will be based upon the Federal Reference Method (FRM) that will be based in part on parts of EPA M28/M28R, ASTM E0353 and IDC that are in play today. Certainly we can not adopt criteria like what has been discussed above and have any hope of "Getting It Right!".

Regards,

Ben Myren
President
Myren Consulting, Inc.

512 Williams Lake Road
Colville, WA 99114
Office: 509 684 1154
Lab: 509 685 9458
email: <myren.ben@gmail.com>

Message

From: George Allen [gallen@nescaum.org]
Sent: 9/17/2020 1:43:10 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
CC: Holder, Amara [holder.amara@epa.gov]; Brashear, Angelina [Brashear.Angelina@epa.gov]; Toney, Mike [Toney.Mike@epa.gov]; Garnett, Kim [Garnett.Kim@epa.gov]; Nash, Dave [Nash.Dave@epa.gov]; lrector@nescaum.org; Lowe, Theresa [Lowe.Theresa@epa.gov]
Subject: RE: key changes to Teom SOP

Hi Stef - thanks; answers to your Qs embedded below with >>
George

At 08:16 AM 9/17/2020, Johnson, Steffan wrote:
Hi George,
Thank you for passing along these questions. My answers are in-line below (hopefully this adds clarity).
Stef

1a. Both Teom filters only get changed when % loading on either channel [eg, whichever hits 120 % first] reaches 120% [or when the flow setpoint can't be maintained, but that would point to a bad pump]. For reference, that's a delta-P across the filter of approx. 0.6 atm or ~ 18" Hg vacuum. Normally they should load almost [but not precisely] identically.
18" is fairly high vacuum. Are there any concerns leak checking the system at this vacuum or higher? What is the vacuum at 100% loading? (just curious) Also, we should provide a note in the protocol that helps identify a pump failure.

>> Leak checks are done at full pump vacuum, which with the pump supplied is about 0.28 atm with 3 lpm flow. Pump vacuum is recorded along with the data every minute, and displayed on the instrument's screen. As long as flow is maintained and leak checks pass, the data should be ok. There is a leak check "wizard" in the instrument software; I don't use it because it's designed for an ambient physical setup, but it could be used with some caveats.

1b. For data validation, should we accept as valid all data with filter loading > 120% as long as the flow is within 5% of the setpoint? Eg, if they are late in changing them, how to validate those data?
Yes, for starters. We will develop some data on different flows during ruggedness testing and that window may open a bit, or close a bit, depending on those data. We need to make sure that allowances such as this provide good quality data.

2. Negative data due to normal filter dynamics are left as is - not set to 0, and not removed. Note that we have occasionally seen short periods with negative concentrations as much as 20 mg/m3 due to extreme filter dynamics.
Yes, and I understand.

3. "missing" data due to filter changes are left missing [or whatever term you prefer here].
Yes. One could conduct modeling exercises and substitute data later, should they wish. HOWEVER, it may be well to make some qualifications in the IDC about certain times when filter changes should be done proactively (such as before a re-load) to prevent someone from changing filters during a period of emissions that we feel are more important to capture. I'm open to thoughts on that, but it makes sense to me that a good method would not allow missing data during periods of peak emissions.

>> That's an interesting idea -- proactive changes but at clearly defined points during the IDC [and of course whenever it hits the max % loading]. It is possible [actually likely] that otherwise changes could occur when

PM emissions are high. This would eliminate missing data for most test runs if changes were done near the end of each phase - eg, before a loading event. It also deals somewhat with my concerns with excessive svoc loss from a very heavily loaded filter.

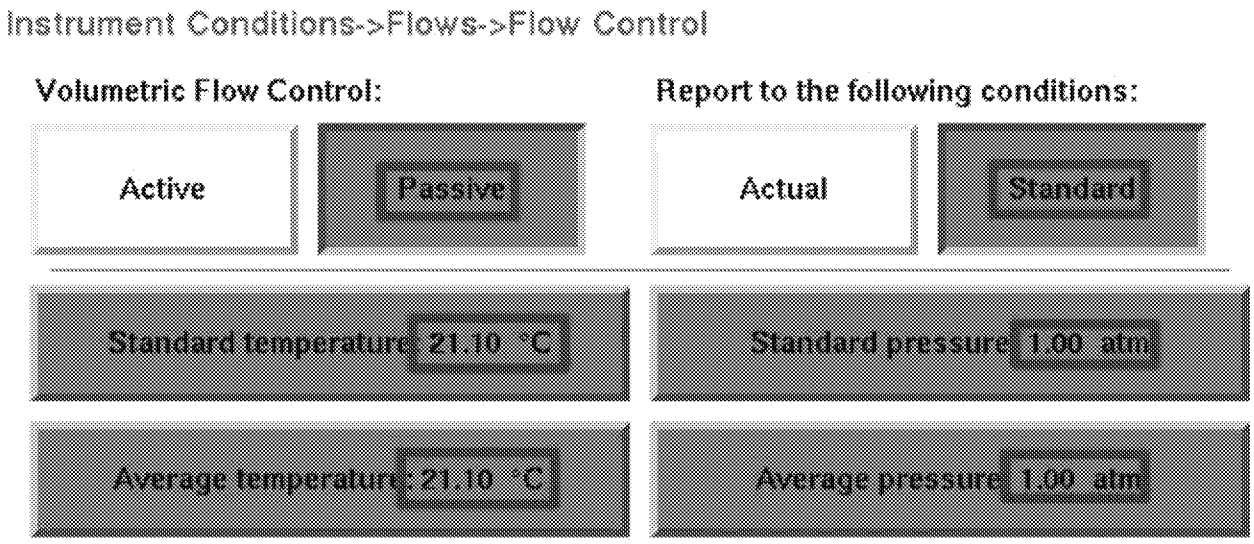
4. Teom Temperature zones are fixed, always at 33 C year round.
Make it so.

5. Sample flow rate: fixed or within a range such as 0.5 to 2 lpm? If it's a fixed value, I'd go for 1.00 lpm. That's a face velocity of 12.5 cm/sec, and should be ok for most devices as long as tunnel flow is at least 500 cfm. Let's start out at 1 lpm and we'll look at this during ruggedness testing to determine an acceptable range.

6. Presumably we are requiring Teom flow and leak checks before and after each test run - please confirm.
Confirmed.

7a. Teom data are to be reported at 70F (21.1C) and 1 Atm, with dry sample flow. Need to confirm standard P of 1 Atm.
Just for clarity, are you saying that the TEOM software can correct the reported concentration based on an inputted reference temp? I am certainly ok with allowing it to collect and report data 'as received' and doing a correction to STP afterward. In fact, I might find that preferable. I'm open to thoughts on that.

>> Yes, shown below. This is covered on page 4-14 of the dichot Teom manual, here: https://assets.thermofisher.com/TFS-Assets/LSG/manuals/EPM-manual-TEOM1405D.pdf I need to check if "raw" pm concentration includes these corrections.



7b. I think we decided to use actual tunnel dewpoint data to "dry" the sample flow, but we could also re-plumb both Teom channels thru a dryer before the internal mass flowmeter. Please confirm how you'd like this to be done.
Let's use the tunnel dewpoint measurement for moisture correction, post-test. This goes hand in hand with post test correction to STP, as mentioned above. Again, I'm open to discussion on this.

Message

From: Johnson, Steffan [johnson.steffan@epa.gov]
Sent: 5/28/2020 11:33:36 AM
To: Lisa Rector [lrector@nescaum.org]
CC: Kelli O'Brien (kelli@clearstak.com) [kelli@clearstak.com]; Toney, Mike [Toney.Mike@epa.gov]; Brashear, Angelina [Brashear.Angelina@epa.gov]
Subject: RE: calibration question

Lisa,

An excellent question, and thank you for asking.

I have no issues with proceeding with testing using the calibration data that ClearStack has in hand from the December calibration study. What I would hope is that a post-test calibration study could be completed before the final report is issued to provide quality assurance that the flow meter remains in good operating condition and reports reliable velocity data.

To simplify the answer, please provide a post-test calibration with your other test report data.

I hope that this is helpful, and please let me know if you have any questions.

Stay safe out there everyone!

Sincerely,

Stef

From: Lisa Rector <lrector@nescaum.org>
Sent: Wednesday, May 27, 2020 4:35 PM
To: Johnson, Steffan <johnson.steffan@epa.gov>
Cc: Kelli O'Brien (kelli@clearstak.com) <kelli@clearstak.com>
Subject: calibration question

Hi Stef, I hope you are doing well and had an enjoyable long weekend.

We are ready to put pellet boilers on the stand for final IDC protocol testing at Clearstak. We want to make sure the data can be used in EPA's test method process so we have a calibration question for you. Clearstak flowmeters were last calibrated in December 2019, and haven't been used since they came back. The company that normally does their calibration doesn't open until June due to covid 19, and in normal circumstances typically take a month to complete the process. Given the situation, if we have to wait for recalibration, we anticipate a 6 week delay in testing. We would prefer not to delay testing, but will if the data will be rendered invalid by EPA due to dates of flowmeter calibration dates. Can you please advise if we can procced with testing or if we need to delay and recalibrate flow meters?

Thanks for your help with this matter.

Lisa

NESCAUM

Lisa Rector, Policy and Program Director at **NESCAUM**
89 South Street, Suite 602, Boston, Massachusetts, 02111 | 802.899.5306| 617.259.2095 | Fax: 617.742.9162
| lrector@nescaum.org

Message

From: Johnson, Steffan [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=EBA5C0DFC5FC4593AFA62CE7C3DD6F02-JOHNSON, STEFFAN]
Sent: 11/19/2020 9:39:03 PM
To: Lisa Rector [lrector@nescaum.org]
CC: Toney, Mike [Toney.Mike@epa.gov]; Brashear, Angelina [Brashear.Angelina@epa.gov]
Subject: RE: Eastern Softwood?

Thank you, Lisa! Much appreciated.

Stef

From: Lisa Rector <lrector@nescaum.org>
Sent: Thursday, November 19, 2020 4:34 PM
To: Johnson, Steffan <johnson.steffan@epa.gov>
Cc: Toney, Mike <Toney.Mike@epa.gov>; Brashear, Angelina <Brashear.Angelina@epa.gov>
Subject: RE: Eastern Softwood?

Stef, off the top of my head the only thing that comes to mind is the Minnesota survey data. On page 30 you can see the species use trends from 1988-2014. (https://www.pca.state.mn.us/sites/default/files/aq-ei4-46.pdf). I will reach out to my forestry friends to see if they have any other data. Thanks!

From: Johnson, Steffan <johnson.steffan@epa.gov>
Sent: Thursday, November 19, 2020 3:54 PM
To: Lisa Rector <lrector@nescaum.org>
Cc: Toney, Mike <Toney.Mike@epa.gov>; Brashear, Angelina <Brashear.Angelina@epa.gov>
Subject: Eastern Softwood?

Lisa,

We have selected Douglas fir and white Oak (quercus garryana) for our West coast IDC fuels. I know that you have data that shows that red maple would be an Eastern hardwood of choice, but I'm wondering if you have any information supporting an Eastern softwood? I recall discussing Southern pine, or Eastern white pine?

Or do you feel that there isn't enough softwood being burned in the East to justify adding a second hardwood fuel instead of a softwood fuel?

Are you aware of any resources that show how common what fuels are in the East/West?

Stef

Steffan M Johnson | Leader – Measurement Technology Group | US EPA Office of Air Quality Planning and Standards | Air Quality Assessment Division | 109 T.W. Alexander Drive, RTP, NC 27710 | Mail Drop: E-143-02 | Phone: (919) 541-4790 | Cell: (919) 698-5096

Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 9/25/2020 9:51:20 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
CC: Garnett, Kim [Garnett.Kim@epa.gov]; Nash, Dave [Nash.Dave@epa.gov]; Brashear, Angelina [Brashear.Angelina@epa.gov]; Toney, Mike [Toney.Mike@epa.gov]; Lowe, Theresa [Lowe.Theresa@epa.gov]; gallen@nescaum.org
Subject: RE: Troubleshooting flow chart for TEOM operation?

Stef, I posed your question to George. His response was a little like mine, slight confusion. A step-by-step daily start-up list (things to do in the first hour or first 90 min before a test) is already in the SOP now. If you are referring to that element, can you tell us what is missing?

If it's an actual trouble-shooting flow chart, that could get complicated, and I am not sure we have the ability, both in terms of resources and experience, to develop such a guide. Our labs have been using the TEOMs for several years, and I am unsure of much trouble-shooting is actually happening, very little I think. I think we are concerned that labs will attempt to use the TEOM without understanding the basics. George and I were thinking of how we, or Thermo, might put a training program in place if/when broader use of the TEOM becomes a reality.

Perhaps we should consider two approaches:

1) During the EPA contract works, and assuming we get funds from NYSERDA to provide tech transfer and support to EPA and their contractors, we could keep a running list of items that come up during the testing. From that effort, we could build a trouble-shooting guide based on actual experiences. If/when they run into stuff they can't resolve, that can be an opportunity to learn. I'm not aware that we have to do much trouble-shooting with the labs that we are currently using, but George may be doing that work, and I am just unaware.
2) EPA could draft a flow chart of anticipated issues, and George could review and assist in development.

Thoughts on either of these options?

From: Johnson, Steffan <johnson.steffan@epa.gov>
Sent: Friday, September 25, 2020 3:05 PM
To: Lisa Rector <lrector@nescaum.org>
Cc: Garnett, Kim <Garnett.Kim@epa.gov>; Nash, Dave <Nash.Dave@epa.gov>; Brashear, Angelina <Brashear.Angelina@epa.gov>; Toney, Mike <Toney.Mike@epa.gov>; Lowe, Theresa <Lowe.Theresa@epa.gov>
Subject: Troubleshooting flow chart for TEOM operation?

Hi Lisa,

Mike and I were talking about the TEOM SOP on Wednesday and he brought up a good suggestion.

That said, it involves George's time and I know how many things you have waiting for George to do, so I thought I'd float this past you to see if it's a workable theory.

It makes sense that with technology transfer, meaning coaching other labs on how to run a TEOM, it would be good to have some sort of flow chart(s) for troubleshooting to accompany a sort of step-by-step daily start up list (things to do in the first hour or first 90 min before a test). We'd like to empower the labs to make a first attempt at a fix before calling for help.

Does this make sense to you and, if so, perhaps you might consider adding it to George's to-do list?

Thank you for your consideration,

Stef

Steffan M Johnson | Leader – Measurement Technology Group | US EPA Office of Air Quality Planning and Standards | Air Quality Assessment Division | 109 T.W. Alexander Drive, RTP, NC 27710 | Mail Drop: E-143-02 | Phone: (919) 541-4790 | Cell: (919) 698-5096

Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 5/27/2021 2:03:16 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]; Jill Mozier [jmozier@scainc.com]; Nash, Dave [Nash.Dave@epa.gov]; Sebastian Button [sebastian.button@pfsteco.com]; John Steinert [john.steinert@pfsteco.com]
CC: Burkhard, Ellen G (NYSERDA) [Ellen.Burkhard@nyserda.ny.gov]
Subject: RE: Teom SOP for posting

Ellen, I think the answer is yes, but I will defer to you.

-----Original Message-----
From: Johnson, Steffan <johnson.steffan@epa.gov>
Sent: Thursday, May 27, 2021 9:32 AM
To: Lisa Rector <lrector@nescaum.org>; Jill Mozier <jmozier@scainc.com>; Nash, Dave <Nash.Dave@epa.gov>; Sebastian Button <sebastian.button@pfsteco.com>; John Steinert <john.steinert@pfsteco.com>
Cc: Burkhard, Ellen G (NYSERDA) <Ellen.Burkhard@nyserda.ny.gov>
Subject: RE: Teom SOP for posting

Lisa,

Thank you very much!

Per my earlier question to Ellen Burkhard, may I presume it is acceptable to post the PDF into our public docket?

Again, my sincere thanks to you and your team,

Stef

-----Original Message-----
From: Lisa Rector <lrector@nescaum.org>
Sent: Thursday, May 27, 2021 9:09 AM
To: Johnson, Steffan <johnson.steffan@epa.gov>; Jill Mozier <jmozier@scainc.com>; Nash, Dave <Nash.Dave@epa.gov>; Sebastian Button <sebastian.button@pfsteco.com>; John Steinert <john.steinert@pfsteco.com>
Subject: FW: Teom SOP for posting

Hi everyone! Attached is the TEOM SOP for EPA's project.

-----Original Message-----
From: George Allen <gallen@nescaum.org>
Sent: Tuesday, May 25, 2021 12:08 PM
To: Lisa Rector <lrector@nescaum.org>
Subject: Teom SOP for docket posting

Attached, secured. If EPA comes back with any requested changes in response to my comment Qs, we can change it. But the big issues discussed today are addressed - minimal QC on between-channel agreement.

Revised Excel data analysis sheet attached also, to reflect minimal QC criteria as discussed on today's call. This is part of the SOP.

Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 5/30/2021 12:28:50 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
CC: Burkhard, Ellen G (NYSERDA) [Ellen.Burkhard@nyserda.ny.gov]
Subject: RE: Teom SOP for docket

I feel like I've sent you too many emails with different versions of each protocol. Would like one email with all them attached?

From: Johnson, Steffan <johnson.steffan@epa.gov>
Sent: Sunday, May 30, 2021 8:27 AM
To: Lisa Rector <lrector@nescaum.org>
Cc: Burkhard, Ellen G (NYSERDA) <Ellen.Burkhard@nyserda.ny.gov>
Subject: Re: Teom SOP for docket

Thank you very much! We look forward to what the future holds.

Stef

Sent from my iPhone

> On May 28, 2021, at 3:37 PM, Lisa Rector <lrector@nescaum.org> wrote:
>
> This time with the TEOM protocol attached.
> <NYSERDA DRAFT TEOM 1405-Dichot SOP 21-05-28 clean for docket-secured.pdf>

Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 2/8/2021 2:15:50 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
CC: gallen@nescaum.org
Subject: IDC stove protocol updated
Attachments: NYSERDA IDC Protocol for Wood Stoves draft version for research protocol 2_8_21 clean.docx; NYSERDA IDC Protocol for Wood Stoves draft version for research protocol 2_8_21 tracked changes.docx

Stef, attached to this email is an updated version of the IDC stove protocol for research purposes. I have attached a clean and tracked changes version.

NESCAUM

Lisa Rector, Policy and Program Director at **NESCAUM**
89 South Street, Suite 602, Boston, Massachusetts, 02111 | 802.899.5306| 617.259.2095 | Fax: 617.742.9162 | lrector@nescaum.org

THIS INTEGRATED-DUTY-CYCLE (IDC) PROTOCOL FOR WOOD STOVES IS THE PROPERTY OF THE NEW YORK STATE ENERGY RESEARCH AND DEVELOPMENT AUTHORITY (NYSERDA) AND CAN BE USED TO TEST TECHNOLOGIES IN A LABORATORY SETTING. ANY DEVIATIONS OR CHANGES TO THIS IDC PROTOCOL FOR WOOD STOVES ARE NOT APPROVED OR SANCTIONED BY NYSERDA.

DO NOT CITE, COPY, or DISTRIBUTE THIS IDC PROTOCOL FOR WOOD STOVES WITHOUT THE WRITTEN PERMISSION OF NYSERDA

Integrated Duty Cycle Test Method for Certification of Wood-Fired Stoves Using Cordwood: Measurement of Particulate Matter (PM) and Carbon Monoxide (CO) Emissions and Heating Efficiency

Note: This method does not include all the specifications (e.g. equipment and supplies) and procedures (e.g., sample and analytical) essential to its performance. Some material is incorporated by reference from other methods. Therefore, to obtain reliable results, persons using this method shall have a thorough knowledge of at least the following EPA Tests

- Method 1- Sample and Velocity Traverses for Stationary Sources
- Method 2- Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube)
- Method 3 – Gas Analysis for the Determination of Dry Molecular Weight
- Method 4 – Determination of Moisture Content in Stack Gases
- Method 5G – Determination of Particulate Matter from Wood Heaters (Dilution Tunnel Sampling Location)
- Method 10 - Carbon Monoxide - Instrumental Analyzer
- Method 28 – Certification and Auditing if Wood Heaters

1. Scope and Application

1.1. This test method specifies operation and fueling for certification and auditing of manually operated wood-fired stoves and heaters.

1.2. This test method measures particulate matter (PM) emissions, carbon monoxide, and efficiency.

1.3. Particulate emissions are measured by the dilution tunnel method as specified in ASTM E2515 Standard Test Method for Determination of Particulate Matter Emissions Collected in a Dilution Tunnel using only Pallflex Emfab filters. Additional particulate matter emissions measurements may also use the Tapered Element Oscillating Microbalance (TEOM) continuous PM method, as detailed in this test method.

1.4. Analyte. Particulate matter (PM). No CAS number assigned. Carbon monoxide (CO). No CAS number assigned.

1.5. Applicability. This method is applicable for the certification and auditing of wood space heaters, which burn cordwood fuel. The test quantifies PM and CO emissions and provides overall efficiency ratings, maximum burn time, and heat output.

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1.6. Distinguishing features of appliances covered by this standard include:

1.6.1. Cordwood fuel is hand-fed into firebox.

1.6.2. A chimney or vent that exhausts combustion products from the appliance.

1.7. The values stated are to be regarded as the standard, whether in I-P or SI units. The values given in parentheses are for information only.

1.8. Data Quality Objectives.

1.8.1. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods.

1.8.2. Measurement of emissions and heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

1.8.3. This is a laboratory method intended to capture operating periods that are representative of actual field use without excessive test burden.

2. Referenced Methods

2.1. NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel

2.2. ASTM 2515: Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel.

3. Definitions

3.1. Appliance – a wood heater capable of and intended for space heating defined in the applicable regulation. The appliance includes combustion chamber, combustion air settings, operating controls, and a thermostat if specified, and any other accessory required for standard operation, such as a barometric damper,

3.2. Catch - any mass from the sample probe system on the filter.

3.3. Certification or audit test - a series of at least three test runs conducted for certification or audit purposes that meets the specifications detailed in this protocol.

3.4. Chop – using a poker or another piece of wood to strike a piece of the fuel charge to break it into smaller pieces.

3.5. Coal-bed Stirring – prior to adding a new fuel charge, using a poker or piece of wood to stir or level the coal bed of the appliance for the sole purpose of ensuring ease of loading of the fuel charge. No special formations can be made, such as creating coal bed formations or pushing coals to one side or creating slopes with the coals.

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3.6. East-west stove – a stove where the firebox dimension parallel to the loading door is greater or equal to the stove depth measurement. Logs are loaded so that they are viewed on the long length of the stove.

3.7. Emission factor – the emission of a pollutant expressed in mass per unit of energy (typically) output from the appliance.

3.8. Firebox - the portion of the chamber in the wood heater in which the test fuel charge is placed and combusted.

3.9. Firebox depth - the horizontal length of the fire chamber dimension measured perpendicular to the loading door. If the manufacturer believes that a portion of the firebox depth is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.10. Firebox Height - the vertical distance extending above the top of the firebox to the floor of the firebox. Firebox height is not necessarily uniform. The measurement must account for variations caused by internal baffles, air channels, or other permanent obstructions. If the manufacturer believes that a portion of the firebox height is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.11. Firebox width - the horizontal fire chamber dimension that is parallel to the loading door. If the manufacturer believes that a portion of the firebox width is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.12. Fuel Adjustment –manipulations to the fuel charge to reflect typical owner practices that allow the cordwood fuel to burn appropriately during the test period. A fuel adjustment does not include chopping the wood or stirring the coal bed.

3.13. Fuel load calculator – The locked excel spreadsheet tool that determines the allowable test fuel load weights and required piece sizes for each individual load.

3.14. Fuel loading direction – Fuel shall be loaded parallel to the greater of the width and depth dimensions for loads 2, 3 and 4. Criss-cross is allowed for startup phase and cannot be used as a load configuration for loads 2, 3 or 4. If the firebox length and width are within 2" fuel shall be loaded in an east/west fashion, parallel to the loading door.

3.15. Kindling pieces – small pieces of wood less than 1" in diameter. No bark or moisture requirements for these pieces, however kindling pieces shall not be dried or stored anywhere but in laboratory ambient conditions. Kindling length shall be of the same as the fuel charge length. and shall represent weights that would enable 8 to 12 pieces equal one pound.

3.16. Large fuel pieces – pieces that are larger for the appliance as defined by the fuel load calculator.

3.17. L1 – Start-up – period of the test when the unit has kindling and startup fuel under the conditions described in Section 11.6.7.

3.18. L2 – High-fire Phase – period of the test when the unit has a small coal bed and the stoves air settings are fully open. Intended to replicate period when homeowners are trying to quickly heat an area, shortly after starting or restarting the appliance.

3.19. L3 - Maintenance-fire phase– period of the test when a fire is maintained with a medium-sized coal bed, and a smaller batch of wood. This is intended to simulate a period when the operator is trying to maintain consistent heat output.

3.20. L4 - Low-burn Rate Phase – period of the test when the stove has a large coal bed, stove is fully loaded, and the adjustable air settings are set to produce the lowest possible burn rate and have the lowest air settings. Intended to simulate a period the operator is trying to maintain heat over a long period of time, such as overnight or while away for significant periods of time.

3.21. North-south stove: a firebox which has its longest dimension measurement perpendicular to the loading door. In this stove type, logs are loaded so that the ends of the fuel are viewed when loaded.

3.22. Phase – A distinct period in the test run with its own operational procedures and conditions.

3.23. Primary air supply – air supply that introduces air to the wood heater in the combustion chamber and is adjusted to target a desired burn rate. The wood heater manufacturer or test facility can document this through design drawings.

3.24. Secondary air supply - air supply that introduces air to the wood heater such that the burn rate is not altered by more than 10 percent when the secondary air supply is adjusted during the test run. The wood heater manufacturer or test facility can document this through design drawings that show the secondary air is introduced only into a mixing chamber or secondary chamber outside the firebox.

3.25. Small fuel pieces - pieces that are small for the appliance as defined by the fuel load calculator.

3.26. Starter fuel – pieces of cordwood that can be smaller than small and large pieces but larger than kindling, as defined by the fuel load calculator.

3.27. Test data– means the data for all test runs conducted on the wood heater, including any data collected during failed and invalid runs and includes records of preparation of standards, identification of equipment used and personnel present, records of calibrations, raw data sheets for field sampling, raw data sheets for field and laboratory analyses, chain-of-custody documentation, and example calculations for reported results.

3.28. Test facility - the area in which the wood heater is installed, operated, and sampled for emissions.

3.29. Test fuel charge - the collection of test fuel pieces used in each of the four phases of the test run. L2, L3, and L4 require that at least 50% of the individual pieces with at least 80% bark on one side of the fuel piece. Bark shall not be removed for certification testing. Any fuel charge that suggests bark was purposely removed or shaped shall deem the certification test invalid. Examples of fuel piece manipulation are provided in Section 11

3.30. Test fuel load – the group of test fuel pieces that are loaded, as specified by phase, throughout the test run. Test fuel loading means the arrangement of the test fuel charge.

3.31. Test fuel loading density - the calculation that determines the weight of the as-fired test fuel load. The calculation is based on the usable volume of the firebox.

3.32. Test run - an individual emission test that includes the four operational phases required by the fueling protocol.

3.33. Usable firebox volume - the calculated volume of the firebox determined using its height, width, and depth as defined in this section. This calculation represents the area where wood is likely to be loaded. If the manufacturer claims that portions of the firebox may not be used in the calculation a justification must be submitted with the test report. If the justification is not approved, the test results will be deemed unrepresentative for certification purposes. It is highly recommended that manufacturers obtain regulatory approval if making claims that portions of the firebox are not appropriate for inclusion in the calculation.

3.34. Wood heater - an enclosed, wood-burning appliance capable of and intended for space heating or domestic water heating, as defined in the applicable regulation.

4. *Interferences*

None.

5. *Summary of Method*

5.1. Particulate matter emissions are measured from a wood heater burning cordwood test fuel in a test facility maintained at a set of prescribed ambient conditions. Procedures for operating the appliance, measuring PM and CO emission rates, and methods for reducing data and calculating results are provided.

5.2. *Dilution Tunnel*. A dilution tunnel following the specifications detailed in ASTM E2515-11 shall be used for particulate measurements.

5.3. *Particulate Matter:* PM emissions are measured in a dilution tunnel with a Thermo model 1405-D 2-channel TEOM using NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel with a dilution tunnel as specified in ASTM 2515 with modifications discussed in Section 10.

5.4. *Carbon Monoxide*. The CO measured in the stack and is used to calculate efficiency determination.

5.5. *Operation*. Appliance operation is conducted on a cold-to-hot test cycle, meaning that the appliance starts the first test run at room temperature and ends with the appliance in fully heated state. The second and third test runs are started a slightly warmer temperature. The appliance is operated at a variety of operational phases representing start-up emissions, high heat demand, low

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heat demand, and refueling. The appliance is operated through four phases. To complete the certification test, a minimum of three full test runs are averaged to determine the test results.

5.6. *Repeatability.* A series of at least three test runs comprised of six different heat demands or phases conducted for certification or audit purposes

6. Significance and Use

6.1. The measurement of particulate matter emission rates is an important test method widely used in the practice of air pollution control.

6.1.1. These measurements, when approved by state or federal agencies, are often required for the purpose of determining compliance with regulations and statutes.

6.1.2. The measurements made before and after design modifications are necessary to demonstrate the effectiveness of design changes in reducing emissions and make this standard an important tool in manufacturers' research and development programs.

6.2. Measurement of heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

7. Safety

7.1. Disclaimer. This method may involve hazardous materials, operations, and equipment. This test method may not address all the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to performing this test method.

7.2. These tests involve combustion of wood, which releases substantial amounts of heat and combustion products. The heating system also produces large quantities of very hot water and the potential for steam production and system pressurization. Appropriate precautions must be taken to protect personnel from burn hazards and respiration of products of combustion. Exposure of personnel to unsafe levels of carbon monoxide must be avoided, and the use of continuous ambient carbon monoxide monitoring is strongly recommended.

8. Equipment and Supplies. The following items are required for sample collection:

8.1. Anemometer. A device capable of detecting air velocities less than 0.10 m/sec (20 ft/min), for measuring air velocities near the test appliance.

8.2. Appliance Flue.

8.2.1. Steel flue pipe extending to 8.5 ±0.5 ft. (2.6 ±0.15 m) above the top of the platform scale, and above this level, insulated solid pack type chimney extending to 15 ±1 ft (4.6 ±0.3 m) above the platform scale, and of the size specified by the appliance manufacturer. This applies to both freestanding and inserts type appliances.

8.2.2. Other chimney types (e.g., solid pack insulated pipe) may be used in place of the steel flue pipe if the appliance manufacturer's written appliance specifications require such chimney for home installation (e.g., zero clearance appliance inserts). Such alternative chimney or flue pipe must remain and be sealed with the appliance following the certification test.

8.2.3. Solid pack insulated chimneys shall have a minimum of 2.5 cm (1 in.) solid-pack insulating material surrounding the entire flue and possess a label demonstrating conformance to U.L. 103 (incorporated by reference—see §60.17).

8.3. Appliance Platform Scale and Monitor. For monitoring of fuel load weight change. The scale shall be capable of measuring weight to within 0.01 kg (0.02 lb.) and calibrated to NIST traceable standards at least annually.

8.4. Barometer. Aneroid or another barometer capable of measuring atmospheric pressure to within 0.1 in. Hg (2.5 mm Hg) with an uncertainty of +/- 0.05 in Hg (+/- 1.27 mm Hg).

8.5. Dilution Tunnel must meet the requirements of ASTM E2515, clauses 6.1.6 and 9.2.

8.6. Dilution Tunnel temperature and relative humidity measurement. A probe capable of measuring tunnel temperature to within 0.9 ˚F (0.5 ˚C)) and tunnel RH to within 2%, such as the Omega HX85-A or equivalent.

8.7. Draft Gauge. Electromanometer or other devices for the determination of flue draft or static pressure readable to within 0.005 in. H2O (1.2 Pa)

8.8. Flue Gas Temperature Measurement. A type K- thermocouple or equivalent located in the centroid of the stack located 8.0 +/- 0.5 ft (2.44 m +/- 150 mm) above the platform scale. Capable of measuring with an accuracy of 4.0˚F (2.2˚C) or 0.75% of reading, whichever is greater.

8.9. Flue Gas Composition Measurement. A sample probe and continuous infrared analyzer or equivalent capable of measuring span of carbon monoxide (CO) and carbon dioxide (CO_2) in the flue gas produced by the appliance tested. Continuous analyzers (or equivalent) shall have maximum zero and span drift, over a 24 h period, of 1% of full scale

8.10. Fuel Scale. Balance capable of weighing the test fuel charge to within 0.02 kg (0.05 lb.) and calibrated to NIST traceable standards at least annually.

8.11. Humidity Gauge. Psychrometer or hygrometer for measuring room humidity to within +/- 4% from 25 to 95% RH.

8.12. Moisture Meter. Calibrated electrical resistance meter for measuring test fuel moisture to within 2 percent moisture content.

8.13. Surface Temperatures. Capable of measuring temperature to within 1.5 percent of expected absolute temperatures with an accuracy of 4.0°F (2.2°C) or 0.75% of reading, whichever is greater.

8.14. Test Facility Temperature Monitor. A thermistor, RTD, Type T-Special thermocouple, or other equivalent device, located centrally in a vertically oriented 150 mm (6 in.) long, 50 mm (2 in.) diameter pipe shield that is open at both ends, capable of measuring temperature to within 1°F of expected temperatures.

8.15. TEOM – Thermo Fisher Scientific TEOM model 1405-D (Thermo part # 1405D-ANF, excluding models 1405, 1405-DF, or 1405-F) to measure and report continuous particulate matter (PM) measurements in an ASTM 2515 dilution tunnel or equivalent dilution method, and operated according to the NESCAUM Dichot TEOM Standard Operating Procedures.

9. Calibration and Standardizations

9.1. Anemometer. Calibrate the anemometer as specified by the manufacturer's instructions before the first certification test and monthly thereafter.

9.2. Appliance Platform Scale. Perform a multi-point calibration (at least five points spanning the operational range) of the platform scale before its initial use. The scale manufacturer's calibration results are sufficient for this purpose. Before each certification test, audit the scale with the wood heater in place by weighing at least one calibration weight (Class F) that corresponds to between 20 percent and 80 percent of the expected test fuel charge weight. If the scale cannot reproduce the value of the calibration weight within 0.0045 kg (0.01 lb.) or 1 percent of the expected test fuel charge weight, whichever is greater, recalibrate the scale before use with at least five calibration weights spanning the operational range of the scale.

9.3. Barometer. Calibrate using a reference pressure monitor calibrator before the first certification test and semiannually after

9.4. Draft Gauge. Calibrate as per the manufacturer's instructions; a liquid manometer does not require calibration (but must be properly leveled, zeroed and the system leak checked).

9.5. Humidity Gauge. Calibrate as per the manufacturer's instructions before the first certification test and annually thereafter.

9.6. Fuel Scale. Calibrate as described in 9.2.

9.7. Moisture Meter. Calibrate as per the manufacturer's instructions before the first certification test and semiannually thereafter.

9.8. Temperature Sensors. Calibrate using at least five points within operating range within specification and in compliance with NIST Monograph 175. To be calibrated before the first certification test and semiannually thereafter.

10. Sampling, Test Specimens, and Test Appliances

10.1. Modifications to ASTM 2515 requirements.

10.1.1. Liquid water should not be present anywhere in the sampling system for a valid sample. The presence of condensed water anywhere in the sampling system invalidates the test run. All data from all invalid test runs shall be included in the report. The reviewing authority shall make a final determination on invalidated runs. Data from any invalidated test run shall not be used to calculate results. If the testing agency believes a run has been invalidated, the test run shall be repeated.

10.1.2. Dilution tunnel temperature and relative humidity shall be measured electronically and logged at one-minute intervals near the sample probe to calculate dewpoint. The temperature measurement method shall have an accuracy of 0.9˚F (0.5˚C) (type T-Special TC or an RTD).

10.1.3. The following section details test conditions that shall be maintained for any valid test run. A valid test shall have no more than two individual deviations from any of the conditions below to remain a valid run. An example of an individual deviation is a single, five-minute rolling average where the dilution tunnel exceeded temperature thresholds. Another five-minute period exceeding the tunnel temperature requirement shall be considered a second deviation.

10.1.3.1. Tunnel temperature shall not exceed 104.0˚F. F (40.0˚C) based on ten-minute rolling averages derived from one-minute data, excluding periods when the appliance door is open.

10.1.3.2. Tunnel relative humidity shall not exceed 90% based on ten-minute rolling averages derived from one-minute data.

10.1.3.3. Tunnel dew point temperature shall not exceed 87.8˚F (31.0˚C).

10.1.3.4. A minimum tunnel flow of 600 CFM is required. Higher tunnel flows may be required to meet the parameters of Section 10.1.3, 10.13.2, and 10.1.3.3.

10.1.3.5. All exceedances must be reported in the test anomalies section, even if deviations are within the test method tolerances.

10.2. Sample Collection. The following are required for sample collection:

10.2.1. Teflon coated glass fiber filters as supplied by the TEOM manufacturer for use with the TEOM model 1405-D. These are Pallflex Emfab (TX40) with an exposed diameter of 13 mm, without organic binder, exhibiting at least 99.95 percent efficiency.

10.3. *Test Specimens.* Appliances shall be supplied as complete systems, including all controls and accessories necessary for installation at the test facility. A full set of specifications, designs, and assembly drawings shall be provided when the product is placed under certification of a third-party agency.

10.4. Preparation of Apparatus

10.4.1. Wood Heater Installation for Certification Testing. Assemble the wood heater appliance and parts in conformance with the manufacturer's provided User Guide. These instructions must match all instructions materials developed by the manufacturer and/or their distributors. Place the wood heater on the platform scale and connect the chimney to the appliance. Clean the flue with an appropriately sized, wire chimney brush before initiating Run 1 of the certification test. Test documentation should include the date and time of flue cleaning.

10.4.2. Wood Heater Temperature Monitors.

10.4.2.1. For catalyst-equipped wood heaters, locate a temperature monitor (optional) about 25 mm (1 in.) upstream of the catalyst at the centroid of the catalyst face area, and locate a temperature monitor (mandatory) that will indicate the catalyst exhaust temperature. This temperature monitor is centrally located within 25 mm (1 in.) downstream at the centroid of the catalyst face area. Record these locations.

10.4.2.2. Locate wood heater surface temperature monitors at five locations on the wood heater firebox exterior surface. Position the temperature monitors centrally on the top surface, centrally on two sidewall surfaces, and centrally on the bottom and back surfaces. Position the monitor sensing tip on the exterior of the firebox surface inside of any heat shield, room air circulation walls, or other wall or shield separated from the firebox exterior surface. Surface temperature locations for unusual design shapes (e.g., spherical, etc.) shall be positioned so that there are four surface temperature monitors in

10.5. Aging

10.5.1. Wood Heater Aging Prior to Certification Testing. A wood heater of any type shall be aged at least 50 hours before initiating a certification test. The aging procedure shall be conducted by the manufacturer prior to sending the appliance to the testing laboratory. The certification lab cannot be involved with wood heater aging in any manner. The appliance shall be operated at a variety of burn rates. Documentation for wood heating aging must be included in the test report. The testing laboratory shall not conduct any firing of the appliance prior to conducting the certification test.

10.5.1.1. The manufacturer shall supply wood heater aging information for the final test reports. Aging data that shall be reported include all fuel parameters (species, moisture content, load weights,

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piece amounts, and size), air settings used, time spent in each air setting phase, amount of fuel burned, and appliance burn rates.

10.5.1.2. If an appliance uses a catalytic combustor, it must be engaged according to the manufacturer's instructions and operate with the catalyst engaged for at least 50 hours during the break-in period. In addition to the reporting requirements listed in 8.1.1, catalytic appliances shall also report hourly catalyst exit temperature data to include the dates and hours of operation.

11. Procedure

11.1. Test Facility Conditions.

11.1.1. The test facility temperature shall be maintained between 55 and 90°F (13 and 32°C) during each test run.

11.1.2. The flue shall discharge into the same space or into a space freely communicating with the test facility. Any hood or similar device used to vent combustion products shall not induce a draft greater than 0.005 in. H_2O (1.25 Pa) on the wood heater measured when the wood heater is not operating.

11.1.3. For test facilities with artificially induced barometric pressures (e.g., pressurized chambers), the barometric pressure in the test facility shall not exceed 30.5 in. Hg (775 mm Hg) during any test run.

11.1.4. Locate the test facility temperature monitor on the horizontal plane that includes the primary air intake opening for the wood heater. Locate the temperature monitor 3 to 6 ft. (1 to 2 m) from the front of the wood heater in the 90° sector in front of the wood heater.

11.1.5. Use an anemometer, to measure the air velocity. Measure and record the room air velocity before the ignition period in L1 Startup and once immediately following the test run completion. Air velocities within 0.6 m (2 ft) of the test appliance and exhaust system shall be less than 0.25 m/sec (50 ft/min) without fire in the unit.

11.1.6. Measure and record the test facility's ambient relative humidity, barometric pressure, and temperature before and after each test run using equipment as specified in Section 6.

11.2. Wood Heater Firebox Volume.

11.2.1. Determine the firebox volume using the definitions for height, width, and length. Volume adjustments due to the presence of firebrick and other permanent fixtures may be necessary. All adjustments shall be detailed in the test report. Include areas adjacent to and above a baffle.

11.2.2. If a manufacturer deems certain areas of the firebox as unusable for fuel load calculations, written documentation stating the basis for that claim and supporting photographic image(s) must be provided and approved by the regulatory authority prior to conducting the certification test. If

approval is not granted prior to the test, then the test may be invalidated if the reviewing agency determines the firebox volume is inaccurate.

11.3. Test Fuel. The test fuel shall conform to the following requirements and meet specifications as required by the fuel loading calculator:

11.3.1. Fuel Species. Untreated, air-dried, cordwood fuel.

11.3.1.1.Allowable species: maple (big leaf, red, silver), oak (white), fir (Douglas), or white birch.

11.3.1.2.Kiln-dried fuel is not permitted.

11.3.1.3.Fuel shall be free of decay, fungus, or other contaminants.

11.3.2. Fuel Moisture.

11.3.2.1.Determine fuel moisture for each fuel piece by averaging four moisture meter readings, one from each of three sides, measured parallel to the wood grain.

11.3.2.2.The test fuel load shall have an average moisture content from 19% to 25%, wet basis.

11.3.2.3.Average individual piece moisture content shall have an average moisture content 18% to 27%.

11.3.2.4.The addition of moisture to previously dried wood is not allowed.

11.3.2.5.It is recommended that the test fuel be stored in a temperature and humidity-controlled room.

11.3.2.6.Fuel moisture shall be measured within 24 hours of using the fuel for the test and shall be stored in a humidity-controlled environment until 2 hours prior to testing.

11.3.3. Fuel Temperature. The test fuel shall be at the test facility temperature of 13 to 32°C (55 to 90°F).

11.3.4. Fuel Dimensions. The dimensions of each test fuel piece shall conform to definitions specified by the protocols using the fuel load calculator.

11.3.4.1.Fuel length:

11.3.4.1.1.The length of the fuel pieces will be determined by the fuel load calculator.

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11.3.4.1.2.Measurements shall be taken, and the length of the test fuel will be determined by entering the firebox dimensions, which calculates the length for all the fuel pieces into a generally available commercial size (14, 16, 18, 20 or 22 inches in length).

11.3.4.1.3.Piece length specified by the fuel calculator shall be communicated and specified for use in the owner's manual and website. Piece size shall be within 0.5" of the log length determined by the calculator, as measured on the shortest length measurement.

11.3.5.Fuel Loading Direction

11.3.5.1.Fuel loading direction shall be determined by the firebox measurement.

11.3.5.1.1.Stoves with a depth measurement greater than two inches from the width measurement shall be tested with the fuel in a north-south configuration and may not test with fuel in an east/west or crisscross configuration in any load other than Load 1 and Load 2.

11.3.5.1.2.Stoves with a width measurement greater than the depth measurement or a width measurement within two inches of the depth measurement shall be tested with the fuel loaded in an east-west configuration and may not test with fuel in a north/south configuration or crisscross configuration in any load other than Load 1 and Load 2.

11.3.6.Fuel piece weight for each phase of the protocol shall be determined by the fuel load calculator.

11.3.6.1.Kindling –shall be:

11.3.6.1.1.pieces of wood less than or equal to 1" in diameter.

11.3.6.1.2.No bark requirements for kindling fuel

11.3.6.1.3.Fuel species may be any species allowed in 7.2.1.1.

11.3.6.1.4.No moisture requirements.

11.3.6.1.5.Length of kindling shall be the fuel length specified by the fuel load calculator.

11.3.6.1.6.Kindling fuel shall conform to the rule that 7 to 12 pieces of kindling equal 1 pound of kindling fuel (+/- 10%).

11.3.6.2. Starter fuel: pieces of cordwood shall be used during the startup phase. Individual piece weight for starter fuel shall be determined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall be not be used in testing (see

Figure 1). Pieces that have squared cross sections shall be split to represent the typical triangle nature of wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible and fuel load pieces shall be composed to include different shapes of wood if using any trapezoidal pieces. .

11.3.6.3.Small fuel pieces: smaller pieces of cordwood by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall not be used (see figure 1). Pieces that have square cross-sections shall be split to represent the typical triangle nature of wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible. No more than 2 small fuel pieces can be trapezoidal in shape (Figure 2) per fuel load.

11.3.6.4.Large fuel pieces: larger pieces of cordwood, by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall be not be used (see figure 1). Pieces that have square cross sections shall be split to represent the typical triangle nature of wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible. No more than 1 large fuel pieces can be trapezoidal in shape (Figure 2) per fuel load.

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Figure 1. Schematic of unacceptable cross-sectional profiles

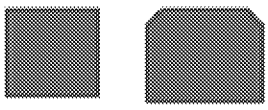


Figure 2.

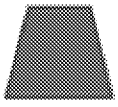
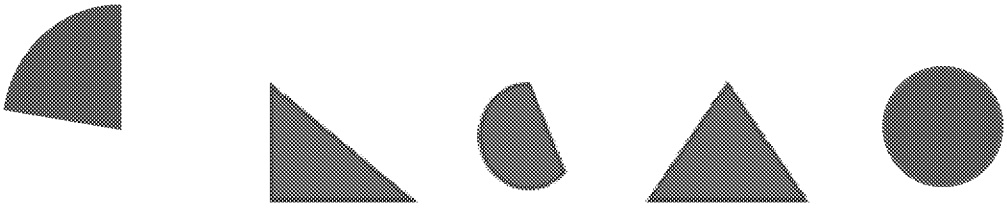


Figure 3. Schematics of acceptable cross-sectional profiles



11.4. Sampling Equipment.

11.4.1. Prepare the PM and ambient sampling equipment as defined by the TEOM Protocol.

11.4.2. Prepare all other equipment as defined by method EPA Method 1, 2, 3, 4 and 5G.

11.5. Manufacturer participation in certification testing

11.5.1. A representative of the manufacturer may observe testing but may not provide instructions to the certification lab, in any form, with testing staff or equipment once the certification tests begin. The names of testing witnesses cannot be withheld as confidential business information (CBI).

11.6. Test Run Procedure.

11.6.1. Before each test series, the firebox shall be vacuumed. Testing shall begin without any ash or other materials in the appliance.

11.6.2. Before initiating the compliance test, clean the flue and dilution tunnel with an appropriately sized wire chimney brush before each certification test. Test documentation should include the date and time of flue cleaning.

11.6.3. Record fuel weight data, temperature measurements, and gas concentrations at 1-minute intervals.

11.6.4. Wood Heater Operation and Adjustments. Record all adjustments made to the air supply controls, adjustments to and additions or subtractions of fuel, and any other changes to wood heater operations that occur during the test period.

11.6.5. The weight of fuel remaining at the end of the test run is determined as the difference between the weight of the wood heater with the remaining coals and fuel and the weight after loading the fuel charge. The starting weight is the tare weight of the cleaned, dry wood heater.

11.6.6. All runs shall be videotaped in their entirety. Videotape shall be of sufficient quality to determine fuel characteristics, fuel loading procedures, and firebox conditions during any testing or aging conducted by the test lab. The testing lab shall have the capacity to allow appropriate agencies the opportunity to remotely witness the test.

11.6.7.L1: Start-up Phase.

11.6.7.1.L1 Appliance requirements.

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11.6.7.1.1.Stove temperature: internal and external stove temperature must not be greater than the ambient temperature +/- 2.0˚F (1.1˚C) for Run 1. There is no stove starting temperature requirement for Runs 2 and 3 except in the case of a failed first run. In this case, if Run 1 is invalid or incomplete and, the stove must meet Run 1 conditions for at least one valid run. Temperature measurements for the external and internal temperatures shall be taken within 15 minutes before starting the test and shall be reported in the test report.

11.6.7.1.2.Tare the appliance scale before starting the test. Record appliance scale weights at the start and end of L1 phase

11.6.7.2.L1 Fuel requirements.

11.6.7.2.1.L1 Fuel type – during the startup phase newspaper (optional up to six full sheets traditional newspaper size), kindling, and starter fuel pieces are used. No other additions are allowed.

11.6.7.2.2.L1 loading density

11.6.7.2.2.1.Kindling loading density: 1 lb. per cubic foot for dry kindling, +/- 5%. The fuel load calculator determines the amount of kindling that can be used.

11.6.7.2.2.2.Starter Fuel loading density: 3 lb. per cubic foot, +/- 5%. The fuel load calculator will determine the minimum piece weight that can be used as starter fuel.

11.6.7.2.3.L1 fuel loading structure: The loading structure of the fire shall be a bottom-up configuration with newspaper on the bottom, kindling on top of the paper, and starter fuel on top of the kindling. Kindling and starter fuel shall be loaded in a crisscross configuration.

11.6.7.3.L1 Operational parameters.

11.6.7.3.1.All kindling, starter fuel, and newspaper must be in the firebox for light off.

11.6.7.3.2.Air settings are fully open.

11.6.7.3.3.Light the fire with a torch for a period of no more than 30 seconds.

11.6.7.3.4.Immediately after lighting the fire and completing the photo requirement, the appliance door shall be moved to a cracked open position. Cracked open position is defined as opening no more than one inch. The appliance door shall be closed 5 minutes after ignition.

11.6.7.4.L1 Fuel Adjustments: up to three fuel adjustments are allowed in the startup phase. The door may be open for 30 seconds during each fuel adjustment.

11.6.7.5.L1 End of Phase – the end of the startup phase is defined by the weight specified by the fuel load calculator.

11.6.7.6.L1 Documentation – Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge.

11.6.8.*L2: High-fire Phase* – the high-fire phase commences immediately after the startup phase ends.

11.6.8.1.L2 Appliance requirements.

11.6.8.1.1.Record the weight of the stove prior to loading the L2 fuel charge, the weight of the fuel charge prior to loading, and the scale weight after loading the L2 fuel charge.

11.6.8.2. L2 Fuel requirements.

11.6.8.2.1. L2 piece size – during the high-fire phase, small cordwood pieces by weight, as defined by the fuel load calculator, are used.

11.6.8.2.2. L2 loading density: 7 lb. per cubic foot, +/- 5%. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.8.3.L2 Operational parameters: Open the door upon completion of the startup phase and load the L2 fuel load within 60 seconds. Once the fuel has been loaded, the appliance doors shall be closed immediately. Air settings shall be left fully open. When 50% of the L2 fuel load mass has been consumed, the air settings shall be moved to the lowest settings.

11.6.8.4.L2 Fuel Adjustments.

11.6.8.4.1.One fuel adjustment shall be made during the high-fire phase prior to moving the primary air control(s) to their lowest setting. The door shall remain open for 30 seconds for fuel adjustments.

11.6.8.4.2.Additional fuel adjustments shall be made if there is a five-minute period without a weight change of 0.1 pounds at any point during the high-fire phase. The door may only be open for 30 seconds for fuel adjustments.

11.6.8.4.3.All fuel adjustments must be documented in the test report notes and summary.

11.6.8.5.End of L2 Phase –The high-fire phase ends when the scale indicates that 90% of the high-fire fuel mass has been consumed.

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11.6.8.6. L2 Documentation - Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge.

11.6.9. *L3: Maintenance-fire Phase* – the L3 maintenance-fire phase commences immediately after the L2 high-fire phase ends.

11.6.9.1.L3 Appliance Requirements.

11.6.9.1.1. Record the weight of the stove prior to loading the maintenance-fire fuel charge, the weight of the fuel charge prior to loading, and the scale weight after loading the maintenance-fire fuel charge.

11.6.9.2.L3 Fuel Requirements.

11.6.9.2.1.Fuel type – during the L3 phase, large cordwood pieces are used. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.9.2.2.L3 fuel loading structure: fuel shall be loaded in the direction specified by the fueling calculator.

11.6.9.2.3. L3 loading density: 5 lb. per cubic foot, +/- 5%. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.9.3. L3 Operational Parameters:

11.6.9.3.1.Open door upon completion of the L2 phase and load the maintenance-fire fuel charge.

11.6.9.3.2.L3 Load - L3 fuel loaded within 30 seconds of the door opening. Close the loading door immediately.

11.6.9.4. L3 Fuel Adjustments: If there is a ten-minute period without weight change (0.1 lb) at any point during the L3-fire phase, a fuel adjustment shall be made to increase the burn rate. The door may be open for up to 30 seconds for fuel adjustments. Only two fuel adjustments may be made during this phase. If after the second fuel adjustment, another period of no weight change (0.1 lb) occurs, the run ends, and it is a failed test run.

11.6.9.5.L3 End of Phase – The L3-fire phase ends when the scale indicates that 90% of the maintenance-fire fuel mass has been consumed.

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11.6.9.6.L3 Documentation - Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge.Photo documentation

11.6.10.*L4: Low burn rate phase* – L4 phase commences immediately after the L3- ends.

11.6.10.1.L4 Appliance Requirements.

11.6.10.1.1.Record the weight of the stove prior to loading the L4-fire fuel charge, the load of the fuel charge prior to loading, and the scale weight after loading the overnight-fire fuel charge. Alternatively, if the scale was zeroed prior to starting the test, record the scale weight before and after loading the overnight-fire fuel charge.

11.6.10.2.L4 Fuel requirements

11.6.10.2.1. L4 fuel type –a mix of small and large cordwood pieces are used. At least 50% of the fuel charge load, by the number of pieces, must be large pieces.

11.6.10.2.2.L4 Loading structure: fuel will be loaded in one direction.

11.6.10.2.3.L4 loading density: The fuel load calculator specifies a load volume of 12 lb/ft^3 .+/-5%. Fuel shall be loaded in a manner to maximize the number of pieces that will fit in the stove without using force.

11.6.10.3. L4 Operational Parameters:

11.6.10.3.1. Open the loading door upon completion of the L3 maintenance-fire phase.

11.6.10.3.2.Load the L4 fuel charge within two minutes (120 seconds).

11.6.10.3.3.Keep the door in the 1" cracked position for five minutes from the beginning of the L4 phase.

11.6.10.3.4.Air controls shall be placed in the fully open position for the first ten minutes of the phase.

11.6.10.4.L4 Fuel Adjustments.

11.6.10.4.1.Unlimited fuel adjustments are allowed within the first five minutes of the phase. After ten minutes, air control(s) shall be moved to their lowest position. A picture of the air setting used

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must be included in the test report. The door may be open for up to 30 seconds for fuel adjustments.

11.6.10.4.2.If there is a ten-minute period without weight change (0.1 lb) during the first hour of the L4-phase, a fuel adjustment shall be made. The door may be open for up to 30 seconds for fuel adjustments.

11.6.10.4.3.Only two fuel adjustments may be made during the first hour. If after the second fuel adjustment, another periods of no weight change (0.1 lb) is observed, the run ends, and it is a failed test run.

11.6.10.4.4.No fuel adjustments are allowed after the first hour of the phase.

11.6.10.4.5.If there is no weight change for a consecutive period of 20 minutes at any point after the first hour of the phase, the unit has failed the test run.

11.6.10.5.L4 End of Phase – The L4 phase shall end when the scale indicates that 90% of the total L4 fuel mass has been consumed. If the fuel load does not burn to 90%, it is a failed test run.

11.6.10.6. L4 Documentation - Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge.

11.7. Test Run. A complete test run requires completion of all four burn phases and loads. For any appliance that will not accommodate the loading arrangement specified in this test method, the test facility personnel shall contact the Agency Administrator to obtain written approval for an alternative loading arrangement:

11.8. Test Run Requirements. The following describes the required parameters for each test run. Each emission test run shall include all phases of the operational and fueling protocol run in order as described.

11.8.1.Consecutive Test Runs. Consecutive test runs may be conducted, provided that the following requirements are met:

11.8.1.1.Run 1 – The appliance shall have an internal and external starting temperature within +/- 2 °F (1.1°C) of laboratory ambient temperature at the beginning of Run 1

11.8.1.2.Run 2 – The second test run may commence 24 hours after the start of Run 1. Stove coals and ash can remain in the stove until 1 hour before conducting Run 2. All coals and ash shall be removed at least one hour prior to commencing Run 2.

11.8.1.3. Run 3 – The third test run may commence 24 hours after the start of Run 2. Stove coals and ash may remain in the stove until 1 hour before conducting Run 3. All coals and ash shall be removed at least one hour prior to commencing Run 2.

11.9. *Failure to Operate at All Test Conditions*

11.9.1. If the appliance fails two runs due to incomplete or failed test runs, it shall be determined that the appliance has failed the certification test and requires a modification to appliance design. All data for incomplete runs shall be reported. Incomplete failed test runs are defined as the following:

11.9.1.1. If a wood heater fails to complete all four phases of the test run, the run shall be considered an incomplete test run.

11.9.1.2. If there is no weight change for a consecutive period of 20 minutes at any point during the test, the unit has failed the test run.

11.9.1.3. If the wood heater fails to comply with test protocol parameters

11.9.2. If a test run violates the parameters of the test method, the run is invalid.

11.9.3. If during certification testing a critical component of the stove is damaged or breaks, the certification test will be stopped and considered invalid.

11.9.3.1. If damage is noted during a test, repairs shall be made by the manufacturer (or by laboratory personnel with written direction from the manufacturer). If the repair involves components that require aging, the appliance shall then undergo another round of wood heater aging as specified in section 10.6. Components requiring aging shall include but are not limited to catalyst elements, gaskets, and refractory components. Manufacturers have the option of aging these elements in other prototypes. The aging process is intended not only to 'cure' the stove but also to cycle parts that may fail with extended use. Alternate aging techniques may be approved by the administrator, depending on the nature of the failure, material, and critical nature.

11.10. Test Run Completion. Once three valid runs have been completed, the testing is complete. No additional runs may be completed.

11.10.1. *Additional Test Runs*. If there is an invalid run, may attempt two additional runs to complete the test series. If more than three test runs are conducted, the results from all valid test runs shall be used in calculating the average emission rate. The measurement data and results of all test runs shall be reported regardless of which values are used in calculating the emission rate. No test run data can be eliminated from the reporting requirements of this method.

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11.10.2. *Invalid Runs.* When a test run fails to meet one of the QA/QC criteria stipulated in the test method, the data are invalid and the run must be repeated. Data for the invalidated test run must be included in the test report but the data must not be used in calculation of average emission values.

11.10.3. *Incomplete Runs.* When an appliance cannot successfully complete all operational elements of the protocol specified in Section 11.6.7 through 11.6.10, it is an incomplete run.

11.11. Auxiliary Wood Heater Equipment Operation. If optional heat exchange blowers are sold for use with the wood heater, three runs with the fan and an additional run without the fan shall be completed. If emissions are more than 1 gram per higher with the fan on, an additional two runs must be completed with the fan on. Heat exchange blowers shall operate in the highest airflow setting. (Automatically operated blowers shall be operated as designed) during the entire test.

11.12. PM Data Recording.

11.13. All data shall be collected and recorded at intervals of no more than 1 minute. TEOM data shall be averaged up to 1-minute intervals for reporting. TEOM operation shall follow the procedures listed in NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

11.13.1. Data shall be reported in an Excel or compatible spreadsheet following the minimum data reporting requirements. All electronic files, including raw instrument data, shall be submitted as part of the test report. Spreadsheet files shall be supplied as part of the publicly available test report.

11.13.2. Room PM measurement – TEOM. A single channel TEOM shall be used to measure ambient lab air PM during the test, as configured in NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel. The sample flow shall be 3 LPM.

12. *Quality Control Measures*

12.1. Dilution tunnel - Conduct sampling equipment leak check and calibration pre- and post-test.

12.2. TEOM – Flow and Leak checks are done before and after every test run per NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel. Additional quality control measures are included in the TEOM Operating Procedure.

12.3. Volume Metering System Checks.

13. *Data Analysis and Calculations. –*

13.1. Emission Calculations. Particulate matter, carbon dioxide, and carbon monoxide shall be calculated using the following methodology and reported in grams per hour, grams per kilogram

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and pounds per million British Thermal Unit (BTU) heat output. All calculations shall be conducted using all decimal values provided by the instrumentation or recorded by the operator. No truncation of data is acceptable. Only the final calculation of the PM emissions rate shall be rounded, to three significant figures.

13.2. TEOM data shall be reported as follows.

13.2.1. TEOM concentration data and tunnel flow are used to calculate PM emission rates in g/h at 1-minute intervals as follows, where net PM is tunnel PM – lab air PM.

g/h = 0.000001699 * (tunnel flow in wet CFM) * (net PM concentration in μg/m3)

The values used for tunnel flow must be the actual (wet) values, measured at intervals of no greater than 10 minutes, except as follows. If the range of 10 minute tunnel flow measurements (100*(Max - Min) / average) is no greater than 5.0% of the run-average tunnel flow, the run average tunnel flow can be used for these calculations.

13.2.2. For calculation of lbs/mmBtu and grams/kg, total grams PM emitted is calculated by multiplying the average g/h rate for the test period of interest times the duration (in hours) of that test period. Grams are converted to lbs by dividing grams by 453.6.

13.2.3. Emissions from each of the 4 phases of the test shall be reported as individual results in grams per hour, grams per kilogram, and lb/MMBtu (heat output), and include % data capture for each phase.

13.2.4. Emissions from the entire test run in grams per hour, grams per kilogram, and lb/MMBtu (heat output), including % data capture for the entire test run.

Nomenclature

AER = Ei/∑N
BR – average dry fuel burn rate, lb./min
$BR_{(x)}$ – Burn rate for specific phase, BR_{L1}, BR_{L2}, BR_{L3}, BR_{L4}
CO – Carbon Monoxide
CO_2 – Carbon Dioxide
H_2- Hydrogen
O_2 – Oxygen
BT = time of 90% of overnight load consumed – time of overnight loading
C_{steel} – Specific heat of steel (0.1 Btu/ lb., ˚F)
E_T – Total particulate emissions for the full test run in grams
$E_{g/MJ}$ – PM Emissions rate in grams per megajoule of heat output
$E_{g/kg}$ – PM Emissions factor in grams per kilogram of dry fuel burned
$E_{g/hr}$ – PM Emissions factor in grams per hour
E_{Rco} – CO emission rate, g/hr.
EIi – Average CO emission index for interval i

E_{ICO} – CO emission index, g/kg dry fuel

EIco,avg – Average CO emission index for the run

HHV – Higher heating value of fuel = Use accredited test results

LHV – Lower heating value of fuel = Use accredited test results

$\%M_d$ = Fuel moisture content, dry basis, percent.

$\%M_w$ = Average moisture in test fuel charge, wet basis, percent

N = Total number of test runs.

PCTCO2– average CO_2 in the dry flue gas (%)

PPMco -average CO in the dry flue gas (ppm)

Q_{out} – Total heat output in BTU's (megajoules)

SC_i – Scale weight at specific time interval, lb.

$t_{(i)}$ – Data sampling interval in minutes

T1 – Surface Temperature 1 ˚F (˚C)

T2 – Surface Temperature 2 ˚F (˚C)

T3 – Surface Temperature 3 ˚F (˚C)

T4 – Surface Temperature 4 ˚F (˚C)

T5 – Surface Temperature 5 ˚F (˚C)

T6 – Pre Catalyst Temperature 1 ˚F (˚C)

T7 – Post Catalyst Temperature 2 ˚F (˚C)

T8 – Tunnel Temperature ˚F (˚C)

T9 - Flue Gas Temperature ˚F (˚C)

T10 – Room Temperature ˚F (˚C)

$TS_{avg(i)}$ – Initial Average Surface Temperature ˚F (˚C)

$TS_{avg(f)}$ – Final Average Surface Temperature ˚F (˚C)

W_{fuel} – Fuel charge weight in pounds (kg)

W_i – Weight of fuel in pounds (kg)

W_{app} – Weight of empty appliance in pounds (kg)

Θ – Total length of test run, hours

$\Theta_{(x)}$ – Total length of test run in hours per phase, X

$\%M_w = 100(\%M_d)/100+\%M_d$

13.3. Average Wood Heater Surface Temperatures. Calculate the average of the wood heater surface temperatures at the start of the phase (L4) and end at the end of the test (L4) of the test run.

L4 $TS_{avg(i)}$ – (T1 + T2 + T3 + T4 + T5) / 5

L4 $TS_{avg(f)}$ – (T1 + T2 + T3 + T4 + T5) / 5

Average surface temperatures at the start and end of any phase can be determined by averaging all five sensors at the beginning and end of each phase.

L_x $TS_{avg(i)}$ – (T1 + T2 + T3 + T4 + T5) / 5

L_x $TS_{avg(f)}$ – (T1 + T2 + T3 + T4 + T5) / 5

13.4. Burn Time Rating– A standardized burn time rating shall be determined by rounding the duration

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of the overnight-fire phase of the test up to the nearest 1 hour. Burn time shall be calculated as the time L4 is loaded into the stove until 90% of the fuel has been consumed. This provides an important rating for consumers and is not intended for any calculation purposes and shall be reported on the all manufacturers materials that provides specifications on appliance performance. Language such as "this stove has demonstrated a low setting burn time of x hours in official testing"

13.5. Determine Burn Rates

BR_{L1} = not applicable
BR_{L2} = (L2 Initial SC_i – L2 Final SC_i) / $\Theta_{(L2)}$, lbs./hr
BR_{L3} = (L3 Initial SC_i – L3 Final SC_i) / $\Theta_{(L3)}$, lbs./hr
BR_{L4} = (L4 Initial SC_i – L4 Final SC_i) / $\Theta_{(L4)}$, lbs./hr

13.6. Emissions

13.6.1. Determine emission rates and emission factors as:

$E_{g/MJ} = E_T/(Q_{out} \times 0.001055)$, g/MJ
$E_{g/kg} = E_T/(W_{fuel}/(1+M\%M_d/100))$, g/dry kg
$E_{g/hr} = E_T/\Theta$, g/hr

13.7. Efficiency calculation.

Ultimate Analysis of dry fuel (% by weight)

Carbon – CA
Hydrogen – HY
Oxygen – OX
Moisture Content – mass of water per mass of dry fuel – Mcdb
Ambient Humidity Ratio – mass of water per unit mass of dry air – ω
Flue gas temperature (F) – Ts
Room temperature (F)-Tr
CO in the dry flue gas (ppm) – PPMco
CO2 in the dry flue gas (%) – PCTCO2
Higher heating value of the dry fuel (lb/MMBtu) – HHV

<u>Combustion Balance Equation:</u>

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

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THIS INTEGRATED-DUTY-CYCLE (IDC) PROTOCOL FOR WOOD STOVES IS THE PROPERTY OF THE NEW YORK STATE ENERGY RESEARCH AND DEVELOPMENT AUTHORITY (NYSERDA) AND CAN BE USED TO TEST TECHNOLOGIES IN A LABORATORY SETTING. ANY DEVIATIONS OR CHANGES TO THIS IDC PROTOCOL FOR WOOD STOVES ARE NOT APPROVED OR SANCTIONED BY NYSERDA.

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Where:

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4] excess air parameter, e.g. if [EMBED Equation.DSMT4] 0.5 there is 50 % excess air

From this:

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

With flue gas CO and CO_2 measured, these two equations can be solved simultaneously for [EMBED Equation.DSMT4] and [EMBED Equation.DSMT4].

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

<u>Calculation of the Molar Coefficient for Each of the Products</u>

For the assumption of 100 kg of dry fuel, this is the number of moles of each product for the input conditions

[EMBED Equation.DSMT4] Molar Coefficient for CO

[EMBED Equation.DSMT4] Molar Coefficient for CO_2

[EMBED Equation.DSMT4] Molar Coefficient for H_2O

[EMBED Equation.DSMT4] Molar Coefficient for O_2

[EMBED Equation.DSMT4] Molar Coefficient for N_2

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Heat Capacity of Exhaust Products

The general equation for representing how the heat capacity of the exhaust products varies with temperature is:

[EMBED Equation.DSMT4]

Where:

C = heat capacity J/mol K or kJ/kgmol K

A and B are constants

Tk = Temperature in °K

The values for A and B for the exhaust components are provided in the table below

Component	A	B
CO	.0056	27.162
CO2	.029	29.54
H2O	.0057	32.859
O2	.009	26.782
N2	.0062	26.626

For each component, heat capacity is calculated at the stack temperature and at room temperature. The average of these is used to calculate sensible heat loss.

Calculation of Heat Losses for Efficiency Determination

[EMBED Equation.DSMT4] Higher heating value in kJ/kg (conversion from Btu/lb)

[EMBED Equation.DSMT4] Latent heat of water vapor in kJ/kgmol

[EMBED Equation.DSMT4] Heat loss in latent heat of water vapor, % of input energy

[EMBED Equation.DSMT4] Heat loss in chemical energy in CO, % of input energy

[EMBED Equation.DSMT4]

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[EMBED Equation.DSMT4] Heat loss in sensible heat in flue gas, % of input energy

[EMBED Equation.DSMT4] Stack loss efficiency, %

14. Reporting Requirements. The report shall include the following:

14.1.1.Introduction

14.1.2.Purpose of test: certification, audit, efficiency,

14.1.3.Name and location of the laboratory conducting the test.

14.1.4.Wood appliance identification – manufacturer, model number/name, design type, description of the appliance tested, stove condition, and date of receipt.

14.1.5.Test information – location of testing, date of tests, sampling methods used, number of test runs, a statement detailing any previous certification testing completed on the wood appliance.

14.1.6.A list of people who conducted research on the appliance, participated in testing preparation, or witnessed the certification testing. This list shall clearly specify their roles in the testing program for the appliance. The list shall include the participant's name, title, company, contact information and the purpose of their participation.

14.1.7.A statement that the test results apply only to the specific appliance tested.

14.2.Summary and Discussion of Results

14.2.1.Table of results to include test run number, average burn rate for entire run and each phase, carbon monoxide and particulate emission rate for full run, particulate and carbon monoxide emission rate for each load phase (L1, L2, L3, L4), efficiency for the full run and each phase, burn time for total run and each phase.

14.2.2.For each test run use the TEOM data and use real-time gas analyzer data for other emissions to report: Θ_1,Θ_2, Θ_3, CO, CO_2, PM, and efficiency for (1) L1 - the startup phase and (2) L2 - high-, (3) L3-maintenance-, and (4) L5 low burn rate fire phases. Calculated results for the emissions shall be reported as total emissions in grams, pounds per million Btu output, grams per MJ, grams per kilogram of dry fuel and grams per hour, and pounds per hour.

14.2.3.A narrative discussion detailing any issues or anomalies that arose during each test run and how those were handled, including comments about the fuel, and loading of the appliance.

14.2.4.A plot of CO emission rate in ppm vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.5.A plot of CO_2 emission rate in ppm vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.6.A plot of PM emission rate in grams/hour vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.7. A plot of PM emission rate in g/kg vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.8. Summary of other data – test facility conditions, surface temperature averages, catalyst temperature averages, pretest fuel weights, test fuel charge weights – total and by phase.

14.3. Discussion. Test run result, specific test run problems and solutions. Comments on fuel, loading, analysis, and anything that may impact the reported result(s).

14.3.1. Details of deviations from, additions to or exclusions from the test method, and their data quality implications on the test results (if any), as well as information on specific test conditions, such as environmental conditions. An explanation of the deviations, additions, or exclusions shall be provided along with an analysis as to why these elements had no impact.

14.4. Process description:

14.4.1. Data and drawings indicating the firebox size and location of the fuel charge.

14.4.2. Drawings and calculations used to determine firebox volume to include volume, height, width, and lengths, weight, and volume adjustments.

14.4.3. Firebox configuration – At a minimum to include air supply locations and operation, air supply introduction location, refractory location and dimensions, catalyst location, baffle and by-pass location and operation (include line drawings or photographs)

14.4.4. Appliance operation during the test – shall supply details on air supply settings and adjustments.

14.5. Test fuel properties – the report shall provide information on the species, density, fuel moisture, fuel temperature, and load details from the fuel load calculator to include all measurements including the number of pieces, individual piece weights, piece length, moisture content and weight.

14.6. Sampling

14.6.1. A description of the test procedures and test equipment, including a schematic or other drawing showing the location of all required test equipment. Also, a description of test fuel sourcing, handling and storage practices shall be included.

14.6.2. Describe the sampling location relative to the wood heater, include drawing or photographs.

14.7. Quality Control and Assurance Procedures

14.7.1. Calibration procedures and results certification procedures, sample and analysis procedures.

14.7.2. Test method quality control procedures to include TEOM leak and flow checks, stratification (velocity) checks, tunnel flow range results, filter temperature range verification and dilution tunnel RH verification.

14.8. Appendices

14.8.1. Results and Example Calculations. Raw data and complete calculations for data included in

summary tables.

14.8.2.Raw data. Copies of all files or sheets for sampling measurement, temperature records, and other materials used by lab related to testing.

14.8.3.Calibration Results. Summary of all calibrations, check, and audits pertinent to the certification.

14.8.4.Sampling and Operation Records. Copies of all uncorrected records of activities not included in raw data sheets (e.g., wood heater door open, times and durations) as well as photographs of fuel loading and air flow settings.

14.8.5.Correspondence. Any correspondence to include written, electronic or verbal communications regarding appliance testing. Items shall include:

14.8.5.1.Request to conduct testing

14.8.5.2.Scheduling of testing

14.8.5.3. Notice to EPA to conduct test, and any modifications to that request.

14.8.5.4. Notice and submission of data to EPA after testing completed.

14.8.6.Test Facility Information. Report test facility temperature, air velocity, and humidity information.

14.8.7.Test Equipment Calibration and Audit Information. Report calibration and audit results for the platform scale, test fuel balance, test fuel moisture meter, and sampling equipment including volume metering systems and gaseous analyzers.

14.8.8.Pretest procedures. Report all pretest procedures conducted at the lab on the appliance to burns, rates, and amounts.

14.8.9.All required data for each test run shall be provided in spreadsheet format both in the printed report and in a computer file such that the data can be easily analyzed and calculations easily verified. Formulas used for all calculations shall be accessible for review.

14.8.10.For each test run: report 1-minute TEOM data per the parameter list in the TEOM SOP TEOM flow and temperature and verification of all TEOM data validation parameters as required in NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

14.8.11.Raw data, calibration records, and other relevant documentation shall be retained by the laboratory for a minimum of 7 years.

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Integrated Duty Cycle Test Method for Certification of Wood-Fired Stoves Using Cordwood: Measurement of Particulate Matter (PM) and Carbon Monoxide (CO) Emissions and Heating Efficiency

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Note: This method does not include all the specifications (e.g. equipment and supplies) and procedures (e.g., sample and analytical) essential to its performance. Some material is incorporated by reference from other methods. Therefore, to obtain reliable results, persons using this method shall have a thorough knowledge of at least the following EPA Tests

- Method 1- Sample and Velocity Traverses for Stationary Sources
- Method 2- Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot

Tube)

- Method 3 – Gas Analysis for the Determination of Dry Molecular Weight
- Method 4 – Determination of Moisture Content in Stack Gases
- Method 5G – Determination of Particulate Matter from Wood Heaters (Dilution Tunnel Sampling Location)
- Method 10 - Carbon Monoxide - Instrumental Analyzer
- Method 28 – Certification and Auditing if Wood Heaters

1. Scope and Application

1.1. This test method specifies operation and fueling for certification and auditing of manually operated wood-fired stoves and heaters.

1.2. This test method measures particulate matter (PM) emissions, carbon monoxide, and efficiency.

1.3. Particulate emissions are measured by the dilution tunnel method as specified in ASTM E2515 Standard Test Method for Determination of Particulate Matter Emissions Collected in a Dilution Tunnel using only ~~Emfab~~ Pallflex Emfab filters. Additional particulate matter emissions measurements may also use the Tapered Element Oscillating Microbalance (TEOM) continuous PM method, as detailed in this test method.

1.4. Analyte. Particulate matter (PM). No CAS number assigned. Carbon monoxide (CO). No CAS number assigned.

1.5. Applicability. This method is applicable for the certification and auditing of wood space heaters, which burn cordwood fuel. The test quantifies PM and CO emissions and provides overall efficiency ratings, maximum burn time, and heat output.

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~~1.6. Data Quality Objectives. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods~~

~~1.7.~~1.6 Distinguishing features of appliances covered by this standard include:

~~1.7.1.~~1.6.1. Cordwood fuel is hand-fed into firebox.

~~1.7.2.~~1.6.2. A chimney or vent that exhausts combustion products from the appliance.

~~1.8.~~1.7. The values stated are to be regarded as the standard, whether in I-P or SI units. The values given in parentheses are for information only.

~~1.9.~~1.8 Data Quality Objectives. ~~Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods~~

~~1.9.1.~~1.8.1 Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods.

~~1.9.2.~~1.8.2. Measurement of emissions and heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

~~1.9.3.~~1.8.3. This is a laboratory method intended to capture operating periods that are representative of actual field use without excessive test burden.

2. *Referenced Methods*

2.1. NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel

2.2. ASTM 2515: Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel.

3. *Definitions*

3.1. Appliance – a wood heater capable of and intended for space heating defined in the applicable regulation. The appliance includes combustion chamber, combustion air settings, operating controls, and a thermostat if specified, and any other accessory required for standard operation, such as a barometric damper,

3.2. Catch - any mass from the sample probe system on the filter.

3.3. Certification or audit test - a series of at least three test runs conducted for certification or audit purposes that meets the specifications detailed in this protocol.

3.4. Chop – using a poker or another piece of wood to strike a piece of the fuel charge to break it into smaller pieces.

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3.5. Coal-bed Stirring – prior to adding a new fuel charge, using a poker or piece of wood to stir or level the coal bed of the appliance for the sole purpose of ensuring ease of loading of the fuel charge. No special formations can be made, such as creating coal bed formations or pushing coals to one side or creating slopes with the coals.

3.6. East-west stove – a stove where the firebox dimension parallel to the loading door is greater or equal to the stove depth measurement. Logs are loaded so that they are viewed on the long length of the stove.

3.7. Emission factor – the emission of a pollutant expressed in mass per unit of energy (typically) output from the appliance.

3.8. Firebox - the portion of the chamber in the wood heater in which the test fuel charge is placed and combusted.

3.9. Firebox depth - the horizontal length of the fire chamber dimension measured perpendicular to the loading door. If the manufacturer believes that a portion of the firebox depth is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.10. Firebox Height - the vertical distance extending above the top of the firebox to the floor of the firebox. Firebox height is not necessarily uniform. The measurement must account for variations caused by internal baffles, air channels, or other permanent obstructions. If the manufacturer believes that a portion of the firebox height is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.11. Firebox width - the horizontal fire chamber dimension that is parallel to the loading door. If the manufacturer believes that a portion of the firebox width is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.12. Fuel Adjustment –manipulations to the fuel charge to reflect typical owner practices that allow the cordwood fuel to burn appropriately during the test period. A fuel adjustment does not include chopping the wood or stirring the coal bed.

3.13. Fuel load calculator – The locked excel spreadsheet tool that determines the allowable test fuel load weights and required piece sizes for each individual load.

3.14. Fuel loading direction – Fuel shall be loaded parallel to the greater of the width and depth dimensions for loads 2, 3 and 4. Criss-cross is allowed for startup phase and cannot be used as a load configuration for loads 2, 3 or 4. If the firebox length and width are within 2" fuel shall be loaded in an east/west fashion, parallel to the loading door.

3.15. Kindling pieces – small pieces of wood less than 1" in diameter. No bark or moisture requirements for these pieces, however kindling pieces shall not be dried or stored anywhere but in laboratory ambient conditions. Kindling length shall be of the same as the fuel charge length. and shall represent weights that would enable 8 to 12 pieces equal one pound.

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3.16. Large fuel pieces – pieces that are larger for the appliance as defined by the fuel load calculator.

3.17. L1 – Start-up – period of the test when the unit has kindling and startup fuel under the conditions described in Section 11.6.7.

3.18. L2 – High-fire Phase – period of the test when the unit has a small coal bed and the stoves air settings are fully open. Intended to replicate period when homeowners are trying to quickly heat an area, shortly after starting or restarting the appliance.

3.19. L3 - Maintenance-fire phase– period of the test when a fire is maintained with a medium-sized coal bed, and a smaller batch of wood. This is intended to simulate a period when the operator is trying to maintain consistent heat output.

3.20. L4 - Low-burn Rate Phase – period of the test when the stove has a large coal bed, stove is fully loaded, and the adjustable air settings are set to produce the lowest possible burn rate and have the lowest air settings. Intended to simulate a period the operator is trying to maintain heat over a long period of time, such as overnight or while away for significant periods of time.

3.21. North-south stove: a firebox which has its longest dimension measurement perpendicular to the loading door. In this stove type, logs are loaded so that the ends of the fuel are viewed when loaded.

3.22. Phase – A distinct period in the test run with its own operational procedures and conditions.

3.23. Primary air supply – air supply that introduces air to the wood heater in the combustion chamber and is adjusted to target a desired burn rate. The wood heater manufacturer or test facility can document this through design drawings.

3.24. Secondary air supply - air supply that introduces air to the wood heater such that the burn rate is not altered by more than 10 percent when the secondary air supply is adjusted during the test run. The wood heater manufacturer or test facility can document this through design drawings that show the secondary air is introduced only into a mixing chamber or secondary chamber outside the firebox.

3.25. Small fuel pieces - pieces that are small for the appliance as defined by the fuel load calculator.

3.26. Starter fuel – pieces of cordwood that can be smaller than small and large pieces but larger than kindling, as defined by the fuel load calculator.

3.27. Test data– means the data for all test runs conducted on the wood heater, including any data collected during failed and invalid runs and includes records of preparation of standards, identification of equipment used and personnel present, records of calibrations, raw data sheets for field sampling, raw data sheets for field and laboratory analyses, chain-of-custody documentation, and example calculations for reported results.

3.28. Test facility - the area in which the wood heater is installed, operated, and sampled for emissions.

3.29. Test fuel charge - the collection of test fuel pieces used in each of the four phases of the test run. L2, L3, and L4 require that at least 50% of the individual pieces with at least 80% bark on one

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side of the fuel piece. Bark shall not be removed for certification testing. Any fuel charge that suggests bark was purposely removed or shaped shall deem the certification test invalid. Examples of fuel piece manipulation are provided in Section 11

3.30. Test fuel load – the group of test fuel pieces that are loaded, as specified by phase, throughout the test run. Test fuel loading means the arrangement of the test fuel charge.

3.31. Test fuel loading density - the calculation that determines the weight of the as-fired test fuel load. The calculation is based on the usable volume of the firebox.

3.32. Test run - an individual emission test that includes the four operational phases required by the fueling protocol.

3.33. Usable firebox volume - the calculated volume of the firebox determined using its height, width, and depth as defined in this section. This calculation represents the area where wood is likely to be loaded. If the manufacturer claims that portions of the firebox may not be used in the calculation a justification must be submitted with the test report. If the justification is not approved, the test results will be deemed unrepresentative for certification purposes. It is highly recommended that manufacturers obtain regulatory approval if making claims that portions of the firebox are not appropriate for inclusion in the calculation.

3.34. Wood heater - an enclosed, wood-burning appliance capable of and intended for space heating or domestic water heating, as defined in the applicable regulation.

4. *Interferences*

None.

5. *Summary of Method*

5.1. Particulate matter emissions are measured from a wood heater burning cordwood test fuel in a test facility maintained at a set of prescribed ambient conditions. Procedures for operating the appliance, measuring PM and CO emission rates, and methods for reducing data and calculating results are provided.

5.2. *Dilution Tunnel*. A dilution tunnel following the specifications detailed in ASTM E2515-11 shall be used for particulate measurements.

5.3. *Particulate Matter:* PM emissions are measured in a dilution tunnel with a Thermo model 1405-D 2-channel TEOM using NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel with a dilution tunnel as specified in ASTM 2515 with modifications discussed in Section 10.

5.4. *Carbon Monoxide*. The CO measured in the stack and is used to calculate efficiency determination.

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5.5. *Operation*. Appliance operation is conducted on a cold-to-hot test cycle, meaning that the appliance starts the first test run at room temperature and ends with the appliance in fully heated state. The second and third test runs are started a slightly warmer temperature. The appliance is operated at a variety of operational phases representing start-up emissions, high heat demand, low heat demand, and refueling. The appliance is operated through four phases. To complete the certification test, a minimum of three full test runs are averaged to determine the test results.

5.6. *Repeatability.* A series of at least three test runs comprised of six different heat demands or phases conducted for certification or audit purposes

6. Significance and Use

6.1. The measurement of particulate matter emission rates is an important test method widely used in the practice of air pollution control.

6.1.1. These measurements, when approved by state or federal agencies, are often required for the purpose of determining compliance with regulations and statutes.

6.1.2. The measurements made before and after design modifications are necessary to demonstrate the effectiveness of design changes in reducing emissions and make this standard an important tool in manufacturers' research and development programs.

6.2. Measurement of heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

7. Safety

7.1. Disclaimer. This method may involve hazardous materials, operations, and equipment. This test method may not address all the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to performing this test method.

7.2. These tests involve combustion of wood, which releases substantial amounts of heat and combustion products. The heating system also produces large quantities of very hot water and the potential for steam production and system pressurization. Appropriate precautions must be taken to protect personnel from burn hazards and respiration of products of combustion. Exposure of personnel to unsafe levels of carbon monoxide must be avoided, and the use of continuous ambient carbon monoxide monitoring is strongly recommended.

8. Equipment and Supplies. The following items are required for sample collection:

8.1. Anemometer. A device capable of detecting air velocities less than 0.10 m/sec (20 ft/min), for measuring air velocities near the test appliance.

8.2. Appliance Flue.

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8.2.1. Steel flue pipe extending to 8.5 ±0.5 ft. (2.6 ±0.15 m) above the top of the platform scale, and above this level, insulated solid pack type chimney extending to 15 ±1 ft (4.6 ±0.3 m) above the platform scale, and of the size specified by the appliance manufacturer. This applies to both freestanding and inserts type appliances.

8.2.2. Other chimney types (e.g., solid pack insulated pipe) may be used in place of the steel flue pipe if the appliance manufacturer's written appliance specifications require such chimney for home installation (e.g., zero clearance appliance inserts). Such alternative chimney or flue pipe must remain and be sealed with the appliance following the certification test.

8.2.3. Solid pack insulated chimneys shall have a minimum of 2.5 cm (1 in.) solid-pack insulating material surrounding the entire flue and possess a label demonstrating conformance to U.L. 103 (incorporated by reference—see §60.17).

8.3. Appliance Platform Scale and Monitor. For monitoring of fuel load weight change. The scale shall be capable of measuring weight to within 0.01 kg (0.02 lb.) and calibrated to NIST traceable standards at least annually.

8.4. Barometer. Aneroid or another barometer capable of measuring atmospheric pressure to within 0.1 in. Hg (2.5 mm Hg) with an uncertainty of +/- 0.05 in Hg (+/- 1.27 mm Hg).

8.5. Dilution Tunnel must meet the requirements of ASTM E2515, clauses 6.1.6 and 9.2.

8.6. Dilution Tunnel temperature and relative humidity measurement. A probe capable of measuring tunnel temperature to within 0.9 °F (0.5 °C)) and tunnel RH to within 2%, such as the Omega HX85-A or equivalent.

8.7. Draft Gauge. Electromanometer or other devices for the determination of flue draft or static pressure readable to within 0.005 in. H2O (1.2 Pa)

8.8. Flue Gas Temperature Measurement. A type K- thermocouple or equivalent located in the centroid of the stack located 8.0 +/- 0.5 ft (2.44 m +/- 150 mm) above the platform scale. Capable of measuring with an accuracy of 4.0°F (2.2°C) or 0.75% of reading, whichever is greater.

8.9. Flue Gas Composition Measurement. A sample probe and continuous infrared analyzer or equivalent capable of measuring span of carbon monoxide (CO) and carbon dioxide (CO_2) in the flue gas produced by the appliance tested. Continuous analyzers (or equivalent) shall have maximum zero and span drift, over a 24 h period, of 1% of full scale

8.10. Fuel Scale. Balance capable of weighing the test fuel charge to within 0.02 kg (0.05 lb.) and calibrated to NIST traceable standards at least annually.

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8.11. Humidity Gauge. Psychrometer or hygrometer for measuring room humidity to within +/- 4% from 25 to 95% RH.

8.12. Moisture Meter. Calibrated electrical resistance meter for measuring test fuel moisture to within 2 percent moisture content.

8.13. Surface Temperatures. Capable of measuring temperature to within 1.5 percent of expected absolute temperatures with an accuracy of 4.0˚F (2.2˚C) or 0.75% of reading, whichever is greater.

8.14. Test Facility Temperature Monitor. A thermistor, RTD, Type T-Special thermocouple, or other equivalent device, located centrally in a vertically oriented 150 mm (6 in.) long, 50 mm (2 in.) diameter pipe shield that is open at both ends, capable of measuring temperature to within 1˚F of expected temperatures.

8.15. TEOM – Thermo Fisher Scientific TEOM model 1405-D (Thermo part # 1405D-ANF, excluding models 1405, 1405-DF, or 1405-F) to measure and report continuous particulate matter (PM) measurements in an ASTM 2515 dilution tunnel or equivalent dilution method, and operated according to the NESCAUM Dichot TEOM Standard Operating Procedures.

9. Calibration and Standardizations

9.1. Anemometer. Calibrate the anemometer as specified by the manufacturer's instructions before the first certification test and monthly thereafter.

9.2. Appliance Platform Scale. Perform a multi-point calibration (at least five points spanning the operational range) of the platform scale before its initial use. The scale manufacturer's calibration results are sufficient for this purpose. Before each certification test, audit the scale with the wood heater in place by weighing at least one calibration weight (Class F) that corresponds to between 20 percent and 80 percent of the expected test fuel charge weight. If the scale cannot reproduce the value of the calibration weight within 0.0045 kg (0.01 lb.) or 1 percent of the expected test fuel charge weight, whichever is greater, recalibrate the scale before use with at least five calibration weights spanning the operational range of the scale.

9.3. Barometer. Calibrate using a reference pressure monitor calibrator before the first certification test and semiannually after

9.4. Draft Gauge. Calibrate as per the manufacturer's instructions; a liquid manometer does not require calibration (but must be properly leveled, zeroed and the system leak checked).

9.5. Humidity Gauge. Calibrate as per the manufacturer's instructions before the first certification test and annually thereafter.

9.6. Fuel Scale. Calibrate as described in 9.2.

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9.7. Moisture Meter. Calibrate as per the manufacturer's instructions before the first certification test and semiannually thereafter.

9.8. Temperature Sensors. Calibrate using at least five points within operating range within specification and in compliance with NIST Monograph 175. To be calibrated before the first certification test and semiannually thereafter.

10. Sampling, Test Specimens, and Test Appliances

10.1. Modifications to ASTM 2515 requirements.

10.1.1. Liquid water should not be present anywhere in the sampling system for a valid sample. The presence of condensed water anywhere in the sampling system invalidates the test run. All data from all invalid test runs shall be included in the report. The reviewing authority shall make a final determination on invalidated runs. Data from any invalidated test run shall not be used to calculate results. If the testing agency believes a run has been invalidated, the test run shall be repeated.

10.1.2. Dilution tunnel temperature and relative humidity shall be measured electronically and logged at one-minute intervals near the sample probe to calculate dewpoint. The temperature measurement method shall have an accuracy of 0.9°F (0.5° ~~degrees~~ C) (type T-Special TC or an RTD).

10.1.3. The following section details test conditions that shall be maintained for any valid test run. A valid test shall have no more than two individual deviations from any of the conditions below to remain a valid run. An example of an individual deviation is a single, five-minute rolling average where the dilution tunnel exceeded temperature thresholds. Another five-minute period exceeding the tunnel temperature requirement shall be considered a second deviation.

10.1.3.1. Tunnel temperature shall not exceed 104.0 ~~°F deg~~. F (40.0°C) based on ten~~five~~-minute rolling averages derived from one-minute data, excluding periods when the appliance door is open.

~~10.1.3.1.~~ 10.1.3.2. Tunnel relative humidity shall not exceed 90% based on ten~~five~~-minute rolling averages derived from one-minute data.

~~10.1.3.2.~~ 10.1.3.3. Tunnel dew point temperature shall not exceed ~~be at least~~ 87.8°F (31.02° ~~deg.~~ C) ~~less than filter temperature based on five-minute rolling averages derived from one-minute data~~.

~~10.1.3.3.~~ 10.1.3.4. A minimum tunnel flow of 600 CFM is required. Higher tunnel flows may be required to meet the parameters of Section 10.1.3, 10.13.2, and 10.1.3.3.

~~10.1.3.4.~~ 10.1.3.5. All exceedances must be reported in the test anomalies section, even if deviations are within the test method tolerances.

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10.2. Sample Collection. The following are required for sample collection:

~~10.3.~~10.2.1. Teflon coated glass fiber filters as supplied by the TEOM manufacturer for use with the TEOM model 1405-D. These are Pallflex Emfab (TX40) with an exposed diameter of 13 mm, without organic binder, exhibiting at least 99.95 percent efficiency.

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~~10.4.~~10.3 *Test Specimens.* Appliances shall be supplied as complete systems, including all controls and accessories necessary for installation at the test facility. A full set of specifications, designs, and assembly drawings shall be provided when the product is placed under certification of a third-party agency.

~~10.5.~~10.4 Preparation of Apparatus

~~10.5.1.~~10.4.1 Wood Heater Installation for Certification Testing. Assemble the wood heater appliance and parts in conformance with the manufacturer's provided User Guide. These instructions must match all instructions materials developed by the manufacturer and/or their distributors. Place the wood heater on the platform scale and connect the chimney to the appliance. Clean the flue with an appropriately sized, wire chimney brush before initiating Run 1 of the certification test. Test documentation should include the date and time of flue cleaning.

~~10.5.2.~~10.4.2 Wood Heater Temperature Monitors.

~~10.5.2.1.~~10.4.2.1 For catalyst-equipped wood heaters, locate a temperature monitor (optional) about 25 mm (1 in.) upstream of the catalyst at the centroid of the catalyst face area, and locate a temperature monitor (mandatory) that will indicate the catalyst exhaust temperature. This temperature monitor is centrally located within 25 mm (1 in.) downstream at the centroid of the catalyst face area. Record these locations.

~~10.5.2.2.~~10.4.2.2 Locate wood heater surface temperature monitors at five locations on the wood heater firebox exterior surface. Position the temperature monitors centrally on the top surface, centrally on two sidewall surfaces, and centrally on the bottom and back surfaces. Position the monitor sensing tip on the exterior of the firebox surface inside of any heat shield, room air circulation walls, or other wall or shield separated from the firebox exterior surface. Surface temperature locations for unusual design shapes (e.g., spherical, etc.) shall be positioned so that there are four surface temperature monitors in

~~10.6.~~10.5 Aging

~~10.6.1.~~10.5.1 Wood Heater Aging Prior to Certification Testing. A wood heater of any type shall be aged at least 50 hours before initiating a certification test. The aging procedure shall be conducted

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by the manufacturer prior to sending the appliance to the testing laboratory. The certification lab cannot be involved with wood heater aging in any manner. The appliance shall be operated at a variety of burn rates. Documentation for wood heating aging must be included in the test report. The testing laboratory shall not conduct any firing of the appliance prior to conducting the certification test.

~~10.6.1.1.~~10.5.1.1 The manufacturer shall supply wood heater aging information for the final test reports. Aging data that shall be reported include all fuel parameters (species, moisture content, load weights, piece amounts, and size), air settings used, time spent in each air setting phase, amount of fuel burned, and appliance burn rates.

~~10.6.1.2.~~10.5.1.2 If an appliance uses a catalytic combustor, it must be engaged according to the manufacturer's instructions and operate with the catalyst engaged for at least 50 hours during the break-in period. In addition to the reporting requirements listed in 8.1.1, catalytic appliances shall also report hourly catalyst exit temperature data to include the dates and hours of operation.

11. Procedure

11.1. Test Facility Conditions.

11.1.1. The test facility temperature shall be maintained between 55 and 90°F (13 and 32°C) during each test run.

11.1.2. The flue shall discharge into the same space or into a space freely communicating with the test facility. Any hood or similar device used to vent combustion products shall not induce a draft greater than 0.005 in. H_2O (1.25 Pa) on the wood heater measured when the wood heater is not operating.

11.1.3. For test facilities with artificially induced barometric pressures (e.g., pressurized chambers), the barometric pressure in the test facility shall not exceed 30.5 in. Hg (775 mm Hg) during any test run.

11.1.4. Locate the test facility temperature monitor on the horizontal plane that includes the primary air intake opening for the wood heater. Locate the temperature monitor 3 to 6 ft. (1 to 2 m) from the front of the wood heater in the 90° sector in front of the wood heater.

11.1.5. Use an anemometer, to measure the air velocity. Measure and record the room air velocity before the ignition period in L1 Startup and once immediately following the test run completion. Air velocities within 0.6 m (2 ft) of the test appliance and exhaust system shall be less than 0.25 m/sec (50 ft/min) without fire in the unit.

11.1.6. Measure and record the test facility's ambient relative humidity, barometric pressure, and temperature before and after each test run using equipment as specified in Section 6.

11.2. Wood Heater Firebox Volume.

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11.2.1. Determine the firebox volume using the definitions for height, width, and length. Volume adjustments due to the presence of firebrick and other permanent fixtures may be necessary. All adjustments shall be detailed in the test report. Include areas adjacent to and above a baffle.

11.2.2. If a manufacturer deems certain areas of the firebox as unusable for fuel load calculations, written documentation stating the basis for that claim and supporting photographic image(s) must be provided and approved by the regulatory authority prior to conducting the certification test. If approval is not granted prior to the test, then the test may be invalidated if the reviewing agency determines the firebox volume is inaccurate.

11.3. Test Fuel. The test fuel shall conform to the following requirements and meet specifications as required by the fuel loading calculator:

11.3.1. Fuel Species. Untreated, air-dried, cordwood fuel.

11.3.1.1. Allowable species: maple (big leaf, red, silver), oak (white), fir (Douglas), or white birch.

11.3.1.2. Kiln-dried fuel is not permitted.

11.3.1.3. Fuel shall be free of decay, fungus, or other contaminants.

11.3.2. Fuel Moisture.

11.3.2.1. Determine fuel moisture for each fuel piece by averaging four moisture meter readings, one from each of three sides, measured parallel to the wood grain.

11.3.2.2. The test fuel load shall have an average moisture content from 19% to 25%, wet basis.

11.3.2.3. Average individual piece moisture content shall have an average moisture content 18% to 27%.

11.3.2.4. The addition of moisture to previously dried wood is not allowed.

11.3.2.5. It is recommended that the test fuel be stored in a temperature and humidity-controlled room.

11.3.2.6. Fuel moisture shall be measured within 24 hours of using the fuel for the test and shall be stored in a humidity-controlled environment until 2 hours prior to testing.

11.3.3. Fuel Temperature. The test fuel shall be at the test facility temperature of 13 to 32°C (55 to 90°F).

11.3.4. Fuel Dimensions. The dimensions of each test fuel piece shall conform to definitions specified by the protocols using the fuel load calculator.

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11.3.4.1.Fuel length:

11.3.4.1.1.The length of the fuel pieces will be determined by the fuel load calculator.

11.3.4.1.2.Measurements shall be taken, and the length of the test fuel will be determined by entering the firebox dimensions, which calculates the length for all the fuel pieces into a generally available commercial size (14, 16, 18, 20 or 22 inches in length).

11.3.4.1.3.Piece length specified by the fuel calculator shall be communicated and specified for use in the owner's manual and website. Piece size shall be within 0.5" of the log length determined by the calculator, as measured on the shortest length measurement.

11.3.5.Fuel Loading Direction

11.3.5.1.Fuel loading direction shall be determined by the firebox measurement.

11.3.5.1.1.Stoves with a depth measurement greater than two inches from the width measurement shall be tested with the fuel in a north-south configuration and may not test with fuel in an east/west or crisscross configuration in any load other than Load 1 and Load 2.

11.3.5.1.2.Stoves with a width measurement greater than the depth measurement or a width measurement within two inches of the depth measurement shall be tested with the fuel loaded in an east-west configuration and may not test with fuel in a north/south configuration or crisscross configuration in any load other than Load 1 and Load 2.

11.3.6.Fuel piece weight for each phase of the protocol shall be determined by the fuel load calculator.

11.3.6.1.Kindling –shall be:

11.3.6.1.1.pieces of wood less than or equal to 1" in diameter.

11.3.6.1.2.No bark requirements for kindling fuel

11.3.6.1.3.Fuel species may be any species allowed in 7.2.1.1.

11.3.6.1.4.No moisture requirements.

11.3.6.1.5.Length of kindling shall be the fuel length specified by the fuel load calculator.

11.3.6.1.6.Kindling fuel shall conform to the rule that 7 to 12 pieces of kindling equal 1 pound of kindling fuel (+/- 10%).

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11.3.6.2. Starter fuel: pieces of cordwood shall be used during the startup phase. Individual piece weight for starter fuel shall be determined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall be not be used in testing (see Figure 1). Pieces that have squared cross sections shall be split to represent the typical triangle nature of wood (see Figure 3~~2~~). Trapezoidal pieces must be minimized to the extent possible and fuel load pieces shall be composed to include different shapes of wood if using any trapezoidal pieces. .

11.3.6.3. Small fuel pieces: smaller pieces of cordwood by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall not be used (see figure 1). Pieces that have square cross-sections shall be split to represent the typical triangle nature of wood (see Figure 3~~2~~). Trapezoidal pieces must be minimized to the extent possible. No more than 2 small fuel pieces can be trapezoidal in shape (Figure 2) per fuel load.

11.3.6.4. Large fuel pieces: larger pieces of cordwood, by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall be not be used (see figure 1). Pieces that have square cross sections shall be split to represent the typical triangle nature of wood (see Figure 3~~2~~). Trapezoidal pieces must be minimized to the extent possible. No more than 1 large fuel pieces can be trapezoidal in shape (Figure 2) per fuel load.

~~11.3.6.4.~~

Commented [LR1]: Piece shape configuration
- Use of trapezoidal shapes L1 rules, L2-4 rules
- How to define piece shape when two ends differ

Intent – piece shapes should be different
Fig 1 squares out are out
Fig 2 If you have a piece with four sides, piece dimensions must differ by and should make up no more than per load no more than pieces.
Fig 3 acceptable pieces
Fuel pieces must use different shapes if load size is less than

Figure 1. Schematic of unacceptable cross-sectional profiles

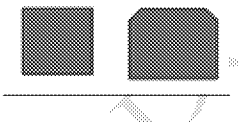

Figure 2.

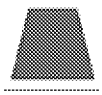

Figure 3. Schematics of acceptable cross-sectional profiles

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11.4. Sampling Equipment.

11.4.1. Prepare the PM and ambient sampling equipment as defined by the TEOM Protocol.

11.4.2. Prepare all other equipment as defined by method EPA Method 1, 2, 3, 4 and 5G.

11.5. Manufacturer participation in certification testing

11.5.1. A representative of the manufacturer may observe testing but may not provide instructions to the certification lab, in any form, with testing staff or equipment once the certification tests begin. The names of testing witnesses cannot be withheld as confidential business information (CBI).

11.6. Test Run Procedure.

11.6.1. Before each test series, the firebox shall be vacuumed. Testing shall begin without any ash or other materials in the appliance.

11.6.2. Before initiating the compliance test, clean the flue and dilution tunnel with an appropriately sized wire chimney brush before each certification test. Test documentation should include the date and time of flue cleaning.

11.6.3. Record fuel weight data, temperature measurements, and gas concentrations at 1-minute intervals.

11.6.4. Wood Heater Operation and Adjustments. Record all adjustments made to the air supply controls, adjustments to and additions or subtractions of fuel, and any other changes to wood heater operations that occur during the test period.

11.6.5. The weight of fuel remaining at the end of the test run is determined as the difference between the weight of the wood heater with the remaining coals and fuel and the weight after loading the fuel charge. The starting weight is the tare weight of the cleaned, dry wood heater.

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11.6.6. All runs shall be videotaped in their entirety. Videotape shall be of sufficient quality to determine fuel characteristics, fuel loading procedures, and firebox conditions during any testing or aging conducted by the test lab. The testing lab shall have the capacity to allow appropriate agencies the opportunity to remotely witness the test.

11.6.7.L1: Start-up Phase.

11.6.7.1.L1 Appliance requirements.

11.6.7.1.1. Stove temperature: internal and external stove temperature must not be greater than the ambient temperature +/- 2.0°F (1.1°C) for Run 1. There is no stove starting temperature requirement for Runs 2 and 3 except in the case of a failed first run. In this case, if Run 1 is invalid or incomplete and, the stove must meet Run 1 conditions for at least one valid run. Temperature measurements for the external and internal temperatures shall be taken within 15 minutes before starting the test and shall be reported in the test report.

11.6.7.1.2. Tare the appliance scale before starting the test. Record appliance scale weights at the start and end of L1 phase

11.6.7.2.L1 Fuel requirements.

11.6.7.2.1.L1 Fuel type – during the startup phase newspaper (optional up to six full sheets traditional newspaper size), kindling, and starter fuel pieces are used. No other additions are allowed.

11.6.7.2.2.L1 loading density

11.6.7.2.2.1. Kindling loading density: 1 lb. per cubic foot for dry kindling, +/- 5%. The fuel load calculator determines the amount of kindling that can be used.

11.6.7.2.2.2. Starter Fuel loading density: 3 lb. per cubic foot, +/- 5%. The fuel load calculator will determine the minimum piece weight that can be used as starter fuel.

11.6.7.2.3.L1 fuel loading structure: The loading structure of the fire shall be a bottom-up configuration with newspaper on the bottom, kindling on top of the paper, and starter fuel on top of the kindling. Kindling and starter fuel shall be loaded in a crisscross configuration.

11.6.7.3.L1 Operational parameters.

11.6.7.3.1. All kindling, starter fuel, and newspaper must be in the firebox for light off.

11.6.7.3.2. Air settings are fully open.

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11.6.7.3.3.Light the fire with a torch for a period of no more than 30 seconds.

11.6.7.3.4.Immediately after lighting the fire and completing the photo requirement, the appliance door shall be moved to a cracked open position. Cracked open position is defined as opening no more than one inch. The appliance door shall be closed 5 minutes after ignition.

11.6.7.4.L1 Fuel Adjustments: up to three fuel adjustments are allowed in the startup phase. The door may be open for 30 seconds during each fuel adjustment.

11.6.7.5.L1 End of Phase – the end of the startup phase is defined by the weight specified by the fuel load calculator.

11.6.7.6.L1 ~~Photo d~~Documentation – Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed and fire when the door is closed ~~Clear, close-up pictures shall be documented with individual pictures that must be included in the test report~~ sufficient to determine fueling positioning, ~~and~~ coal bed conditions, appliance operation, and fuel charge combustion conditions, Photo of the fuel charge.

~~11.6.7.6.1.Picture(s) of the air setting before light-off~~

~~11.6.7.6.2.Picture(s) of the air setting at the end of L1 phase~~

~~11.6.7.6.3.Picture(s) fuel loaded in the stove prior to light-off~~

~~11.6.7.6.4.Picture(s) fuel just after light-off but prior to door cracked open period.~~

~~11.6.7.6.5.Picture(s) of the coal bed at the end L1 phase~~

11.6.8. ~~*L2:*~~ *High-fire Phase* – the high-fire phase commences immediately after the startup phase ends.

11.6.8.1.L2 Appliance requirements.

11.6.8.1.1.Record the weight of the stove prior to loading the L2 fuel charge, the weight of the fuel charge prior to loading, and the scale weight after loading the L2 fuel charge.

11.6.8.2. L2 Fuel requirements.

11.6.8.2.1. L2 piece size – during the high-fire phase, small cordwood pieces by weight, as defined by the fuel load calculator, are used.

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11.6.8.2.2. L2 loading density: 7 lb. per cubic foot, +/- 5%. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.8.3.L2 Operational parameters: Open the door upon completion of the startup phase and load the L2 fuel load within 60 seconds. Once the fuel has been loaded, the appliance doors shall be closed immediately. Air settings shall be left fully open. When 50% of the L2 fuel load mass has been consumed, the air settings shall be moved to the lowest settings.

11.6.8.4.L2 Fuel Adjustments.

11.6.8.4.1.One fuel adjustment shall be made during the high-fire phase prior to moving the primary air control(s) to their lowest setting. The door shall remain open for 30 seconds for fuel adjustments.

11.6.8.4.2.Additional fuel adjustments shall be made if there is a fivefive-minute period without a weight change of 0.1 pounds at any point during the high-fire phase. The door may only be open for 30 seconds for fuel adjustments.

11.6.8.4.3.All fuel adjustments must be documented in the test report notes and summary.

11.6.8.5.End of L2 Phase –The high-fire phase ends when the scale indicates that 90% of the high-fire fuel mass has been consumed.

~~11.6.8.6.~~ L2 Documentation - Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge.~~Photo documentation~~

~~11.6.8.6.1.Picture(s) of the L2 loaded into the stove with the door open and fuel loading pattern distinguishable.~~

~~11.6.8.6.2. Picture(s) of the air settings at the beginning of the L2 phase~~

~~11.6.8.6.3.Picture(s) of the air setting after 50% fuel consumption~~

~~11.6.8.6.4.Picture(s) of the air settings at the end of the L2 phase.~~

~~11.6.8.6.5.Picture(s) of the coal bed at the end of L2 phase.~~

~~11.6.8.6.6.Pictures before and after L2 fuel adjustments.~~

11.6.8.6.

Commented [LR2]: From PFS – During the High Fire phase, A fuel adjustment is required, but there does not appear to be any guidance or criteria on when is shall be done?

Commented [LR3R2]: Mandatory for research ATM /Regulatory method – modify to within, and rules for fuel adjustment.

Commented [LR4]: 11.6.8.4.2/11.6.9.4– Additional fuel adjustments shall be made if there is a [variable length of time depending on which burn cycle] period without a weight change, is a weight change defined as 0.02 lbs (specified resolution of the scale)?

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11.6.9. *L3: Maintenance-fire Phase* – the L3 maintenance-fire phase commences immediately after the L2 high-fire phase ends.

11.6.9.1.L3 Appliance Requirements.

11.6.9.1.1. Record the weight of the stove prior to loading the maintenance-fire fuel charge, the weight of the fuel charge prior to loading, and the scale weight after loading the maintenance-fire fuel charge.

11.6.9.2.L3 Fuel Requirements.

11.6.9.2.1.Fuel type – during the L3 phase, large cordwood pieces are used. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.9.2.2.L3 fuel loading structure: fuel shall be loaded in the direction specified by the fueling calculator.

11.6.9.2.3. L3 loading density: 5 lb. per cubic foot, +/- 5%. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.9.3. L3 Operational Parameters:

11.6.9.3.1.Open door upon completion of the L2 phase and load the maintenance-fire fuel charge.

11.6.9.3.2.L3 Load - L3 fuel loaded within 30 seconds of the door opening. Close the loading door immediately.

11.6.9.4. L3 Fuel Adjustments: If there is a ten~~fifteen~~-minute period without weight change (0.1 lb) at any point during the L3-fire phase, a fuel adjustment shall be made to increase the burn rate. The door may be open for up to 30 seconds for fuel adjustments. Only two fuel adjustments may be made during this phase. If after the second fuel adjustment, another period of no weight change (0.1 lb) occurs, the run ends, and it is a failed test run.

Commented [LR5]: 11.6.8.4.2/11.6.9.4– Additional fuel adjustments shall be made if there is a [variable length of time depending on which burn cycle] period without a weight change, is a weight change defined as 0.02 lbs (specified resolution of the scale)?

11.6.9.5.L3 End of Phase – The L3-fire phase ends when the scale indicates that 90% of the maintenance-fire fuel mass has been consumed.

11.6.9.6.L3 Documentation - -Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge.Photo documentation

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~~11.6.9.6.1.Picture(s) of the L3 loaded into the stove with the door open and fuel loading pattern distinguishable.~~

~~11.6.9.6.2. Picture(s) of the air settings at the beginning of the L3 phase~~

~~11.6.9.6.3.Picture(s) of the air settings at the end of the L3 phase.~~

~~11.6.9.6.4.Picture(s) of the coal bed at the end of L3 phase.~~

~~11.6.9.6.5.Pictures before and after fuel adjustments in L3.~~

11.6.10.*L4: Low burn rate phase* – L4 phase commences immediately after the L3- ends.

11.6.10.1.L4 Appliance Requirements.

11.6.10.1.1.Record the weight of the stove prior to loading the L4-fire fuel charge, the load of the fuel charge prior to loading, and the scale weight after loading the overnight-fire fuel charge. Alternatively, if the scale was zeroed prior to starting the test, record the scale weight before and after loading the overnight-fire fuel charge.

11.6.10.2.L4 Fuel requirements

11.6.10.2.1. L4 fuel type –a mix of small and large cordwood pieces are used. At least 50% of the fuel charge load, by the number of pieces, must be large pieces.

11.6.10.2.2.L4 Loading structure: fuel will be loaded in one direction.

11.6.10.2.3.L4 loading density: The fuel load calculator specifies a load volume of 12 lb/ft^3 .+/-5%. Fuel shall be loaded in a manner to maximize the number of pieces that will fit in the stove without using force.

11.6.10.3. L4 Operational Parameters:

11.6.10.3.1. Open the loading door upon completion of the L3 maintenance-fire phase.

11.6.10.3.2.Load the L4 fuel charge within two minutes (120 seconds).

11.6.10.3.3.Keep the door in the 1" cracked position for five minutes from the beginning of the L4 phase.

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11.6.10.3.4.Air controls shall be placed in the fully open position for the first ten minutes of the phase.

11.6.10.4.L4 Fuel Adjustments.

11.6.10.4.1.Unlimited fuel adjustments are allowed within the first five minutes of the phase. After ten minutes, air control(s) shall be moved to their lowest position. A picture of the air setting used must be included in the test report. The door may be open for up to 30 seconds for fuel adjustments.

11.6.10.4.2.If there is a ten-minute period without weight change (0.1 lb) during the first hour of the L4-phase, a fuel adjustment shall be made. The door may be open for up to 30 seconds for fuel adjustments.

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Commented [LR6]: 11.6.8.4.2/11.6.9.4– Additional fuel adjustments shall be made if there is a [variable length of time depending on which burn cycle] period without a weight change, is a weight change defined as 0.02 lbs (specified resolution of the scale)?

11.6.10.4.3.Only two fuel adjustments may be made during the first hour. If after the second fuel adjustment, another periods of no weight change (0.1 lb) is observed, the run ends, and it is a failed test run.

11.6.10.4.4.No fuel adjustments are allowed after the first hour of the phase.

11.6.10.4.5.If there is no weight change for a consecutive period of 20 minutes at any point after the first hour of the phase, the unit has failed the test run.

~~11.6.10.4.1.~~

11.6.10.5.L4 End of Phase – The L4 phase shall end when the scale indicates that 90% of the total L4 fuel mass has been consumed. If the fuel load does not burn to 90%, it is a failed test run.

~~11.6.10.6.~~ L4 Documentation - ~~L3 Photo documentation~~

~~11.6.10.6.1.Picture(s) of the L4 loaded into the stove with the door open and fuel loading pattern distinguishable.~~

~~11.6.10.6.2. Picture(s) of the air settings at the beginning of the L4 phase~~

~~11.6.10.6.3.Picture(s) of the air settings at the end of the L4 phase.~~

~~11.6.10.6.4.Picture(s) of the coal bed at the end of L4 phase.~~

~~11.6.10.6.5.Pictures before and after fuel adjustments in L4.~~

~~11.6.10.7.~~11.6.10.6.~~L4 Photo documentation~~Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed and fire when the door is

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closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge.

11.7. Test Run. A complete test run requires completion of all four burn phases and loads. For any appliance that will not accommodate the loading arrangement specified in this test method, the test facility personnel shall contact the Agency Administrator to obtain written approval for an alternative loading arrangement:

11.8. Test Run Requirements. The following describes the required parameters for each test run. Each emission test run shall include all phases of the operational and fueling protocol run in order as described.

11.8.1. Consecutive Test Runs. Consecutive test runs may be conducted, provided that the following requirements are met:

11.8.1.1. Run 1 – The appliance shall have an internal and external starting temperature within +/- 2 °F (1.1°C) of laboratory ambient temperature at the beginning of Run 1

11.8.1.2. Run 2 – The second test run may commence 24 hours after the start of Run 1. Stove coals and ash can remain in the stove until 1 hour before conducting Run 2. All coals and ash shall be removed at least one hour prior to commencing Run 2.

11.8.1.3. Run 3 – The third test run may commence 24 hours after the start of Run 2. Stove coals and ash may remain in the stove until 1 hour before conducting Run 3. All coals and ash shall be removed at least one hour prior to commencing Run 2.

11.9. *Failure to Operate at All Test Conditions*

11.9.1. If the appliance fails two runs due to incomplete or failed test runs, it shall be determined that the appliance has failed the certification test and requires a modification to appliance design. All data for incomplete runs shall be reported. Incomplete failed test runs are defined as the following:

11.9.1.1. If a wood heater fails to complete all four phases of the test run, the run shall be considered an incomplete ~~failed~~ test run.

11.9.1.2. If there is no weight change for a consecutive period of ~~30~~20 minutes at any point during the test, the unit has failed the test run.

11.9.1.3. If the wood heater fails to comply with test protocol parameters

11.9.2. If a test run violates the parameters of the test method, the run is invalid.

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11.9.3. If during certification testing a critical component of the stove is damaged or breaks, the certification test will be stopped and considered invalid.

11.9.3.1. If damage is noted during a test, repairs shall be made by the manufacturer (or by laboratory personnel with written direction from the manufacturer). If the repair involves components that require~~would need~~ aging, the appliance shall then undergo another round of wood heater aging as specified in section 10.6. ~~These c~~Components requiring aging shall~~may~~ include but are not limited to catalyst elements, gaskets, and refractory components. Manufacturers have the option of aging these elements in other prototypes. The aging process is intended not only to 'cure' the stove but also to cycle parts that may fail with extended use. Alternate aging techniques may be approved by the administrator, depending on the nature of the failure, material, and critical nature.

11.10. Test Run Completion. Once three valid runs have been completed, the testing is complete. No additional runs may be completed.

11.10.1. *Additional Test Runs*. If there is an invalid run, may attempt two additional runs to complete the test series. If more than three test runs are conducted, the results from all valid test runs shall be used in calculating the average emission rate. The measurement data and results of all test runs shall be reported regardless of which values are used in calculating the emission rate. No test run data can be eliminated from the reporting requirements of this method.

11.10.2. *Invalid Runs*. When a test run fails to meet one of the QA/QC criteria stipulated in the test method, the data are invalid and the run must be repeated. Data for the invalidated test run must be included in the test report but the data must not be used in calculation of average emission values.

11.10.3. *Incomplete Runs*. When an appliance cannot successfully complete all operational elements of the protocol specified in Section 11.6.7 through 11.6.10, it is an incomplete run.

~~11.10.1.~~

11.11. Auxiliary Wood Heater Equipment Operation. If optional heat exchange blowers are sold for use with the wood heater, three runs with~~out~~ the fan and an additional run without the fan shall be completed. If emissions are more than 1 gram per higher with the fan on, an additional two runs must be completed with the fan on. Heat exchange blowers shall operate in the highest airflow setting. (Automatically operated blowers shall be operated as designed) during the entire test.

11.12. PM Data Recording.

11.13. All data shall be collected and recorded at intervals of no more than 1 minute. TEOM data shall be averaged up to 1-minute intervals for reporting. TEOM operation shall follow the procedures listed in NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

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11.13.1. Data shall be reported in an Excel or compatible spreadsheet following the minimum data reporting requirements. All electronic files, including raw instrument data, shall be submitted as part of the test report. Spreadsheet files shall be supplied as part of the publicly available test report.

11.13.2. Room PM measurement – TEOM. A single channel TEOM shall be used to measure ambient lab air PM during the test, as configured in NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel. The sample flow shall be 32 LPM.

Commented [LR7]: What is the purpose of using a TEOM monitor lab ambient air? A far as I can tell it is not used to back out dilution tunnel results?

12. Quality Control Measures

12.1. Dilution tunnel - Conduct sampling equipment leak check and calibration pre- and post-test.

12.2. TEOM – Flow and Leak checks are done before and after every test run per NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel. Additional quality control measures are included in the TEOM Operating Procedure.

12.3. Volume Metering System Checks.

13. Data Analysis and Calculations. –

13.1. Emission Calculations. Particulate matter, carbon dioxide, and carbon monoxide shall be calculated using the following methodology and reported in grams per hour, grams per kilogram and pounds per million British Thermal Unit (BTU) heat output. All calculations shall be conducted using all decimal values provided by the instrumentation or recorded by the operator. No truncation of data is acceptable. Only the final calculation of the PM emissions rate shall be rounded, to three significant figures.

13.2. TEOM data shall be reported as follows.

13.2.1. TEOM concentration data and tunnel flow are used to calculate PM emission rates in g/h at 1-minute intervals as follows, where net PM is tunnel PM – lab air PM.

g/h = 0.000001699 * (tunnel flow in wet CFM) * (net PM concentration in µg/m3)

Commented [GA8]: [SEQ CHAPTER \h \r 1]10^{-6} ug/g * .02832 m^3/ft^3 *60 min/h = 1.699 * 10^{-6}

The values used for tunnel flow must be the actual (wet) values, measured at intervals of no greater than 10 minutes, except as follows. If the range of 10 minute tunnel flow measurements (100*(Max - Min) / average) is no greater than 5.0% of the run-average tunnel flow, the run average tunnel flow can be used for these calculations.

13.2.2. For calculation of lbs/mmBtu and grams/kg, total grams PM emitted is calculated by multiplying the average g/h rate for the test period of interest times the duration (in hours) of that test period. Grams are converted to lbs by dividing grams by 453.6.

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13.2.3. Emissions from each of the 4 phases of the test shall be reported as individual results in grams per hour, grams per kilogram, and lb/MMBtu (heat output), and include % data capture for each phase.

13.2.4. Emissions from the entire test run in grams per hour, grams per kilogram, and lb/MMBtu (heat output), including % data capture for the entire test run.

~~13.2.1. Emissions from each of the 4 phases of the test shall be reported as individual results in grams per hour, grams per kilogram, and lb/MMBtu (heat output).~~

~~Emissions from the entire test run in grams per hour, grams per kilogram, and lb/MMBtu (heat output).~~

Nomenclature

AER = Ei/∑N
BR – average dry fuel burn rate, lb./min
$BR_{(x)}$ – Burn rate for specific phase, BR_{L1}, BR_{L2}, BR_{L3}, BR_{L4}
CO – Carbon Monoxide
CO_2 – Carbon Dioxide
H_2- Hydrogen
O_2 – Oxygen
BT = time of 90% of overnight load consumed – time of overnight loading
C_{steel} – Specific heat of steel (0.1 Btu/ lb., ˚F)
E_T – Total particulate emissions for the full test run in grams
$E_{g/MJ}$ – PM Emissions rate in grams per megajoule of heat output
$E_{g/kg}$ – PM Emissions factor in grams per kilogram of dry fuel burned
$E_{g/hr}$ – PM Emissions factor in grams per hour
E_{Rco} – CO emission rate, g/hr.
EIi – Average CO emission index for interval i
E_{ICO} – CO emission index, g/kg dry fuel
EIco,avg – Average CO emission index for the run
HHV – Higher heating value of fuel = Use accredited test results
LHV – Lower heating value of fuel = Use accredited test results
$\%M_d$ = Fuel moisture content, dry basis, percent.
$\%M_w$ = Average moisture in test fuel charge, wet basis, percent
N = Total number of test runs.
PCTCO2– average CO_2 in the dry flue gas (%)
PPMco -average CO in the dry flue gas (ppm)
Q_{out} – Total heat output in BTU's (megajoules)
SC_i – Scale weight at specific time interval, lb.
$t_{(i)}$ – Data sampling interval in minutes
T1 – Surface Temperature 1 ˚F (˚C)

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T2 – Surface Temperature 2 ˚F (˚C)
T3 – Surface Temperature 3 ˚F (˚C)
T4 – Surface Temperature 4 ˚F (˚C)
T5 – Surface Temperature 5 ˚F (˚C)
T6 – Pre Catalyst Temperature 1 ˚F (˚C)
T7 – Post Catalyst Temperature 2 ˚F (˚C)
T8 – Tunnel Temperature ˚F (˚C)
T9 - Flue Gas Temperature ˚F (˚C)
T10 – Room Temperature ˚F (˚C)
$TS_{avg(i)}$ – Initial Average Surface Temperature ˚F (˚C)
$TS_{avg(f)}$ – Final Average Surface Temperature ˚F (˚C)
W_{fuel} – Fuel charge weight in pounds (kg)
W_i – Weight of fuel in pounds (kg)
W_{app} – Weight of empty appliance in pounds (kg)
Θ – Total length of test run, hours
$\Theta_{(x)}$ – Total length of test run in hours per phase, X
$\%M_w = 100(\%M_d)/100+\%M_d$

13.3. Average Wood Heater Surface Temperatures. Calculate the average of the wood heater surface temperatures at the start of the phase (L4) and end at the end of the test (L4) of the test run.
L4 $TS_{avg(i)}$ - (T1 + T2 + T3 + T4 + T5) / 5
L4 $TS_{avg(f)}$ - (T1 + T2 + T3 + T4 + T5) / 5
Average surface temperatures at the start and end of any phase can be determined by averaging all five sensors at the beginning and end of each phase.
L_x $TS_{avg(i)}$ - (T1 + T2 + T3 + T4 + T5) / 5
L_x $TS_{avg(f)}$ - (T1 + T2 + T3 + T4 + T5) / 5

13.4. Burn Time Rating– A standardized burn time rating shall be determined by rounding the duration of the overnight-fire phase of the test up to the nearest 1 hour. Burn time shall be calculated as the time L4 is loaded into the stove until 90% of the fuel has been consumed. This provides an important rating for consumers and is not intended for any calculation purposes and shall be reported on the all manufacturers materials that provides specifications on appliance performance. Language such as "this stove has demonstrated a low setting burn time of x hours in official testing"

13.5. Determine Burn Rates

BR_{L1} = not applicable
BR_{L2} = (L2 Initial SC_i – L2 Final SC_i) / $\Theta_{(L2)}$, lbs./hr
BR_{L3} = (L3 Initial SC_i – L3 Final SC_i) / $\Theta_{(L3)}$, lbs./hr
BR_{L4} = (L4 Initial SC_i – L4 Final SC_i) / $\Theta_{(L4)}$, lbs./hr

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13.6. Emissions

13.6.1. Determine emission rates and emission factors as:

$E_{g/MJ} = E_T/(Q_{out} \times 0.001055)$, g/MJ

$E_{g/kg} = E_T/(W_{fuel}/(1+M\%M_d/100))$, g/dry kg

$E_{g/hr} = E_T/\Theta$, g/hr

13.7. Efficiency calculation.

Ultimate Analysis of dry fuel (% by weight)

Carbon – CA
Hydrogen – HY
Oxygen – OX
Moisture Content – mass of water per mass of dry fuel – Mcdb
Ambient Humidity Ratio – mass of water per unit mass of dry air – ω
Flue gas temperature (F) – Ts
Room temperature (F)-Tr
CO in the dry flue gas (ppm) – PPMco
CO2 in the dry flue gas (%) – PCTCO2
Higher heating value of the dry fuel (lb/MMBtu) – HHV

<u>Combustion Balance Equation:</u>

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

Where:

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4] excess air parameter, e.g. if [EMBED Equation.DSMT4] 0.5 there is 50 % excess air

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[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

With flue gas CO and CO_2 measured, these two equations can be solved simultaneously for [EMBED Equation.DSMT4] and [EMBED Equation.DSMT4].

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

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Calculation of the Molar Coefficient for Each of the Products

For the assumption of 100 kg of dry fuel, this is the number of moles of each product for the input conditions

[EMBED Equation.DSMT4] Molar Coefficient for CO

[EMBED Equation.DSMT4] Molar Coefficient for CO_2

[EMBED Equation.DSMT4] Molar Coefficient for H_2O

[EMBED Equation.DSMT4] Molar Coefficient for O_2

[EMBED Equation.DSMT4] Molar Coefficient for N_2

Heat Capacity of Exhaust Products

The general equation for representing how the heat capacity of the exhaust products varies with temperature is:

[EMBED Equation.DSMT4]

Where:

C = heat capacity J/mol K or kJ/kgmol K

A and B are constants

Tk = Temperature in °K

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The values for A and B for the exhaust components are provided in the table below

Component	A	B
CO	.0056	27.162
CO2	.029	29.54
H2O	.0057	32.859
O2	.009	26.782
N2	.0062	26.626

For each component, heat capacity is calculated at the stack temperature and at room temperature. The average of these is used to calculate sensible heat loss.

Calculation of Heat Losses for Efficiency Determination

[EMBED Equation.DSMT4] Higher heating value in kJ/kg (conversion from Btu/lb)

[EMBED Equation.DSMT4] Latent heat of water vapor in kJ/kgmol

[EMBED Equation.DSMT4] Heat loss in latent heat of water vapor, % of input energy

[EMBED Equation.DSMT4] Heat loss in chemical energy in CO, % of input energy

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4] Heat loss in sensible heat in flue gas, % of input energy

[EMBED Equation.DSMT4] Stack loss efficiency, %

14. Reporting Requirements. The report shall include the following:

14.1.1. Introduction

14.1.2. Purpose of test: certification, audit, efficiency,

14.1.3. Name and location of the laboratory conducting the test.

14.1.4. Wood appliance identification – manufacturer, model number/name, design type, description of the appliance tested, stove condition, and date of receipt.

14.1.5. Test information – location of testing, date of tests, sampling methods used, number of test runs, a statement detailing any previous certification testing completed on the wood appliance.

14.1.6. A list of people who conducted research on the appliance, participated in testing preparation, or

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witnessed the certification testing. This list shall clearly specify their roles in the testing program for the appliance. The list shall include the participant's name, title, company, contact information and the purpose of their participation.

14.1.7. A statement that the test results apply only to the specific appliance tested.

14.2. Summary and Discussion of Results

14.2.1. Table of results to include test run number, average burn rate for entire run and each phase, carbon monoxide and particulate emission rate for full run, particulate and carbon monoxide emission rate for each load phase (L1, L2, L3, L4), efficiency for the full run and each phase, burn time for total run and each phase.

14.2.2. For each test run use the TEOM data and use real-time gas analyzer data for other emissions to report: Θ_1,Θ_2, Θ_3, CO, CO_2, PM, and efficiency for (1) L1 - the startup phase and (2) L2 - high-, (3) L3-maintenance-, and (4) L5 low burn rate fire phases. Calculated results for the emissions shall be reported as total emissions in grams, pounds per million Btu output, grams per MJ, grams per kilogram of dry fuel and grams per hour, and pounds per hour.

14.2.3. A narrative discussion detailing any issues or anomalies that arose during each test run and how those were handled, including comments about the fuel, and loading of the appliance.

14.2.4. A plot of CO emission rate in ppm vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.5. A plot of CO_2 emission rate in ppm vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.6. A plot of PM emission rate in grams/hour vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.7. A plot of PM emission rate in g/kg vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.8. Summary of other data – test facility conditions, surface temperature averages, catalyst temperature averages, pretest fuel weights, test fuel charge weights – total and by phase.

14.3. Discussion. Test run result, specific test run problems and solutions. Comments on fuel, loading, analysis, and anything that may impact the reported result(s).

14.3.1. Details of deviations from, additions to or exclusions from the test method, and their data quality implications on the test results (if any), as well as information on specific test conditions, such as environmental conditions. An explanation of the deviations, additions, or exclusions shall be provided along with an analysis as to why these elements had no impact.

14.4. Process description:

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14.4.1. Data and drawings indicating the firebox size and location of the fuel charge.

14.4.2. Drawings and calculations used to determine firebox volume to include volume, height, width, and lengths, weight, and volume adjustments.

14.4.3. Firebox configuration – At a minimum to include air supply locations and operation, air supply introduction location, refractory location and dimensions, catalyst location, baffle and by-pass location and operation (include line drawings or photographs)

14.4.4. Appliance operation during the test – shall supply details on air supply settings and adjustments.

14.5. Test fuel properties – the report shall provide information on the species, density, fuel moisture, fuel temperature, and load details from the fuel load calculator to include all measurements including the number of pieces, individual piece weights, piece length, moisture content and weight.

14.6. Sampling

14.6.1. A description of the test procedures and test equipment, including a schematic or other drawing showing the location of all required test equipment. Also, a description of test fuel sourcing, handling and storage practices shall be included.

14.6.2. Describe the sampling location relative to the wood heater, include drawing or photographs.

~~14.6.3. Provide data on sampling blanks.~~

14.7. Quality Control and Assurance Procedures

14.7.1. Calibration procedures and results certification procedures, sample and analysis procedures.

14.7.2. Test method quality control procedures to include TEOM leak and flow checks, stratification (velocity) checks, tunnel flow range results, filter temperature range verification and dilution tunnel RH verification.

14.8. Appendices

14.8.1. Results and Example Calculations. Raw data and complete calculations for data included in summary tables.

14.8.2. Raw data. Copies of all files or sheets for sampling measurement, temperature records, and other materials used by lab related to testing.

14.8.3. Calibration Results. Summary of all calibrations, check, and audits pertinent to the certification.

14.8.4. Sampling and Operation Records. Copies of all uncorrected records of activities not included in raw data sheets (e.g., wood heater door open, times and durations) as well as photographs of fuel loading and air flow settings.

14.8.5. Correspondence. Any correspondence to include written, electronic or verbal communications regarding appliance testing. Items shall include:

14.8.5.1. Request to conduct testing

14.8.5.2. Scheduling of testing

14.8.5.3. Notice to EPA to conduct test, and any modifications to that request.

14.8.5.4. Notice and submission of data to EPA after testing completed.

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14.8.6. Test Facility Information. Report test facility temperature, air velocity, and humidity information.

14.8.7. Test Equipment Calibration and Audit Information. Report calibration and audit results for the platform scale, test fuel balance, test fuel moisture meter, and sampling equipment including volume metering systems and gaseous analyzers.

14.8.8. Pretest procedures. Report all pretest procedures conducted at the lab on the appliance to burns, rates, and amounts.

14.8.9. All required data for each test run shall be provided in spreadsheet format both in the printed report and in a computer file such that the data can be easily analyzed and calculations easily verified. Formulas used for all calculations shall be accessible for review.

14.8.10. For each test run: report~~t~~ 1-minute TEOM data per the parameter list in the TEOM SOP TEOM flow and temperature and verification of all TEOM data validation parameters as required in NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

14.8.11. Raw data, calibration records, and other relevant documentation shall be retained by the laboratory for a minimum of 7 years.

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Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 2/3/2021 9:21:36 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]; Toney, Mike [Toney.Mike@epa.gov]; Brashear, Angelina [Brashear.Angelina@epa.gov]
Subject: revised protocol
Attachments: NYSERDA IDC Protocol for Wood Stoves draft version for research protocol 2_3_21.docx; NYSERDA IDC Protocol for Wood Stoves draft version for research protocol 2_3_21clean.docx

Hi Stef, attached to this email is a revised protocol (one with track changes, one clean) based on our conversations last week for the research program effort. ATM version will have similar changes. Can you please review and confirm these reflect previous week's discussion?

Lisa

NESCAUM

Lisa Rector, Policy and Program Director at **NESCAUM**
89 South Street, Suite 602, Boston, Massachusetts, 02111 | 802.899.5306| 617.259.2095 | Fax: 617.742.9162
| lrector@nescaum.org

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Integrated Duty Cycle Test Method for Certification of Wood-Fired Stoves Using Cordwood: Measurement of Particulate Matter (PM) and Carbon Monoxide (CO) Emissions and Heating Efficiency

Note: This method does not include all the specifications (e.g. equipment and supplies) and procedures (e.g., sample and analytical) essential to its performance. Some material is incorporated by reference from other methods. Therefore, to obtain reliable results, persons using this method shall have a thorough knowledge of at least the following EPA Tests

- Method 1- Sample and Velocity Traverses for Stationary Sources
- Method 2- Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot

Tube)

- Method 3 – Gas Analysis for the Determination of Dry Molecular Weight
- Method 4 – Determination of Moisture Content in Stack Gases
- Method 5G – Determination of Particulate Matter from Wood Heaters (Dilution Tunnel Sampling Location)
- Method 10 - Carbon Monoxide - Instrumental Analyzer
- Method 28 – Certification and Auditing if Wood Heaters

1. Scope and Application

1.1. This test method specifies operation and fueling for certification and auditing of manually operated wood-fired stoves and heaters.

1.2. This test method measures particulate matter (PM) emissions, carbon monoxide, and efficiency.

1.3. Particulate emissions are measured by the dilution tunnel method as specified in ASTM E2515 Standard Test Method for Determination of Particulate Matter Emissions Collected in a Dilution Tunnel using only Emfab Pallflex filters. Additional particulate matter emissions measurements may also use the Tapered Element Oscillating Microbalance (TEOM) continuous PM method, as detailed in this test method.

1.4. Analyte. Particulate matter (PM). No CAS number assigned. Carbon monoxide (CO). No CAS number assigned.

1.5. Applicability. This method is applicable for the certification and auditing of wood space heaters, which burn cordwood fuel. The test quantifies PM and CO emissions and provides overall efficiency ratings, maximum burn time, and heat output.

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1.6. Data Quality Objectives. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods

1.7. Distinguishing features of appliances covered by this standard include:

1.7.1. Cordwood fuel is hand-fed into firebox.

1.7.2. A chimney or vent that exhausts combustion products from the appliance.

1.8. The values stated are to be regarded as the standard, whether in I-P or SI units. The values given in parentheses are for information only.

1.9. Data Quality Objectives.

1.9.1. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods.

1.9.2. Measurement of emissions and heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

1.9.3. This is a laboratory method intended to capture operating periods that are representative of actual field use without excessive test burden.

2. *Referenced Methods*

2.1. NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel

2.2. ASTM 2515: Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel.

3. *Definitions*

3.1. Appliance – a wood heater capable of and intended for space heating defined in the applicable regulation. The appliance includes combustion chamber, combustion air settings, operating controls, and a thermostat if specified, and any other accessory required for standard operation, such as a barometric damper,

3.2. Catch - any mass from the sample probe system on the filter.

3.3. Certification or audit test - a series of at least three test runs conducted for certification or audit purposes that meets the specifications detailed in this protocol.

3.4. Chop – using a poker or another piece of wood to strike a piece of the fuel charge to break it into smaller pieces.

3.5. Coal-bed Stirring – prior to adding a new fuel charge, using a poker or piece of wood to stir or level the coal bed of the appliance for the sole purpose of ensuring ease of loading of the fuel

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charge. No special formations can be made, such as creating coal bed formations or pushing coals to one side or creating slopes with the coals.

3.6. East-west stove – a stove where the firebox dimension parallel to the loading door is greater or equal to the stove depth measurement. Logs are loaded so that they are viewed on the long length of the stove.

3.7. Emission factor – the emission of a pollutant expressed in mass per unit of energy (typically) output from the appliance.

3.8. Firebox - the portion of the chamber in the wood heater in which the test fuel charge is placed and combusted.

3.9. Firebox depth - the horizontal length of the fire chamber dimension measured perpendicular to the loading door. If the manufacturer believes that a portion of the firebox depth is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.10. Firebox Height - the vertical distance extending above the top of the firebox to the floor of the firebox. Firebox height is not necessarily uniform. The measurement must account for variations caused by internal baffles, air channels, or other permanent obstructions. If the manufacturer believes that a portion of the firebox height is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.11. Firebox width - the horizontal fire chamber dimension that is parallel to the loading door. If the manufacturer believes that a portion of the firebox width is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.12. Fuel Adjustment –manipulations to the fuel charge to reflect typical owner practices that allow the cordwood fuel to burn appropriately during the test period. A fuel adjustment does not include chopping the wood or stirring the coal bed.

3.13. Fuel load calculator – The locked excel spreadsheet tool that determines the allowable test fuel load weights and required piece sizes for each individual load.

3.14. Fuel loading direction – Fuel shall be loaded parallel to the greater of the width and depth dimensions for loads 2, 3 and 4. Criss-cross is allowed for startup phase and cannot be used as a load configuration for loads 2, 3 or 4. If the firebox length and width are within 2" fuel shall be loaded in an east/west fashion, parallel to the loading door.

3.15. Kindling pieces – small pieces of wood less than 1" in diameter. No bark or moisture requirements for these pieces, however kindling pieces shall not be dried or stored anywhere but in laboratory ambient conditions. Kindling length shall be of the same as the fuel charge length. and shall represent weights that would enable 8 to 12 pieces equal one pound.

3.16. Large fuel pieces – pieces that are larger for the appliance as defined by the fuel load calculator.

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3.17. L1 – Start-up – period of the test when the unit has kindling and startup fuel under the conditions described in Section 11.6.7.

3.18. L2 – High-fire Phase – period of the test when the unit has a small coal bed and the stoves air settings are fully open. Intended to replicate period when homeowners are trying to quickly heat an area, shortly after starting or restarting the appliance.

3.19. L3 - Maintenance-fire phase– period of the test when a fire is maintained with a medium-sized coal bed, and a smaller batch of wood. This is intended to simulate a period when the operator is trying to maintain consistent heat output.

3.20. L4 - Low-burn Rate Phase – period of the test when the stove has a large coal bed, stove is fully loaded, and the adjustable air settings are set to produce the lowest possible burn rate and have the lowest air settings. Intended to simulate a period the operator is trying to maintain heat over a long period of time, such as overnight or while away for significant periods of time.

3.21. North-south stove: a firebox which has its longest dimension measurement perpendicular to the loading door. In this stove type, logs are loaded so that the ends of the fuel are viewed when loaded.

3.22. Phase – A distinct period in the test run with its own operational procedures and conditions.

3.23. Primary air supply – air supply that introduces air to the wood heater in the combustion chamber and is adjusted to target a desired burn rate. The wood heater manufacturer or test facility can document this through design drawings.

3.24. Secondary air supply - air supply that introduces air to the wood heater such that the burn rate is not altered by more than 10 percent when the secondary air supply is adjusted during the test run. The wood heater manufacturer or test facility can document this through design drawings that show the secondary air is introduced only into a mixing chamber or secondary chamber outside the firebox.

3.25. Small fuel pieces - pieces that are small for the appliance as defined by the fuel load calculator.

3.26. Starter fuel – pieces of cordwood that can be smaller than small and large pieces but larger than kindling, as defined by the fuel load calculator.

3.27. Test data– means the data for all test runs conducted on the wood heater, including any data collected during failed and invalid runs and includes records of preparation of standards, identification of equipment used and personnel present, records of calibrations, raw data sheets for field sampling, raw data sheets for field and laboratory analyses, chain-of-custody documentation, and example calculations for reported results.

3.28. Test facility - the area in which the wood heater is installed, operated, and sampled for emissions.

3.29. Test fuel charge - the collection of test fuel pieces used in each of the four phases of the test run. L2, L3, and L4 require that at least 50% of the individual pieces with at least 80% bark on one side of the fuel piece. Bark shall not be removed for certification testing. Any fuel charge that

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suggests bark was purposely removed or shaped shall deem the certification test invalid. Examples of fuel piece manipulation are provided in Section 11

3.30. Test fuel load – the group of test fuel pieces that are loaded, as specified by phase, throughout the test run. Test fuel loading means the arrangement of the test fuel charge.

3.31. Test fuel loading density - the calculation that determines the weight of the as-fired test fuel load. The calculation is based on the usable volume of the firebox.

3.32. Test run - an individual emission test that includes the four operational phases required by the fueling protocol.

3.33. Usable firebox volume - the calculated volume of the firebox determined using its height, width, and depth as defined in this section. This calculation represents the area where wood is likely to be loaded. If the manufacturer claims that portions of the firebox may not be used in the calculation a justification must be submitted with the test report. If the justification is not approved, the test results will be deemed unrepresentative for certification purposes. It is highly recommended that manufacturers obtain regulatory approval if making claims that portions of the firebox are not appropriate for inclusion in the calculation.

3.34. Wood heater - an enclosed, wood-burning appliance capable of and intended for space heating or domestic water heating, as defined in the applicable regulation.

4. Interferences

None.

5. Summary of Method

5.1. Particulate matter emissions are measured from a wood heater burning cordwood test fuel in a test facility maintained at a set of prescribed ambient conditions. Procedures for operating the appliance, measuring PM and CO emission rates, and methods for reducing data and calculating results are provided.

5.2. *Dilution Tunnel.* A dilution tunnel following the specifications detailed in ASTM E2515-11 shall be used for particulate measurements.

5.3. *Particulate Matter:* PM emissions are measured in a dilution tunnel with a Thermo model 1405-D 2-channel TEOM using NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel with a dilution tunnel as specified in ASTM 2515 with modifications discussed in Section 10.

5.4. *Carbon Monoxide*. The CO measured in the stack and is used to calculate efficiency determination.

5.5. *Operation*. Appliance operation is conducted on a cold-to-hot test cycle, meaning that the appliance starts the first test run at room temperature and ends with the appliance in fully heated

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state. The second and third test runs are started a slightly warmer temperature. The appliance is operated at a variety of operational phases representing start-up emissions, high heat demand, low heat demand, and refueling. The appliance is operated through four phases. To complete the certification test, a minimum of three full test runs are averaged to determine the test results.

5.6. *Repeatability.* A series of at least three test runs comprised of six different heat demands or phases conducted for certification or audit purposes

6. Significance and Use

6.1. The measurement of particulate matter emission rates is an important test method widely used in the practice of air pollution control.

6.1.1. These measurements, when approved by state or federal agencies, are often required for the purpose of determining compliance with regulations and statutes.

6.1.2. The measurements made before and after design modifications are necessary to demonstrate the effectiveness of design changes in reducing emissions and make this standard an important tool in manufacturers' research and development programs.

6.2. Measurement of heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

7. Safety

7.1. Disclaimer. This method may involve hazardous materials, operations, and equipment. This test method may not address all the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to performing this test method.

7.2. These tests involve combustion of wood, which releases substantial amounts of heat and combustion products. The heating system also produces large quantities of very hot water and the potential for steam production and system pressurization. Appropriate precautions must be taken to protect personnel from burn hazards and respiration of products of combustion. Exposure of personnel to unsafe levels of carbon monoxide must be avoided, and the use of continuous ambient carbon monoxide monitoring is strongly recommended.

8. Equipment and Supplies. The following items are required for sample collection:

8.1. Anemometer. A device capable of detecting air velocities less than 0.10 m/sec (20 ft/min), for measuring air velocities near the test appliance.

8.2. Appliance Flue.

8.2.1. Steel flue pipe extending to 8.5 ±0.5 ft. (2.6 ±0.15 m) above the top of the platform scale, and above this level, insulated solid pack type chimney extending to 15 ±1 ft (4.6 ±0.3 m) above the

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platform scale, and of the size specified by the appliance manufacturer. This applies to both freestanding and inserts type appliances.

8.2.2. Other chimney types (e.g., solid pack insulated pipe) may be used in place of the steel flue pipe if the appliance manufacturer's written appliance specifications require such chimney for home installation (e.g., zero clearance appliance inserts). Such alternative chimney or flue pipe must remain and be sealed with the appliance following the certification test.

8.2.3. Solid pack insulated chimneys shall have a minimum of 2.5 cm (1 in.) solid-pack insulating material surrounding the entire flue and possess a label demonstrating conformance to U.L. 103 (incorporated by reference—see §60.17).

8.3. Appliance Platform Scale and Monitor. For monitoring of fuel load weight change. The scale shall be capable of measuring weight to within 0.01 kg (0.02 lb.) and calibrated to NIST traceable standards at least annually.

8.4. Barometer. Aneroid or another barometer capable of measuring atmospheric pressure to within 0.1 in. Hg (2.5 mm Hg) with an uncertainty of +/- 0.05 in Hg (+/- 1.27 mm Hg).

8.5. Dilution Tunnel must meet the requirements of ASTM E2515, clauses 6.1.6 and 9.2.

8.6. Dilution Tunnel temperature and relative humidity measurement. A probe capable of measuring tunnel temperature to within 0.9 °F (0.5 °C)) and tunnel RH to within 2%, such as the Omega HX85-A or equivalent.

8.7. Draft Gauge. Electromanometer or other devices for the determination of flue draft or static pressure readable to within 0.005 in. H2O (1.2 Pa)

8.8. Flue Gas Temperature Measurement. A type K- thermocouple or equivalent located in the centroid of the stack located 8.0 +/- 0.5 ft (2.44 m +/- 150 mm) above the platform scale. Capable of measuring with an accuracy of 4.0°F (2.2°C) or 0.75% of reading, whichever is greater.

8.9. Flue Gas Composition Measurement. A sample probe and continuous infrared analyzer or equivalent capable of measuring span of carbon monoxide (CO) and carbon dioxide (CO_2) in the flue gas produced by the appliance tested. Continuous analyzers (or equivalent) shall have maximum zero and span drift, over a 24 h period, of 1% of full scale

8.10. Fuel Scale. Balance capable of weighing the test fuel charge to within 0.02 kg (0.05 lb.) and calibrated to NIST traceable standards at least annually.

8.11. Humidity Gauge. Psychrometer or hygrometer for measuring room humidity to within +/- 4% from 25 to 95% RH.

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8.12. Moisture Meter. Calibrated electrical resistance meter for measuring test fuel moisture to within 2 percent moisture content.

8.13. Surface Temperatures. Capable of measuring temperature to within 1.5 percent of expected absolute temperatures with an accuracy of 4.0˚F (2.2˚C) or 0.75% of reading, whichever is greater.

8.14. Test Facility Temperature Monitor. A thermistor, RTD, or other equivalent device, located centrally in a vertically oriented 150 mm (6 in.) long, 50 mm (2 in.) diameter pipe shield that is open at both ends, capable of measuring temperature to within 1˚F of expected temperatures.

8.15. TEOM – Thermo Fisher Scientific TEOM model 1405-D (Thermo part # 1405D-ANF, excluding models 1405, 1405-DF, or 1405-F) to measure and report continuous particulate matter (PM) measurements in an ASTM 2515 dilution tunnel or equivalent dilution method, and operated according to the NESCAUM Dichot TEOM Standard Operating Procedures.

9. Calibration and Standardizations

9.1. Anemometer. Calibrate the anemometer as specified by the manufacturer's instructions before the first certification test and monthly thereafter.

9.2. Appliance Platform Scale. Perform a multi-point calibration (at least five points spanning the operational range) of the platform scale before its initial use. The scale manufacturer's calibration results are sufficient for this purpose. Before each certification test, audit the scale with the wood heater in place by weighing at least one calibration weight (Class F) that corresponds to between 20 percent and 80 percent of the expected test fuel charge weight. If the scale cannot reproduce the value of the calibration weight within 0.0045 kg (0.01 lb.) or 1 percent of the expected test fuel charge weight, whichever is greater, recalibrate the scale before use with at least five calibration weights spanning the operational range of the scale.

9.3. Barometer. Calibrate using a reference pressure monitor calibrator before the first certification test and semiannually after

9.4. Draft Gauge. Calibrate as per the manufacturer's instructions; a liquid manometer does not require calibration (but must be properly leveled, zeroed and the system leak checked).

9.5. Humidity Gauge. Calibrate as per the manufacturer's instructions before the first certification test and annually thereafter.

9.6. Fuel Scale. Calibrate as described in 9.2.

9.7. Moisture Meter. Calibrate as per the manufacturer's instructions before the first certification test and semiannually thereafter.

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9.8. Temperature Sensors. Calibrate using at least five points within operating range within specification and in compliance with NIST Monograph 175. To be calibrated before the first certification test and semiannually thereafter.

10. Sampling, Test Specimens, and Test Appliances

10.1. Modifications to ASTM 2515 requirements.

10.1.1. Liquid water should not be present anywhere in the sampling system for a valid sample. The presence of condensed water anywhere in the sampling system invalidates the test run. All data from all invalid test runs shall be included in the report. The reviewing authority shall make a final determination on invalidated runs. Data from any invalidated test run shall not be used to calculate results. If the testing agency believes a run has been invalidated, the test run shall be repeated.

10.1.2. Dilution tunnel temperature and relative humidity shall be measured electronically and logged at one-minute intervals near the sample probe to calculate dewpoint. The temperature measurement method shall have an accuracy of 0.9°F (0.5° ~~degrees~~ C) (type T-Special TC or an RTD).

10.1.3. The following section details test conditions that shall be maintained for any valid test run. A valid test shall have no more than two individual deviations from any of the conditions below to remain a valid run. An example of an individual deviation is a single, five-minute rolling average where the dilution tunnel exceeded temperature thresholds. Another five-minute period exceeding the tunnel temperature requirement shall be considered a second deviation.

10.1.3.1. Tunnel temperature shall ~~not exceed~~ 104.0 ~~F deg~~. F (40.0°C) based on ten~~five~~-minute rolling averages derived from one-minute data, excluding periods when the appliance door is open.

~~10.1.3.1.~~ 10.1.3.2. Tunnel relative humidity shall not exceed 90% based on ten~~five~~-minute rolling averages derived from one-minute data.

~~10.1.3.2.~~ 10.1.3.3. Tunnel dew point temperature shall not exceed~~be at least~~ 87.8°F (31.02° ~~deg.~~ C) ~~less than filter temperature based on five-minute rolling averages derived from one-minute data~~.

~~10.1.3.3.~~ 10.1.3.4. A minimum tunnel flow of 600 CFM is required. Higher tunnel flows may be required to meet the parameters of Section 10.1.3.

~~10.1.3.4.~~ 10.1.3.5. All exceedances must be reported in the test anomalies section, even if deviations are within the test method tolerances.

10.2. Sample Collection. The following are required for sample collection:

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10.3. Teflon coated glass fiber filters as supplied by the TEOM manufacturer for use with the TEOM model 1405-D. These are Pallflex Emfab (TX40) with an exposed diameter of 13 mm, without organic binder, exhibiting at least 99.95 percent efficiency.

10.4. *Test Specimens*. Appliances shall be supplied as complete systems, including all controls and accessories necessary for installation at the test facility. A full set of specifications, designs, and assembly drawings shall be provided when the product is placed under certification of a third-party agency.

10.5. Preparation of Apparatus

10.5.1. Wood Heater Installation for Certification Testing. Assemble the wood heater appliance and parts in conformance with the manufacturer's provided User Guide. These instructions must match all instructions materials developed by the manufacturer and/or their distributors. Place the wood heater on the platform scale and connect the chimney to the appliance. Clean the flue with an appropriately sized, wire chimney brush before initiating Run 1 of the certification test. Test documentation should include the date and time of flue cleaning.

10.5.2. Wood Heater Temperature Monitors.

10.5.2.1. For catalyst-equipped wood heaters, locate a temperature monitor (optional) about 25 mm (1 in.) upstream of the catalyst at the centroid of the catalyst face area, and locate a temperature monitor (mandatory) that will indicate the catalyst exhaust temperature. This temperature monitor is centrally located within 25 mm (1 in.) downstream at the centroid of the catalyst face area. Record these locations.

10.5.2.2. Locate wood heater surface temperature monitors at five locations on the wood heater firebox exterior surface. Position the temperature monitors centrally on the top surface, centrally on two sidewall surfaces, and centrally on the bottom and back surfaces. Position the monitor sensing tip on the exterior of the firebox surface inside of any heat shield, room air circulation walls, or other wall or shield separated from the firebox exterior surface. Surface temperature locations for unusual design shapes (e.g., spherical, etc.) shall be positioned so that there are four surface temperature monitors in

10.6. Aging

10.6.1. Wood Heater Aging Prior to Certification Testing. A wood heater of any type shall be aged at least 50 hours before initiating a certification test. The aging procedure shall be conducted by the manufacturer prior to sending the appliance to the testing laboratory. The certification lab cannot be involved with wood heater aging in any manner. The appliance shall be operated at a variety of burn rates. Documentation for wood heating aging must be included in the test report. The testing laboratory shall not conduct any firing of the appliance prior to conducting the certification test.

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10.6.1.1. The manufacturer shall supply wood heater aging information for the final test reports. Aging data that shall be reported include all fuel parameters (species, moisture content, load weights, piece amounts, and size), air settings used, time spent in each air setting phase, amount of fuel burned, and appliance burn rates.

10.6.1.2. If an appliance uses a catalytic combustor, it must be engaged according to the manufacturer's instructions and operate with the catalyst engaged for at least 50 hours during the break-in period. In addition to the reporting requirements listed in 8.1.1, catalytic appliances shall also report hourly catalyst exit temperature data to include the dates and hours of operation.

11. Procedure

11.1. Test Facility Conditions.

11.1.1. The test facility temperature shall be maintained between 55 and 90°F (13 and 32°C) during each test run.

11.1.2. The flue shall discharge into the same space or into a space freely communicating with the test facility. Any hood or similar device used to vent combustion products shall not induce a draft greater than 0.005 in. H_2O (1.25 Pa) on the wood heater measured when the wood heater is not operating.

11.1.3. For test facilities with artificially induced barometric pressures (e.g., pressurized chambers), the barometric pressure in the test facility shall not exceed 30.5 in. Hg (775 mm Hg) during any test run.

11.1.4. Locate the test facility temperature monitor on the horizontal plane that includes the primary air intake opening for the wood heater. Locate the temperature monitor 3 to 6 ft. (1 to 2 m) from the front of the wood heater in the 90° sector in front of the wood heater.

11.1.5. Use an anemometer, to measure the air velocity. Measure and record the room air velocity before the ignition period in L1 Startup and once immediately following the test run completion. Air velocities within 0.6 m (2 ft) of the test appliance and exhaust system shall be less than 0.25 m/sec (50 ft/min) without fire in the unit.

11.1.6. Measure and record the test facility's ambient relative humidity, barometric pressure, and temperature before and after each test run using equipment as specified in Section 6.

11.2. Wood Heater Firebox Volume.

11.2.1. Determine the firebox volume using the definitions for height, width, and length. Volume adjustments due to the presence of firebrick and other permanent fixtures may be necessary. All adjustments shall be detailed in the test report. Include areas adjacent to and above a baffle.

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11.2.2. If a manufacturer deems certain areas of the firebox as unusable for fuel load calculations, written documentation stating the basis for that claim and supporting photographic image(s) must be provided and approved by the regulatory authority prior to conducting the certification test. If approval is not granted prior to the test, then the test may be invalidated if the reviewing agency determines the firebox volume is inaccurate.

11.3. Test Fuel. The test fuel shall conform to the following requirements and meet specifications as required by the fuel loading calculator:

11.3.1. Fuel Species. Untreated, air-dried, cordwood fuel.

11.3.1.1. Allowable species: maple (big leaf, red, silver), oak (white), fir (Douglas), or white birch.

11.3.1.2. Kiln-dried fuel is not permitted.

11.3.1.3. Fuel shall be free of decay, fungus, or other contaminants.

11.3.2. Fuel Moisture.

11.3.2.1. Determine fuel moisture for each fuel piece by averaging four moisture meter readings, one from each of three sides, measured parallel to the wood grain.

11.3.2.2. The test fuel load shall have an average moisture content from 19% to 25%, wet basis.

11.3.2.3. Average individual piece moisture content shall have an average moisture content 18% to 27%.

11.3.2.4. The addition of moisture to previously dried wood is not allowed.

11.3.2.5. It is recommended that the test fuel be stored in a temperature and humidity-controlled room.

11.3.2.6. Fuel moisture shall be measured within 24 hours of using the fuel for the test and shall be stored in a humidity-controlled environment until 2 hours prior to testing.

11.3.3. Fuel Temperature. The test fuel shall be at the test facility temperature of 13 to 32°C (55 to 90°F).

11.3.4. Fuel Dimensions. The dimensions of each test fuel piece shall conform to definitions specified by the protocols using the fuel load calculator.

11.3.4.1. Fuel length:

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11.3.4.1.1.The length of the fuel pieces will be determined by the fuel load calculator.

11.3.4.1.2.Measurements shall be taken, and the length of the test fuel will be determined by entering the firebox dimensions, which calculates the length for all the fuel pieces into a generally available commercial size (14, 16, 18, 20 or 22 inches in length).

11.3.4.1.3.Piece length specified by the fuel calculator shall be communicated and specified for use in the owner's manual and website. Piece size shall be within 0.5" of the log length determined by the calculator, as measured on the shortest length measurement.

11.3.5.Fuel Loading Direction

11.3.5.1.Fuel loading direction shall be determined by the firebox measurement.

11.3.5.1.1.Stoves with a depth measurement greater than two inches from the width measurement shall be tested with the fuel in a north-south configuration and may not test with fuel in an east/west or crisscross configuration in any load other than Load 1 and Load 2.

11.3.5.1.2.Stoves with a width measurement greater than the depth measurement or a width measurement within two inches of the depth measurement shall be tested with the fuel loaded in an east-west configuration and may not test with fuel in a north/south configuration or crisscross configuration in any load other than Load 1 and Load 2.

11.3.6.Fuel piece weight for each phase of the protocol shall be determined by the fuel load calculator.

11.3.6.1.Kindling –shall be:

11.3.6.1.1.pieces of wood less than or equal to 1" in diameter.

11.3.6.1.2.No bark requirements for kindling fuel

11.3.6.1.3.Fuel species may be any species allowed in 7.2.1.1.

11.3.6.1.4.No moisture requirements.

11.3.6.1.5.Length of kindling shall be the fuel length specified by the fuel load calculator.

11.3.6.1.6.Kindling fuel shall conform to the rule that 7 to 12 pieces of kindling equal 1 pound of kindling fuel (+/- 10%).

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11.3.6.2. Starter fuel: pieces of cordwood shall be used during the startup phase. Individual piece weight for starter fuel shall be determined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall be not be used in testing (see Figure 1). Pieces that have squared cross sections shall be split to represent the typical triangle nature of wood (see Figure 3~~2~~). Trapezoidal pieces must be minimized to the extent possible and fuel load pieces shall be composed to include different shapes of wood if using any trapezoidal pieces. .

11.3.6.3. Small fuel pieces: smaller pieces of cordwood by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall not be used (see figure 1). Pieces that have square cross-sections shall be split to represent the typical triangle nature of wood (see Figure 3~~2~~). Trapezoidal pieces must be minimized to the extent possible. No more than 2 small fuel pieces can be trapezoidal in shape (Figure 2) per fuel load.

11.3.6.4. Large fuel pieces: larger pieces of cordwood, by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall be not be used (see figure 1). Pieces that have square cross sections shall be split to represent the typical triangle nature of wood (see Figure 3~~2~~). Trapezoidal pieces must be minimized to the extent possible. No more than 1 large fuel pieces can be trapezoidal in shape (Figure 2) per fuel load.

~~11.3.6.4.~~

Commented [LR1]: Piece shape configuration
- Use of trapezoidal shapes L1 rules, L2 4 rules
- How to define piece shape when two ends differ

Intent – piece shapes should be different
Fig 1 squares out are out
Fig 2 If you have a piece with four sides, piece dimensions must differ by and should make up no more than per load no more than pieces.
Fig 3 acceptable pieces
Fuel pieces must use different shapes if load size is less than

Figure 1. Schematic of unacceptable cross-sectional profiles

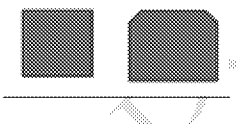

Figure 2.

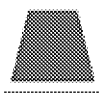

Figure 3. Schematics of acceptable cross-sectional profiles

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11.4. Sampling Equipment.

11.4.1. Prepare the PM and ambient sampling equipment as defined by the TEOM Protocol.

11.4.2. Prepare all other equipment as defined by method EPA Method 1, 2, 3, 4 and 5G.

11.5. Manufacturer participation in certification testing

11.5.1. A representative of the manufacturer may observe testing but may not provide instructions to the certification lab, in any form, with testing staff or equipment once the certification tests begin. The names of testing witnesses cannot be withheld as confidential business information (CBI).

11.6. Test Run Procedure.

11.6.1. Before each test series, the firebox shall be vacuumed. Testing shall begin without any ash or other materials in the appliance.

11.6.2. Before initiating the compliance test, clean the flue and dilution tunnel with an appropriately sized wire chimney brush before each certification test. Test documentation should include the date and time of flue cleaning.

11.6.3. Record fuel weight data, temperature measurements, and gas concentrations at 1-minute intervals.

11.6.4. Wood Heater Operation and Adjustments. Record all adjustments made to the air supply controls, adjustments to and additions or subtractions of fuel, and any other changes to wood heater operations that occur during the test period.

11.6.5. The weight of fuel remaining at the end of the test run is determined as the difference between the weight of the wood heater with the remaining coals and fuel and the weight after loading the fuel charge. The starting weight is the tare weight of the cleaned, dry wood heater.

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11.6.6. All runs shall be videotaped in their entirety. Videotape shall be of sufficient quality to determine fuel characteristics, fuel loading procedures, and firebox conditions during any testing or aging conducted by the test lab. The testing lab shall have the capacity to allow appropriate agencies the opportunity to remotely witness the test.

11.6.7.L1: Start-up Phase.

11.6.7.1.L1 Appliance requirements.

11.6.7.1.1. Stove temperature: internal and external stove temperature must not be greater than the ambient temperature +/- 2.0°F (1.1°C) for Run 1. There is no stove starting temperature requirement for Runs 2 and 3 except in the case of a failed first run. In this case, if Run 1 is invalid or incomplete and, the stove must meet Run 1 conditions for at least one valid run. Temperature measurements for the external and internal temperatures shall be taken within 15 minutes before starting the test and shall be reported in the test report.

11.6.7.1.2. Tare the appliance scale before starting the test. Record appliance scale weights at the start and end of L1 phase

11.6.7.2.L1 Fuel requirements.

11.6.7.2.1.L1 Fuel type – during the startup phase newspaper (optional up to six full sheets traditional newspaper size), kindling, and starter fuel pieces are used. No other additions are allowed.

11.6.7.2.2.L1 loading density

11.6.7.2.2.1. Kindling loading density: 1 lb. per cubic foot for dry kindling, +/- 5%. The fuel load calculator determines the amount of kindling that can be used.

11.6.7.2.2.2. Starter Fuel loading density: 3 lb. per cubic foot, +/- 5%. The fuel load calculator will determine the minimum piece weight that can be used as starter fuel.

11.6.7.2.3.L1 fuel loading structure: The loading structure of the fire shall be a bottom-up configuration with newspaper on the bottom, kindling on top of the paper, and starter fuel on top of the kindling. Kindling and starter fuel shall be loaded in a crisscross configuration.

11.6.7.3.L1 Operational parameters.

11.6.7.3.1. All kindling, starter fuel, and newspaper must be in the firebox for light off.

11.6.7.3.2. Air settings are fully open.

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11.6.7.3.3.Light the fire with a torch for a period of no more than 30 seconds.

11.6.7.3.4.Immediately after lighting the fire and completing the photo requirement, the appliance door shall be moved to a cracked open position. Cracked open position is defined as opening no more than one inch. The appliance door shall be closed 5 minutes after ignition.

11.6.7.4.L1 Fuel Adjustments: up to three fuel adjustments are allowed in the startup phase. The door may be open for 30 seconds during each fuel adjustment.

11.6.7.5.L1 End of Phase – the end of the startup phase is defined by the weight specified by the fuel load calculator.

11.6.7.6.L1 ~~Photo d~~Documentation – Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed and fire when the door is closed ~~Clear, close-up pictures shall be documented with individual pictures that must be included in the test report~~ sufficient to determine fueling positioning, ~~and~~ coal bed conditions, appliance operation, and fuel charge combustion conditions, Photo of the fuel charge.

~~11.6.7.6.1.Picture(s) of the air setting before light-off~~

~~11.6.7.6.2.Picture(s) of the air setting at the end of L1 phase~~

~~11.6.7.6.3.Picture(s) fuel loaded in the stove prior to light-off~~

~~11.6.7.6.4.Picture(s) fuel just after light-off but prior to door cracked open period.~~

~~11.6.7.6.5.Picture(s) of the coal bed at the end L1 phase~~

11.6.8. ~~*L2:*~~ *High-fire Phase* – the high-fire phase commences immediately after the startup phase ends.

11.6.8.1.L2 Appliance requirements.

11.6.8.1.1.Record the weight of the stove prior to loading the L2 fuel charge, the weight of the fuel charge prior to loading, and the scale weight after loading the L2 fuel charge.

11.6.8.2. L2 Fuel requirements.

11.6.8.2.1. L2 piece size – during the high-fire phase, small cordwood pieces by weight, as defined by the fuel load calculator, are used.

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11.6.8.2.2. L2 loading density: 7 lb. per cubic foot, +/- 5%. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.8.3.L2 Operational parameters: Open the door upon completion of the startup phase and load the L2 fuel load within 60 seconds. Once the fuel has been loaded, the appliance doors shall be closed immediately. Air settings shall be left fully open. When 50% of the L2 fuel load mass has been consumed, the air settings shall be moved to the lowest settings.

11.6.8.4.L2 Fuel Adjustments.

11.6.8.4.1.One fuel adjustment shall be made during the high-fire phase prior to moving the primary air control(s) to their lowest setting. The door shall remain open for 30 seconds for fuel adjustments.

11.6.8.4.2.Additional fuel adjustments shall be made if there is a fivefive-minute period without a weight change of 0.1 pounds at any point during the high-fire phase. The door may only be open for 30 seconds for fuel adjustments.

11.6.8.4.3.All fuel adjustments must be documented in the test report notes and summary.

11.6.8.5.End of L2 Phase –The high-fire phase ends when the scale indicates that 90% of the high-fire fuel mass has been consumed.

~~11.6.8.6.~~ L2 Documentation - Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge.~~Photo documentation~~

~~11.6.8.6.1.Picture(s) of the L2 loaded into the stove with the door open and fuel loading pattern distinguishable.~~

~~11.6.8.6.2. Picture(s) of the air settings at the beginning of the L2 phase~~

~~11.6.8.6.3.Picture(s) of the air setting after 50% fuel consumption~~

~~11.6.8.6.4.Picture(s) of the air settings at the end of the L2 phase.~~

~~11.6.8.6.5.Picture(s) of the coal bed at the end of L2 phase.~~

~~11.6.8.6.6.Pictures before and after L2 fuel adjustments.~~

11.6.8.6.

Commented [LR2]: From PFS – During the High Fire phase, A fuel adjustment is required, but there does not appear to be any guidance or criteria on when is shall be done?

Commented [LR3R2]: Mandatory for research ATM /Regulatory method – modify to within, and rules for fuel adjustment.

Commented [LR4]: 11.6.8.4.2/11.6.9.4– Additional fuel adjustments shall be made if there is a [variable length of time depending on which burn cycle] period without a weight change, is a weight change defined as 0.02 lbs (specified resolution of the scale)?

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11.6.9. *L3: Maintenance-fire Phase* – the L3 maintenance-fire phase commences immediately after the L2 high-fire phase ends.

11.6.9.1.L3 Appliance Requirements.

11.6.9.1.1. Record the weight of the stove prior to loading the maintenance-fire fuel charge, the weight of the fuel charge prior to loading, and the scale weight after loading the maintenance-fire fuel charge.

11.6.9.2.L3 Fuel Requirements.

11.6.9.2.1.Fuel type – during the L3 phase, large cordwood pieces are used. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.9.2.2.L3 fuel loading structure: fuel shall be loaded in the direction specified by the fueling calculator.

11.6.9.2.3. L3 loading density: 5 lb. per cubic foot, +/- 5%. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.9.3. L3 Operational Parameters:

11.6.9.3.1.Open door upon completion of the L2 phase and load the maintenance-fire fuel charge.

11.6.9.3.2.L3 Load - L3 fuel loaded within 30 seconds of the door opening. Close the loading door immediately.

11.6.9.4. L3 Fuel Adjustments: If there is a ten~~fifteen~~-minute period without weight change (0.1 lb) at any point during the L3-fire phase, a fuel adjustment shall be made to increase the burn rate. The door may be open for up to 30 seconds for fuel adjustments. Only two fuel adjustments may be made during this phase. If after the second fuel adjustment, another period of no weight change (0.1 lb) occurs, the run ends, and it is a failed test run.

Commented [LR5]: 11.6.8.4.2/11.6.9.4– Additional fuel adjustments shall be made if there is a [variable length of time depending on which burn cycle] period without a weight change, is a weight change defined as 0.02 lbs (specified resolution of the scale)?

11.6.9.5.L3 End of Phase – The L3-fire phase ends when the scale indicates that 90% of the maintenance-fire fuel mass has been consumed.

11.6.9.6.L3 Documentation - -Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge.Photo documentation

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~~11.6.9.6.1.Picture(s) of the L3 loaded into the stove with the door open and fuel loading pattern distinguishable.~~

~~11.6.9.6.2. Picture(s) of the air settings at the beginning of the L3 phase~~

~~11.6.9.6.3.Picture(s) of the air settings at the end of the L3 phase.~~

~~11.6.9.6.4.Picture(s) of the coal bed at the end of L3 phase.~~

~~11.6.9.6.5.Pictures before and after fuel adjustments in L3.~~

11.6.10.*L4: Low burn rate phase* – L4 phase commences immediately after the L3- ends.

11.6.10.1.L4 Appliance Requirements.

11.6.10.1.1.Record the weight of the stove prior to loading the L4-fire fuel charge, the load of the fuel charge prior to loading, and the scale weight after loading the overnight-fire fuel charge. Alternatively, if the scale was zeroed prior to starting the test, record the scale weight before and after loading the overnight-fire fuel charge.

11.6.10.2.L4 Fuel requirements

11.6.10.2.1. L4 fuel type –a mix of small and large cordwood pieces are used. At least 50% of the fuel charge load, by the number of pieces, must be large pieces.

11.6.10.2.2.L4 Loading structure: fuel will be loaded in one direction.

11.6.10.2.3.L4 loading density: The fuel load calculator specifies a load volume of 12 lb/ft^3 .+/-5%. Fuel shall be loaded in a manner to maximize the number of pieces that will fit in the stove without using force.

11.6.10.3. L4 Operational Parameters:

11.6.10.3.1. Open the loading door upon completion of the L3 maintenance-fire phase.

11.6.10.3.2.Load the L4 fuel charge within two minutes (120 seconds).

11.6.10.3.3.Keep the door in the 1" cracked position for five minutes from the beginning of the L4 phase.

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11.6.10.3.4.Air controls shall be placed in the fully open position for the first ten minutes of the phase.

11.6.10.4.L4 Fuel Adjustments.

11.6.10.4.1.Unlimited fuel adjustments are allowed within the first five minutes of the phase. After ten minutes, air control(s) shall be moved to their lowest position. A picture of the air setting used must be included in the test report. The door may be open for up to 30 seconds for fuel adjustments.

11.6.10.4.2.If there is a ten-minute period without weight change (0.1 lb) during the first hour of the L4-phase, a fuel adjustment shall be made. The door may be open for up to 30 seconds for fuel adjustments.

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Commented [LR6]: 11.6.8.4.2/11.6.9.4– Additional fuel adjustments shall be made if there is a [variable length of time depending on which burn cycle] period without a weight change, is a weight change defined as 0.02 lbs (specified resolution of the scale)?

11.6.10.4.3.Only two fuel adjustments may be made during the first hour. If after the second fuel adjustment, another periods of no weight change (0.1 lb) is observed, the run ends, and it is a failed test run.

11.6.10.4.4.No fuel adjustments are allowed after the first hour of the phase.

11.6.10.4.5.If there is no weight change for a consecutive period of 20 minutes at any point after the first hour of the phase, the unit has failed the test run.

~~11.6.10.4.1.~~

11.6.10.5.L4 End of Phase – The L4 phase shall end when the scale indicates that 90% of the total L4 fuel mass has been consumed. If the fuel load does not burn to 90%, it is a failed test run.

~~11.6.10.6.~~ L4 Documentation - ~~L3 Photo documentation~~

~~11.6.10.6.1.Picture(s) of the L4 loaded into the stove with the door open and fuel loading pattern distinguishable.~~

~~11.6.10.6.2. Picture(s) of the air settings at the beginning of the L4 phase~~

~~11.6.10.6.3.Picture(s) of the air settings at the end of the L4 phase.~~

~~11.6.10.6.4.Picture(s) of the coal bed at the end of L4 phase.~~

~~11.6.10.6.5.Pictures before and after fuel adjustments in L4.~~

~~11.6.10.7.~~11.6.10.6.~~L4 Photo documentation~~Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed and fire when the door is

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closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge.

11.7. Test Run. A complete test run requires completion of all four burn phases and loads. For any appliance that will not accommodate the loading arrangement specified in this test method, the test facility personnel shall contact the Agency Administrator to obtain written approval for an alternative loading arrangement:

11.8. Test Run Requirements. The following describes the required parameters for each test run. Each emission test run shall include all phases of the operational and fueling protocol run in order as described.

11.8.1. Consecutive Test Runs. Consecutive test runs may be conducted, provided that the following requirements are met:

11.8.1.1. Run 1 – The appliance shall have an internal and external starting temperature within +/- 2 °F (1.1°C) of laboratory ambient temperature at the beginning of Run 1

11.8.1.2. Run 2 – The second test run may commence 24 hours after the start of Run 1. Stove coals and ash can remain in the stove until 1 hour before conducting Run 2. All coals and ash shall be removed at least one hour prior to commencing Run 2.

11.8.1.3. Run 3 – The third test run may commence 24 hours after the start of Run 2. Stove coals and ash may remain in the stove until 1 hour before conducting Run 3. All coals and ash shall be removed at least one hour prior to commencing Run 2.

11.9. *Failure to Operate at All Test Conditions*

11.9.1. If the appliance fails two runs due to incomplete or failed test runs, it shall be determined that the appliance has failed the certification test and requires a modification to appliance design. All data for incomplete runs shall be reported. Incomplete failed test runs are defined as the following:

11.9.1.1. If a wood heater fails to complete all four phases of the test run, the run shall be considered an incomplete ~~failed~~ test run.

11.9.1.2. If there is no weight change for a consecutive period of ~~30~~20 minutes at any point during the test, the unit has failed the test run.

11.9.1.3. If the wood heater fails to comply with test protocol parameters

11.9.2. If a test run violates the parameters of the test method, the run is invalid.

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11.9.3. If during certification testing a critical component of the stove is damaged or breaks, the certification test will be stopped and considered invalid.

11.9.3.1. If damage is noted during a test, repairs shall be made by the manufacturer (or by laboratory personnel with written direction from the manufacturer). If the repair involves components that require~~would need~~ aging, the appliance shall then undergo another round of wood heater aging as specified in section 10.6. ~~These c~~Components requiring aging shall~~may~~ include but are not limited to catalyst elements, gaskets, and refractory components. Manufacturers have the option of aging these elements in other prototypes. The aging process is intended not only to 'cure' the stove but also to cycle parts that may fail with extended use. Alternate aging techniques may be approved by the administrator, depending on the nature of the failure, material, and critical nature.

11.10. Test Run Completion. Once three valid runs have been completed, the testing is complete. No additional runs may be completed.

11.10.1. *Additional Test Runs*. If there is an invalid run, may attempt two additional runs to complete the test series. If more than three test runs are conducted, the results from all valid test runs shall be used in calculating the average emission rate. The measurement data and results of all test runs shall be reported regardless of which values are used in calculating the emission rate. No test run data can be eliminated from the reporting requirements of this method.

11.10.2. *Invalid Runs*. When a test run fails to meet one of the QA/QC criteria stipulated in the test method, the data are invalid and the run must be repeated. Data for the invalidated test run must be included in the test report but the data must not be used in calculation of average emission values.

11.10.3. *Incomplete Runs*. When an appliance cannot successfully complete all operational elements of the protocol specified in Section 11.6.7 through 11.6.10, it is an incomplete run.

~~11.10.1.~~

11.11. Auxiliary Wood Heater Equipment Operation. If optional heat exchange blowers are sold for use with the wood heater, three runs with~~out~~ the fan and an additional run without the fan shall be completed. If emissions are more than 1 gram per higher with the fan on, an additional two runs must be completed with the fan on. Heat exchange blowers shall operate in the highest airflow setting. (Automatically operated blowers shall be operated as designed) during the entire test.

11.12. PM Data Recording.

11.13. All data shall be collected and recorded at intervals of no more than 1 minute. TEOM data shall be averaged up to 1-minute intervals for reporting. TEOM operation shall follow the procedures listed in NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

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11.13.1. Data shall be reported in an Excel or compatible spreadsheet following the minimum data reporting requirements. All electronic files shall be submitted as part of the test report. Spreadsheet files shall be supplied as part of the publicly available test report.

11.13.2. Room PM measurement – TEOM. A TEOM shall be used to measure ambient lab air PM during the test, as configured in NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel. The sample flow shall be 2 LPM.

Commented [LR7]: What is the purpose of using a TEOM monitor lab ambient air? A far as I can tell it is not used to back out dilution tunnel results?

12. Quality Control Measures

12.1. Dilution tunnel - Conduct sampling equipment leak check and calibration pre- and post-test.

12.2. TEOM – Flow and Leak checks are done before and after every test run per NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

12.3. Volume Metering System Checks.

13. Data Analysis and Calculations. –

13.1. Emission Calculations. Particulate matter, carbon dioxide, and carbon monoxide shall be calculated using the following methodology and reported in grams per hour, grams per kilogram and pounds per million British Thermal Unit (BTU) heat output. All calculations shall be conducted using all decimal values provided by the instrumentation or recorded by the operator. No truncation of data is acceptable. Only the final calculation of the PM emissions rate shall be rounded, to three significant figures.

13.2. TEOM data shall be reported as follows.

13.2.1. Emissions from each of the 4 phases of the test shall be reported as individual results in grams per hour, grams per kilogram, and lb/MMBtu (heat output).

Emissions from the entire test run in grams per hour, grams per kilogram, and lb/MMBtu (heat output).

Nomenclature

$AER = Ei/\sum N$

BR – average dry fuel burn rate, lb./min

$BR_{(x)}$ – Burn rate for specific phase, BR_{L1}, BR_{L2}, BR_{L3}, BR_{L4}

CO – Carbon Monoxide

CO_2 – Carbon Dioxide

H_2- Hydrogen

O_2 – Oxygen

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BT = time of 90% of overnight load consumed – time of overnight loading
C_{steel} – Specific heat of steel (0.1 Btu/ lb., ˚F)
E_T – Total particulate emissions for the full test run in grams
$E_{g/MJ}$ – PM Emissions rate in grams per megajoule of heat output
$E_{g/kg}$ – PM Emissions factor in grams per kilogram of dry fuel burned
$E_{g/hr}$ – PM Emissions factor in grams per hour
E_{Rco} – CO emission rate, g/hr.
EIi – Average CO emission index for interval i
E_{ICO} – CO emission index, g/kg dry fuel
EIco,avg – Average CO emission index for the run
HHV – Higher heating value of fuel = Use accredited test results
LHV – Lower heating value of fuel = Use accredited test results
$\%M_d$ = Fuel moisture content, dry basis, percent.
$\%M_w$ = Average moisture in test fuel charge, wet basis, percent
N = Total number of test runs.
PCTCO2– average CO_2 in the dry flue gas (%)
PPMco -average CO in the dry flue gas (ppm)
Q_{out} – Total heat output in BTU's (megajoules)
SC_i – Scale weight at specific time interval, lb.
$t_{(i)}$ – Data sampling interval in minutes
T1 – Surface Temperature 1 ˚F (˚C)
T2 – Surface Temperature 2 ˚F (˚C)
T3 – Surface Temperature 3 ˚F (˚C)
T4 – Surface Temperature 4 ˚F (˚C)
T5 – Surface Temperature 5 ˚F (˚C)
T6 – Pre Catalyst Temperature 1 ˚F (˚C)
T7 – Post Catalyst Temperature 2 ˚F (˚C)
T8 – Tunnel Temperature ˚F (˚C)
T9 - Flue Gas Temperature ˚F (˚C)
T10 – Room Temperature ˚F (˚C)
$TS_{avg(i)}$ – Initial Average Surface Temperature ˚F (˚C)
$TS_{avg(f)}$ – Final Average Surface Temperature ˚F (˚C)
W_{fuel} – Fuel charge weight in pounds (kg)
W_i – Weight of fuel in pounds (kg)
W_{app} – Weight of empty appliance in pounds (kg)
Θ – Total length of test run, hours
$\Theta_{(x)}$ – Total length of test run in hours per phase, X
$\%M_w = 100(\%M_d)/100+\%M_d$

13.3. Average Wood Heater Surface Temperatures. Calculate the average of the wood heater surface temperatures at the start of the phase (L4) and end at the end of the test (L4) of the test run.

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$L4\ TS_{avg(i)} - (T1 + T2 + T3 + T4 + T5) / 5$

$L4\ TS_{avg(f)} - (T1 + T2 + T3 + T4 + T5) / 5$

Average surface temperatures at the start and end of any phase can be determined by averaging all five sensors at the beginning and end of each phase.

$L_x\ TS_{avg(i)} - (T1 + T2 + T3 + T4 + T5) / 5$

$L_x\ TS_{avg(f)} - (T1 + T2 + T3 + T4 + T5) / 5$

13.4. Burn Time Rating– A standardized burn time rating shall be determined by rounding the duration of the overnight-fire phase of the test up to the nearest 1 hour. Burn time shall be calculated as the time L4 is loaded into the stove until 90% of the fuel has been consumed. This provides an important rating for consumers and is not intended for any calculation purposes and shall be reported on the all manufacturers materials that provides specifications on appliance performance. Language such as "this stove has demonstrated a low setting burn time of x hours in official testing"

13.5. Determine Burn Rates

BR_{L1} = not applicable

BR_{L2} = (L2 Initial SC_i – L2 Final SC_i) / $\Theta_{(L2)}$, lbs./hr

BR_{L3} = (L3 Initial SC_i – L3 Final SC_i) / $\Theta_{(L3)}$, lbs./hr

BR_{L4} = (L4 Initial SC_i – L4 Final SC_i) / $\Theta_{(L4)}$, lbs./hr

13.6. Emissions

13.6.1. Determine emission rates and emission factors as:

$E_{g/MJ} = E_T/(Q_{out} \times 0.001055)$, g/MJ

$E_{g/kg} = E_T/(W_{fuel}/(1+M\%M_d/100))$, g/dry kg

$E_{g/hr} = E_T/\Theta$, g/hr

13.7. Efficiency calculation.

Ultimate Analysis of dry fuel (% by weight)

Carbon – CA

Hydrogen – HY

Oxygen – OX

Moisture Content – mass of water per mass of dry fuel – Mcdb

Ambient Humidity Ratio – mass of water per unit mass of dry air – ω

Flue gas temperature (F) – Ts

Room temperature (F)-Tr

CO in the dry flue gas (ppm) – PPMco

CO2 in the dry flue gas (%) – PCTCO2

Higher heating value of the dry fuel (lb/MMBtu) – HHV

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Combustion Balance Equation:

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

Where:

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4] excess air parameter, e.g. if [EMBED Equation.DSMT4] 0.5 there is 50 % excess air

From this:

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

Commented [LR8]: George says this is missing something, Kelli, Mark, can you help?

With flue gas CO and CO_2 measured, these two equations can be solved simultaneously for [EMBED Equation.DSMT4] and [EMBED Equation.DSMT4].

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

Calculation of the Molar Coefficient for Each of the Products

For the assumption of 100 kg of dry fuel, this is the number of moles of each product for the input conditions

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[EMBED Equation.DSMT4] Molar Coefficient for CO

[EMBED Equation.DSMT4] Molar Coefficient for CO_2

[EMBED Equation.DSMT4] Molar Coefficient for H_2O

[EMBED Equation.DSMT4] Molar Coefficient for O_2

[EMBED Equation.DSMT4] Molar Coefficient for N_2

Heat Capacity of Exhaust Products

The general equation for representing how the heat capacity of the exhaust products varies with temperature is:

[EMBED Equation.DSMT4]

Where:

C = heat capacity J/mol K or kJ/kgmol K

A and B are constants

Tk = Temperature in °K

The values for A and B for the exhaust components are provided in the table below

Component	A	B
CO	.0056	27.162
CO2	.029	29.54
H2O	.0057	32.859
O2	.009	26.782
N2	.0062	26.626

For each component, heat capacity is calculated at the stack temperature and at room temperature. The average of these is used to calculate sensible heat loss.

Calculation of Heat Losses for Efficiency Determination

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[EMBED Equation.DSMT4] Higher heating value in kJ/kg (conversion from Btu/lb)

[EMBED Equation.DSMT4] Latent heat of water vapor in kJ/kgmol

[EMBED Equation.DSMT4] Heat loss in latent heat of water vapor, % of input energy

[EMBED Equation.DSMT4] Heat loss in chemical energy in CO, % of input energy

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4] Heat loss in sensible heat in flue gas, % of input energy

[EMBED Equation.DSMT4] Stack loss efficiency, %

14. Reporting Requirements. The report shall include the following:

14.1.1. Introduction

14.1.2. Purpose of test: certification, audit, efficiency,

14.1.3. Name and location of the laboratory conducting the test.

14.1.4. Wood appliance identification – manufacturer, model number/name, design type, description of the appliance tested, stove condition, and date of receipt.

14.1.5. Test information – location of testing, date of tests, sampling methods used, number of test runs, a statement detailing any previous certification testing completed on the wood appliance.

14.1.6. A list of people who conducted research on the appliance, participated in testing preparation, or witnessed the certification testing. This list shall clearly specify their roles in the testing program for the appliance. The list shall include the participant's name, title, company, contact information and the purpose of their participation.

14.1.7. A statement that the test results apply only to the specific appliance tested.

14.2. Summary and Discussion of Results

14.2.1. Table of results to include test run number, average burn rate for entire run and each phase, carbon monoxide and particulate emission rate for full run, particulate and carbon monoxide emission rate for each load phase (L1, L2, L3, L4), efficiency for the full run and each phase, burn time for total run and each phase.

14.2.2. For each test run use the TEOM data and use real-time gas analyzer data for other emissions to report: Θ_1, Θ_2, Θ_3, CO, CO_2, PM, and efficiency for (1) L1 - the startup phase and (2) L2 - high-, (3) L3-maintenance-, and (4) L5 low burn rate fire phases. Calculated results for the emissions shall be reported as total emissions in grams, pounds per million Btu output, grams per MJ, grams per kilogram of dry fuel and grams per hour, and pounds per hour.

14.2.3. A narrative discussion detailing any issues or anomalies that arose during each test run and how those were handled, including comments about the fuel, and loading of the appliance.

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14.2.4. A plot of CO emission rate in ppm vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.5. A plot of CO_2 emission rate in ppm vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.6. A plot of PM emission rate in grams/hour vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.7. A plot of PM emission rate in g/kg vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.8. Summary of other data – test facility conditions, surface temperature averages, catalyst temperature averages, pretest fuel weights, test fuel charge weights – total and by phase.

14.3. Discussion. Test run result, specific test run problems and solutions. Comments on fuel, loading, analysis, and anything that may impact the reported result(s).

14.3.1. Details of deviations from, additions to or exclusions from the test method, and their data quality implications on the test results (if any), as well as information on specific test conditions, such as environmental conditions. An explanation of the deviations, additions, or exclusions shall be provided along with an analysis as to why these elements had no impact.

14.4. Process description:

14.4.1. Data and drawings indicating the firebox size and location of the fuel charge.

14.4.2. Drawings and calculations used to determine firebox volume to include volume, height, width, and lengths, weight, and volume adjustments.

14.4.3. Firebox configuration – At a minimum to include air supply locations and operation, air supply introduction location, refractory location and dimensions, catalyst location, baffle and by-pass location and operation (include line drawings or photographs)

14.4.4. Appliance operation during the test – shall supply details on air supply settings and adjustments.

14.5. Test fuel properties – the report shall provide information on the species, density, fuel moisture, fuel temperature, and load details from the fuel load calculator to include all measurements including the number of pieces, individual piece weights, piece length, moisture content and weight.

14.6. Sampling

14.6.1. A description of the test procedures and test equipment, including a schematic or other drawing showing the location of all required test equipment. Also, a description of test fuel sourcing, handling and storage practices shall be included.

14.6.2. Describe the sampling location relative to the wood heater, include drawing or photographs.

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14.6.3. Provide data on sampling blanks.

14.7. Quality Control and Assurance Procedures

14.7.1. Calibration procedures and results certification procedures, sample and analysis procedures.

14.7.2. Test method quality control procedures to include TEOM leak and flow checks, stratification (velocity) checks, tunnel flow range results, filter temperature range verification and dilution tunnel RH verification.

14.8. Appendices

14.8.1. Results and Example Calculations. Raw data and complete calculations for data included in summary tables.

14.8.2. Raw data. Copies of all files or sheets for sampling measurement, temperature records, and other materials used by lab related to testing.

14.8.3. Calibration Results. Summary of all calibrations, check, and audits pertinent to the certification.

14.8.4. Sampling and Operation Records. Copies of all uncorrected records of activities not included in raw data sheets (e.g., wood heater door open, times and durations) as well as photographs of fuel loading and air flow settings.

14.8.5. Correspondence. Any correspondence to include written, electronic or verbal communications regarding appliance testing. Items shall include:

14.8.5.1. Request to conduct testing

14.8.5.2. Scheduling of testing

14.8.5.3. Notice to EPA to conduct test, and any modifications to that request.

14.8.5.4. Notice and submission of data to EPA after testing completed.

14.8.6. Test Facility Information. Report test facility temperature, air velocity, and humidity information.

14.8.7. Test Equipment Calibration and Audit Information. Report calibration and audit results for the platform scale, test fuel balance, test fuel moisture meter, and sampling equipment including volume metering systems and gaseous analyzers.

14.8.8. Pretest procedures. Report all pretest procedures conducted at the lab on the appliance to burns, rates, and amounts.

14.8.9. All required data for each test run shall be provided in spreadsheet format both in the printed report and in a computer file such that the data can be easily analyzed and calculations easily verified. Formulas used for all calculations shall be accessible for review.

14.8.10. For each test run: report TEOM flow and temperature and verification of all TEOM data validation parameters as required in NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

14.8.11. Raw data, calibration records, and other relevant documentation shall be retained by the laboratory for a minimum of 7 years.

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Integrated Duty Cycle Test Method for Certification of Wood-Fired Stoves Using Cordwood: Measurement of Particulate Matter (PM) and Carbon Monoxide (CO) Emissions and Heating Efficiency

Note: This method does not include all the specifications (e.g. equipment and supplies) and procedures (e.g., sample and analytical) essential to its performance. Some material is incorporated by reference from other methods. Therefore, to obtain reliable results, persons using this method shall have a thorough knowledge of at least the following EPA Tests

- Method 1- Sample and Velocity Traverses for Stationary Sources
- Method 2- Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube)
- Method 3 – Gas Analysis for the Determination of Dry Molecular Weight
- Method 4 – Determination of Moisture Content in Stack Gases
- Method 5G – Determination of Particulate Matter from Wood Heaters (Dilution Tunnel Sampling Location)
- Method 10 - Carbon Monoxide - Instrumental Analyzer
- Method 28 – Certification and Auditing if Wood Heaters

1. Scope and Application

1.1. This test method specifies operation and fueling for certification and auditing of manually operated wood-fired stoves and heaters.

1.2. This test method measures particulate matter (PM) emissions, carbon monoxide, and efficiency.

1.3. Particulate emissions are measured by the dilution tunnel method as specified in ASTM E2515 Standard Test Method for Determination of Particulate Matter Emissions Collected in a Dilution Tunnel using only Emfab Pallflex filters. Additional particulate matter emissions measurements may also use the Tapered Element Oscillating Microbalance (TEOM) continuous PM method, as detailed in this test method.

1.4. Analyte. Particulate matter (PM). No CAS number assigned. Carbon monoxide (CO). No CAS number assigned.

1.5. Applicability. This method is applicable for the certification and auditing of wood space heaters, which burn cordwood fuel. The test quantifies PM and CO emissions and provides overall efficiency ratings, maximum burn time, and heat output.

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1.6. Data Quality Objectives. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods

1.7. Distinguishing features of appliances covered by this standard include:

1.7.1. Cordwood fuel is hand-fed into firebox.

1.7.2. A chimney or vent that exhausts combustion products from the appliance.

1.8. The values stated are to be regarded as the standard, whether in I-P or SI units. The values given in parentheses are for information only.

1.9. Data Quality Objectives.

1.9.1. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods.

1.9.2. Measurement of emissions and heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

1.9.3. This is a laboratory method intended to capture operating periods that are representative of actual field use without excessive test burden.

2. Referenced Methods

2.1. NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel

2.2. ASTM 2515: Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel.

3. Definitions

3.1. Appliance – a wood heater capable of and intended for space heating defined in the applicable regulation. The appliance includes combustion chamber, combustion air settings, operating controls, and a thermostat if specified, and any other accessory required for standard operation, such as a barometric damper,

3.2. Catch - any mass from the sample probe system on the filter.

3.3. Certification or audit test - a series of at least three test runs conducted for certification or audit purposes that meets the specifications detailed in this protocol.

3.4. Chop – using a poker or another piece of wood to strike a piece of the fuel charge to break it into smaller pieces.

3.5. Coal-bed Stirring – prior to adding a new fuel charge, using a poker or piece of wood to stir or level the coal bed of the appliance for the sole purpose of ensuring ease of loading of the fuel

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charge. No special formations can be made, such as creating coal bed formations or pushing coals to one side or creating slopes with the coals.

3.6. East-west stove – a stove where the firebox dimension parallel to the loading door is greater or equal to the stove depth measurement. Logs are loaded so that they are viewed on the long length of the stove.

3.7. Emission factor – the emission of a pollutant expressed in mass per unit of energy (typically) output from the appliance.

3.8. Firebox - the portion of the chamber in the wood heater in which the test fuel charge is placed and combusted.

3.9. Firebox depth - the horizontal length of the fire chamber dimension measured perpendicular to the loading door. If the manufacturer believes that a portion of the firebox depth is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.10. Firebox Height - the vertical distance extending above the top of the firebox to the floor of the firebox. Firebox height is not necessarily uniform. The measurement must account for variations caused by internal baffles, air channels, or other permanent obstructions. If the manufacturer believes that a portion of the firebox height is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.11. Firebox width - the horizontal fire chamber dimension that is parallel to the loading door. If the manufacturer believes that a portion of the firebox width is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.12. Fuel Adjustment –manipulations to the fuel charge to reflect typical owner practices that allow the cordwood fuel to burn appropriately during the test period. A fuel adjustment does not include chopping the wood or stirring the coal bed.

3.13. Fuel load calculator – The locked excel spreadsheet tool that determines the allowable test fuel load weights and required piece sizes for each individual load.

3.14. Fuel loading direction – Fuel shall be loaded parallel to the greater of the width and depth dimensions for loads 2, 3 and 4. Criss-cross is allowed for startup phase and cannot be used as a load configuration for loads 2, 3 or 4. If the firebox length and width are within 2" fuel shall be loaded in an east/west fashion, parallel to the loading door.

3.15. Kindling pieces – small pieces of wood less than 1" in diameter. No bark or moisture requirements for these pieces, however kindling pieces shall not be dried or stored anywhere but in laboratory ambient conditions. Kindling length shall be of the same as the fuel charge length. and shall represent weights that would enable 8 to 12 pieces equal one pound.

3.16. Large fuel pieces – pieces that are larger for the appliance as defined by the fuel load calculator.

3.17. L1 – Start-up – period of the test when the unit has kindling and startup fuel under the conditions described in Section 11.6.7.

3.18. L2 – High-fire Phase – period of the test when the unit has a small coal bed and the stoves air settings are fully open. Intended to replicate period when homeowners are trying to quickly heat an area, shortly after starting or restarting the appliance.

3.19. L3 - Maintenance-fire phase– period of the test when a fire is maintained with a medium-sized coal bed, and a smaller batch of wood. This is intended to simulate a period when the operator is trying to maintain consistent heat output.

3.20. L4 - Low-burn Rate Phase – period of the test when the stove has a large coal bed, stove is fully loaded, and the adjustable air settings are set to produce the lowest possible burn rate and have the lowest air settings. Intended to simulate a period the operator is trying to maintain heat over a long period of time, such as overnight or while away for significant periods of time.

3.21. North-south stove: a firebox which has its longest dimension measurement perpendicular to the loading door. In this stove type, logs are loaded so that the ends of the fuel are viewed when loaded.

3.22. Phase – A distinct period in the test run with its own operational procedures and conditions.

3.23. Primary air supply – air supply that introduces air to the wood heater in the combustion chamber and is adjusted to target a desired burn rate. The wood heater manufacturer or test facility can document this through design drawings.

3.24. Secondary air supply - air supply that introduces air to the wood heater such that the burn rate is not altered by more than 10 percent when the secondary air supply is adjusted during the test run. The wood heater manufacturer or test facility can document this through design drawings that show the secondary air is introduced only into a mixing chamber or secondary chamber outside the firebox.

3.25. Small fuel pieces - pieces that are small for the appliance as defined by the fuel load calculator.

3.26. Starter fuel – pieces of cordwood that can be smaller than small and large pieces but larger than kindling, as defined by the fuel load calculator.

3.27. Test data– means the data for all test runs conducted on the wood heater, including any data collected during failed and invalid runs and includes records of preparation of standards, identification of equipment used and personnel present, records of calibrations, raw data sheets for field sampling, raw data sheets for field and laboratory analyses, chain-of-custody documentation, and example calculations for reported results.

3.28. Test facility - the area in which the wood heater is installed, operated, and sampled for emissions.

3.29. Test fuel charge - the collection of test fuel pieces used in each of the four phases of the test run. L2, L3, and L4 require that at least 50% of the individual pieces with at least 80% bark on one side of the fuel piece. Bark shall not be removed for certification testing. Any fuel charge that

suggests bark was purposely removed or shaped shall deem the certification test invalid. Examples of fuel piece manipulation are provided in Section 11

3.30. Test fuel load – the group of test fuel pieces that are loaded, as specified by phase, throughout the test run. Test fuel loading means the arrangement of the test fuel charge.

3.31. Test fuel loading density - the calculation that determines the weight of the as-fired test fuel load. The calculation is based on the usable volume of the firebox.

3.32. Test run - an individual emission test that includes the four operational phases required by the fueling protocol.

3.33. Usable firebox volume - the calculated volume of the firebox determined using its height, width, and depth as defined in this section. This calculation represents the area where wood is likely to be loaded. If the manufacturer claims that portions of the firebox may not be used in the calculation a justification must be submitted with the test report. If the justification is not approved, the test results will be deemed unrepresentative for certification purposes. It is highly recommended that manufacturers obtain regulatory approval if making claims that portions of the firebox are not appropriate for inclusion in the calculation.

3.34. Wood heater - an enclosed, wood-burning appliance capable of and intended for space heating or domestic water heating, as defined in the applicable regulation.

4. *Interferences*

None.

5. *Summary of Method*

5.1. Particulate matter emissions are measured from a wood heater burning cordwood test fuel in a test facility maintained at a set of prescribed ambient conditions. Procedures for operating the appliance, measuring PM and CO emission rates, and methods for reducing data and calculating results are provided.

5.2. *Dilution Tunnel.* A dilution tunnel following the specifications detailed in ASTM E2515-11 shall be used for particulate measurements.

5.3. *Particulate Matter:* PM emissions are measured in a dilution tunnel with a Thermo model 1405-D 2-channel TEOM using NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel with a dilution tunnel as specified in ASTM 2515 with modifications discussed in Section 10.

5.4. *Carbon Monoxide*. The CO measured in the stack and is used to calculate efficiency determination.

5.5. *Operation*. Appliance operation is conducted on a cold-to-hot test cycle, meaning that the appliance starts the first test run at room temperature and ends with the appliance in fully heated

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state. The second and third test runs are started a slightly warmer temperature. The appliance is operated at a variety of operational phases representing start-up emissions, high heat demand, low heat demand, and refueling. The appliance is operated through four phases. To complete the certification test, a minimum of three full test runs are averaged to determine the test results.

5.6. *Repeatability.* A series of at least three test runs comprised of six different heat demands or phases conducted for certification or audit purposes

6. Significance and Use

6.1. The measurement of particulate matter emission rates is an important test method widely used in the practice of air pollution control.

6.1.1. These measurements, when approved by state or federal agencies, are often required for the purpose of determining compliance with regulations and statutes.

6.1.2. The measurements made before and after design modifications are necessary to demonstrate the effectiveness of design changes in reducing emissions and make this standard an important tool in manufacturers' research and development programs.

6.2. Measurement of heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

7. Safety

7.1. Disclaimer. This method may involve hazardous materials, operations, and equipment. This test method may not address all the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to performing this test method.

7.2. These tests involve combustion of wood, which releases substantial amounts of heat and combustion products. The heating system also produces large quantities of very hot water and the potential for steam production and system pressurization. Appropriate precautions must be taken to protect personnel from burn hazards and respiration of products of combustion. Exposure of personnel to unsafe levels of carbon monoxide must be avoided, and the use of continuous ambient carbon monoxide monitoring is strongly recommended.

8. Equipment and Supplies. The following items are required for sample collection:

8.1. Anemometer. A device capable of detecting air velocities less than 0.10 m/sec (20 ft/min), for measuring air velocities near the test appliance.

8.2. Appliance Flue.

8.2.1. Steel flue pipe extending to 8.5 ±0.5 ft. (2.6 ±0.15 m) above the top of the platform scale, and above this level, insulated solid pack type chimney extending to 15 ±1 ft (4.6 ±0.3 m) above the

platform scale, and of the size specified by the appliance manufacturer. This applies to both freestanding and inserts type appliances.

8.2.2. Other chimney types (e.g., solid pack insulated pipe) may be used in place of the steel flue pipe if the appliance manufacturer's written appliance specifications require such chimney for home installation (e.g., zero clearance appliance inserts). Such alternative chimney or flue pipe must remain and be sealed with the appliance following the certification test.

8.2.3. Solid pack insulated chimneys shall have a minimum of 2.5 cm (1 in.) solid-pack insulating material surrounding the entire flue and possess a label demonstrating conformance to U.L. 103 (incorporated by reference—see §60.17).

8.3. Appliance Platform Scale and Monitor. For monitoring of fuel load weight change. The scale shall be capable of measuring weight to within 0.01 kg (0.02 lb.) and calibrated to NIST traceable standards at least annually.

8.4. Barometer. Aneroid or another barometer capable of measuring atmospheric pressure to within 0.1 in. Hg (2.5 mm Hg) with an uncertainty of +/- 0.05 in Hg (+/- 1.27 mm Hg).

8.5. Dilution Tunnel must meet the requirements of ASTM E2515, clauses 6.1.6 and 9.2.

8.6. Dilution Tunnel temperature and relative humidity measurement. A probe capable of measuring tunnel temperature to within 0.9 °F (0.5 °C)) and tunnel RH to within 2%, such as the Omega HX85-A or equivalent.

8.7. Draft Gauge. Electromanometer or other devices for the determination of flue draft or static pressure readable to within 0.005 in. H2O (1.2 Pa)

8.8. Flue Gas Temperature Measurement. A type K- thermocouple or equivalent located in the centroid of the stack located 8.0 +/- 0.5 ft (2.44 m +/- 150 mm) above the platform scale. Capable of measuring with an accuracy of 4.0°F (2.2°C) or 0.75% of reading, whichever is greater.

8.9. Flue Gas Composition Measurement. A sample probe and continuous infrared analyzer or equivalent capable of measuring span of carbon monoxide (CO) and carbon dioxide (CO_2) in the flue gas produced by the appliance tested. Continuous analyzers (or equivalent) shall have maximum zero and span drift, over a 24 h period, of 1% of full scale

8.10. Fuel Scale. Balance capable of weighing the test fuel charge to within 0.02 kg (0.05 lb.) and calibrated to NIST traceable standards at least annually.

8.11. Humidity Gauge. Psychrometer or hygrometer for measuring room humidity to within +/- 4% from 25 to 95% RH.

8.12. Moisture Meter. Calibrated electrical resistance meter for measuring test fuel moisture to within 2 percent moisture content.

8.13. Surface Temperatures. Capable of measuring temperature to within 1.5 percent of expected absolute temperatures with an accuracy of 4.0°F (2.2°C) or 0.75% of reading, whichever is greater.

8.14. Test Facility Temperature Monitor. A thermistor, RTD, or other equivalent device, located centrally in a vertically oriented 150 mm (6 in.) long, 50 mm (2 in.) diameter pipe shield that is open at both ends, capable of measuring temperature to within 1°F of expected temperatures.

8.15. TEOM – Thermo Fisher Scientific TEOM model 1405-D (Thermo part # 1405D-ANF, excluding models 1405, 1405-DF, or 1405-F) to measure and report continuous particulate matter (PM) measurements in an ASTM 2515 dilution tunnel or equivalent dilution method, and operated according to the NESCAUM Dichot TEOM Standard Operating Procedures.

9. Calibration and Standardizations

9.1. Anemometer. Calibrate the anemometer as specified by the manufacturer's instructions before the first certification test and monthly thereafter.

9.2. Appliance Platform Scale. Perform a multi-point calibration (at least five points spanning the operational range) of the platform scale before its initial use. The scale manufacturer's calibration results are sufficient for this purpose. Before each certification test, audit the scale with the wood heater in place by weighing at least one calibration weight (Class F) that corresponds to between 20 percent and 80 percent of the expected test fuel charge weight. If the scale cannot reproduce the value of the calibration weight within 0.0045 kg (0.01 lb.) or 1 percent of the expected test fuel charge weight, whichever is greater, recalibrate the scale before use with at least five calibration weights spanning the operational range of the scale.

9.3. Barometer. Calibrate using a reference pressure monitor calibrator before the first certification test and semiannually after

9.4. Draft Gauge. Calibrate as per the manufacturer's instructions; a liquid manometer does not require calibration (but must be properly leveled, zeroed and the system leak checked).

9.5. Humidity Gauge. Calibrate as per the manufacturer's instructions before the first certification test and annually thereafter.

9.6. Fuel Scale. Calibrate as described in 9.2.

9.7. Moisture Meter. Calibrate as per the manufacturer's instructions before the first certification test and semiannually thereafter.

9.8. Temperature Sensors. Calibrate using at least five points within operating range within specification and in compliance with NIST Monograph 175. To be calibrated before the first certification test and semiannually thereafter.

10. Sampling, Test Specimens, and Test Appliances

10.1. Modifications to ASTM 2515 requirements.

10.1.1. Liquid water should not be present anywhere in the sampling system for a valid sample. The presence of condensed water anywhere in the sampling system invalidates the test run. All data from all invalid test runs shall be included in the report. The reviewing authority shall make a final determination on invalidated runs. Data from any invalidated test run shall not be used to calculate results. If the testing agency believes a run has been invalidated, the test run shall be repeated.

10.1.2. Dilution tunnel temperature and relative humidity shall be measured electronically and logged at one-minute intervals near the sample probe to calculate dewpoint. The temperature measurement method shall have an accuracy of 0.9°F (0.5°C) (type T-Special TC or an RTD).

10.1.3. The following section details test conditions that shall be maintained for any valid test run. A valid test shall have no more than two individual deviations from any of the conditions below to remain a valid run. An example of an individual deviation is a single, five-minute rolling average where the dilution tunnel exceeded temperature thresholds. Another five-minute period exceeding the tunnel temperature requirement shall be considered a second deviation.

10.1.3.1. Tunnel temperature shall not exceed 104.0°F. F (40.0°C) based on ten-minute rolling averages derived from one-minute data, excluding periods when the appliance door is open.

10.1.3.2. Tunnel relative humidity shall not exceed 90% based on ten-minute rolling averages derived from one-minute data.

10.1.3.3. Tunnel dew point temperature shall not exceed 87.8°F (31.0°C).

10.1.3.4. A minimum tunnel flow of 600 CFM is required. Higher tunnel flows may be required to meet the parameters of Section 10.1.3.

10.1.3.5. All exceedances must be reported in the test anomalies section, even if deviations are within the test method tolerances.

10.2. Sample Collection. The following are required for sample collection:

10.3. Teflon coated glass fiber filters as supplied by the TEOM manufacturer for use with the TEOM model 1405-D. These are Pallflex Emfab (TX40) with an exposed diameter of 13 mm, without organic binder, exhibiting at least 99.95 percent efficiency.

10.4. *Test Specimens.* Appliances shall be supplied as complete systems, including all controls and accessories necessary for installation at the test facility. A full set of specifications, designs, and assembly drawings shall be provided when the product is placed under certification of a third-party agency.

10.5. Preparation of Apparatus

10.5.1. Wood Heater Installation for Certification Testing. Assemble the wood heater appliance and parts in conformance with the manufacturer's provided User Guide. These instructions must match all instructions materials developed by the manufacturer and/or their distributors. Place the wood heater on the platform scale and connect the chimney to the appliance. Clean the flue with an appropriately sized, wire chimney brush before initiating Run 1 of the certification test. Test documentation should include the date and time of flue cleaning.

10.5.2. Wood Heater Temperature Monitors.

10.5.2.1. For catalyst-equipped wood heaters, locate a temperature monitor (optional) about 25 mm (1 in.) upstream of the catalyst at the centroid of the catalyst face area, and locate a temperature monitor (mandatory) that will indicate the catalyst exhaust temperature. This temperature monitor is centrally located within 25 mm (1 in.) downstream at the centroid of the catalyst face area. Record these locations.

10.5.2.2. Locate wood heater surface temperature monitors at five locations on the wood heater firebox exterior surface. Position the temperature monitors centrally on the top surface, centrally on two sidewall surfaces, and centrally on the bottom and back surfaces. Position the monitor sensing tip on the exterior of the firebox surface inside of any heat shield, room air circulation walls, or other wall or shield separated from the firebox exterior surface. Surface temperature locations for unusual design shapes (e.g., spherical, etc.) shall be positioned so that there are four surface temperature monitors in

10.6. Aging

10.6.1. Wood Heater Aging Prior to Certification Testing. A wood heater of any type shall be aged at least 50 hours before initiating a certification test. The aging procedure shall be conducted by the manufacturer prior to sending the appliance to the testing laboratory. The certification lab cannot be involved with wood heater aging in any manner. The appliance shall be operated at a variety of burn rates. Documentation for wood heating aging must be included in the test report. The testing laboratory shall not conduct any firing of the appliance prior to conducting the certification test.

10.6.1.1. The manufacturer shall supply wood heater aging information for the final test reports. Aging data that shall be reported include all fuel parameters (species, moisture content, load weights, piece amounts, and size), air settings used, time spent in each air setting phase, amount of fuel burned, and appliance burn rates.

10.6.1.2. If an appliance uses a catalytic combustor, it must be engaged according to the manufacturer's instructions and operate with the catalyst engaged for at least 50 hours during the break-in period. In addition to the reporting requirements listed in 8.1.1, catalytic appliances shall also report hourly catalyst exit temperature data to include the dates and hours of operation.

11. Procedure

11.1. Test Facility Conditions.

11.1.1. The test facility temperature shall be maintained between 55 and 90°F (13 and 32°C) during each test run.

11.1.2. The flue shall discharge into the same space or into a space freely communicating with the test facility. Any hood or similar device used to vent combustion products shall not induce a draft greater than 0.005 in. H_2O (1.25 Pa) on the wood heater measured when the wood heater is not operating.

11.1.3. For test facilities with artificially induced barometric pressures (e.g., pressurized chambers), the barometric pressure in the test facility shall not exceed 30.5 in. Hg (775 mm Hg) during any test run.

11.1.4. Locate the test facility temperature monitor on the horizontal plane that includes the primary air intake opening for the wood heater. Locate the temperature monitor 3 to 6 ft. (1 to 2 m) from the front of the wood heater in the 90° sector in front of the wood heater.

11.1.5. Use an anemometer, to measure the air velocity. Measure and record the room air velocity before the ignition period in L1 Startup and once immediately following the test run completion. Air velocities within 0.6 m (2 ft) of the test appliance and exhaust system shall be less than 0.25 m/sec (50 ft/min) without fire in the unit.

11.1.6. Measure and record the test facility's ambient relative humidity, barometric pressure, and temperature before and after each test run using equipment as specified in Section 6.

11.2. Wood Heater Firebox Volume.

11.2.1. Determine the firebox volume using the definitions for height, width, and length. Volume adjustments due to the presence of firebrick and other permanent fixtures may be necessary. All adjustments shall be detailed in the test report. Include areas adjacent to and above a baffle.

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11.2.2. If a manufacturer deems certain areas of the firebox as unusable for fuel load calculations, written documentation stating the basis for that claim and supporting photographic image(s) must be provided and approved by the regulatory authority prior to conducting the certification test. If approval is not granted prior to the test, then the test may be invalidated if the reviewing agency determines the firebox volume is inaccurate.

11.3. Test Fuel. The test fuel shall conform to the following requirements and meet specifications as required by the fuel loading calculator:

11.3.1. Fuel Species. Untreated, air-dried, cordwood fuel.

11.3.1.1. Allowable species: maple (big leaf, red, silver), oak (white), fir (Douglas), or white birch.

11.3.1.2. Kiln-dried fuel is not permitted.

11.3.1.3. Fuel shall be free of decay, fungus, or other contaminants.

11.3.2. Fuel Moisture.

11.3.2.1. Determine fuel moisture for each fuel piece by averaging four moisture meter readings, one from each of three sides, measured parallel to the wood grain.

11.3.2.2. The test fuel load shall have an average moisture content from 19% to 25%, wet basis.

11.3.2.3. Average individual piece moisture content shall have an average moisture content 18% to 27%.

11.3.2.4. The addition of moisture to previously dried wood is not allowed.

11.3.2.5. It is recommended that the test fuel be stored in a temperature and humidity-controlled room.

11.3.2.6. Fuel moisture shall be measured within 24 hours of using the fuel for the test and shall be stored in a humidity-controlled environment until 2 hours prior to testing.

11.3.3. Fuel Temperature. The test fuel shall be at the test facility temperature of 13 to 32°C (55 to 90°F).

11.3.4. Fuel Dimensions. The dimensions of each test fuel piece shall conform to definitions specified by the protocols using the fuel load calculator.

11.3.4.1. Fuel length:

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11.3.4.1.1.The length of the fuel pieces will be determined by the fuel load calculator.

11.3.4.1.2.Measurements shall be taken, and the length of the test fuel will be determined by entering the firebox dimensions, which calculates the length for all the fuel pieces into a generally available commercial size (14, 16, 18, 20 or 22 inches in length).

11.3.4.1.3.Piece length specified by the fuel calculator shall be communicated and specified for use in the owner's manual and website. Piece size shall be within 0.5" of the log length determined by the calculator, as measured on the shortest length measurement.

11.3.5.Fuel Loading Direction

11.3.5.1.Fuel loading direction shall be determined by the firebox measurement.

11.3.5.1.1.Stoves with a depth measurement greater than two inches from the width measurement shall be tested with the fuel in a north-south configuration and may not test with fuel in an east/west or crisscross configuration in any load other than Load 1 and Load 2.

11.3.5.1.2.Stoves with a width measurement greater than the depth measurement or a width measurement within two inches of the depth measurement shall be tested with the fuel loaded in an east-west configuration and may not test with fuel in a north/south configuration or crisscross configuration in any load other than Load 1 and Load 2.

11.3.6.Fuel piece weight for each phase of the protocol shall be determined by the fuel load calculator.

11.3.6.1.Kindling –shall be:

11.3.6.1.1.pieces of wood less than or equal to 1" in diameter.

11.3.6.1.2.No bark requirements for kindling fuel

11.3.6.1.3.Fuel species may be any species allowed in 7.2.1.1.

11.3.6.1.4.No moisture requirements.

11.3.6.1.5.Length of kindling shall be the fuel length specified by the fuel load calculator.

11.3.6.1.6.Kindling fuel shall conform to the rule that 7 to 12 pieces of kindling equal 1 pound of kindling fuel (+/- 10%).

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11.3.6.2. Starter fuel: pieces of cordwood shall be used during the startup phase. Individual piece weight for starter fuel shall be determined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall be not be used in testing (see Figure 1). Pieces that have squared cross sections shall be split to represent the typical triangle nature of wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible and fuel load pieces shall be composed to include different shapes of wood if using any trapezoidal pieces. .

11.3.6.3.Small fuel pieces: smaller pieces of cordwood by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall not be used (see figure 1). Pieces that have square cross-sections shall be split to represent the typical triangle nature of wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible. No more than 2 small fuel pieces can be trapezoidal in shape (Figure 2) per fuel load.

11.3.6.4.Large fuel pieces: larger pieces of cordwood, by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall be not be used (see figure 1). Pieces that have square cross sections shall be split to represent the typical triangle nature of wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible. No more than 1 large fuel pieces can be trapezoidal in shape (Figure 2) per fuel load.

Figure 1. Schematic of unacceptable cross-sectional profiles

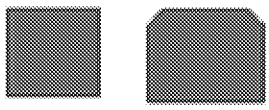

Figure 2.

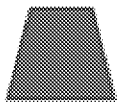

Figure 3. Schematics of acceptable cross-sectional profiles

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11.4. Sampling Equipment.

11.4.1. Prepare the PM and ambient sampling equipment as defined by the TEOM Protocol.

11.4.2. Prepare all other equipment as defined by method EPA Method 1, 2, 3, 4 and 5G.

11.5. Manufacturer participation in certification testing

11.5.1. A representative of the manufacturer may observe testing but may not provide instructions to the certification lab, in any form, with testing staff or equipment once the certification tests begin. The names of testing witnesses cannot be withheld as confidential business information (CBI).

11.6. Test Run Procedure.

11.6.1. Before each test series, the firebox shall be vacuumed. Testing shall begin without any ash or other materials in the appliance.

11.6.2. Before initiating the compliance test, clean the flue and dilution tunnel with an appropriately sized wire chimney brush before each certification test. Test documentation should include the date and time of flue cleaning.

11.6.3. Record fuel weight data, temperature measurements, and gas concentrations at 1-minute intervals.

11.6.4. Wood Heater Operation and Adjustments. Record all adjustments made to the air supply controls, adjustments to and additions or subtractions of fuel, and any other changes to wood heater operations that occur during the test period.

11.6.5. The weight of fuel remaining at the end of the test run is determined as the difference between the weight of the wood heater with the remaining coals and fuel and the weight after loading the fuel charge. The starting weight is the tare weight of the cleaned, dry wood heater.

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11.6.6. All runs shall be videotaped in their entirety. Videotape shall be of sufficient quality to determine fuel characteristics, fuel loading procedures, and firebox conditions during any testing or aging conducted by the test lab. The testing lab shall have the capacity to allow appropriate agencies the opportunity to remotely witness the test.

11.6.7.L1: Start-up Phase.

11.6.7.1.L1 Appliance requirements.

11.6.7.1.1.Stove temperature: internal and external stove temperature must not be greater than the ambient temperature +/- 2.0°F (1.1°C) for Run 1. There is no stove starting temperature requirement for Runs 2 and 3 except in the case of a failed first run. In this case, if Run 1 is invalid or incomplete and, the stove must meet Run 1 conditions for at least one valid run. Temperature measurements for the external and internal temperatures shall be taken within 15 minutes before starting the test and shall be reported in the test report.

11.6.7.1.2.Tare the appliance scale before starting the test. Record appliance scale weights at the start and end of L1 phase

11.6.7.2.L1 Fuel requirements.

11.6.7.2.1.L1 Fuel type – during the startup phase newspaper (optional up to six full sheets traditional newspaper size), kindling, and starter fuel pieces are used. No other additions are allowed.

11.6.7.2.2.L1 loading density

11.6.7.2.2.1.Kindling loading density: 1 lb. per cubic foot for dry kindling, +/- 5%. The fuel load calculator determines the amount of kindling that can be used.

11.6.7.2.2.2.Starter Fuel loading density: 3 lb. per cubic foot, +/- 5%. The fuel load calculator will determine the minimum piece weight that can be used as starter fuel.

11.6.7.2.3.L1 fuel loading structure: The loading structure of the fire shall be a bottom-up configuration with newspaper on the bottom, kindling on top of the paper, and starter fuel on top of the kindling. Kindling and starter fuel shall be loaded in a crisscross configuration.

11.6.7.3.L1 Operational parameters.

11.6.7.3.1.All kindling, starter fuel, and newspaper must be in the firebox for light off.

11.6.7.3.2.Air settings are fully open.

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11.6.7.3.3.Light the fire with a torch for a period of no more than 30 seconds.

11.6.7.3.4.Immediately after lighting the fire and completing the photo requirement, the appliance door shall be moved to a cracked open position. Cracked open position is defined as opening no more than one inch. The appliance door shall be closed 5 minutes after ignition.

11.6.7.4.L1 Fuel Adjustments: up to three fuel adjustments are allowed in the startup phase. The door may be open for 30 seconds during each fuel adjustment.

11.6.7.5.L1 End of Phase – the end of the startup phase is defined by the weight specified by the fuel load calculator.

11.6.7.6.L1 Documentation – Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge.

11.6.8.*L2: High-fire Phase* – the high-fire phase commences immediately after the startup phase ends.

11.6.8.1.L2 Appliance requirements.

11.6.8.1.1.Record the weight of the stove prior to loading the L2 fuel charge, the weight of the fuel charge prior to loading, and the scale weight after loading the L2 fuel charge.

11.6.8.2. L2 Fuel requirements.

11.6.8.2.1. L2 piece size – during the high-fire phase, small cordwood pieces by weight, as defined by the fuel load calculator, are used.

11.6.8.2.2. L2 loading density: 7 lb. per cubic foot, +/- 5%. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.8.3.L2 Operational parameters: Open the door upon completion of the startup phase and load the L2 fuel load within 60 seconds. Once the fuel has been loaded, the appliance doors shall be closed immediately. Air settings shall be left fully open. When 50% of the L2 fuel load mass has been consumed, the air settings shall be moved to the lowest settings.

11.6.8.4.L2 Fuel Adjustments.

11.6.8.4.1.One fuel adjustment shall be made during the high-fire phase prior to moving the primary air control(s) to their lowest setting. The door shall remain open for 30 seconds for fuel adjustments.

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11.6.8.4.2.Additional fuel adjustments shall be made if there is a five-minute period without a weight change of 0.1 pounds at any point during the high-fire phase. The door may only be open for 30 seconds for fuel adjustments.

11.6.8.4.3.All fuel adjustments must be documented in the test report notes and summary.

11.6.8.5.End of L2 Phase –The high-fire phase ends when the scale indicates that 90% of the high-fire fuel mass has been consumed.

11.6.8.6. L2 Documentation - Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge.

11.6.9. *L3: Maintenance-fire Phase* – the L3 maintenance-fire phase commences immediately after the L2 high-fire phase ends.

11.6.9.1.L3 Appliance Requirements.

11.6.9.1.1. Record the weight of the stove prior to loading the maintenance-fire fuel charge, the weight of the fuel charge prior to loading, and the scale weight after loading the maintenance-fire fuel charge.

11.6.9.2.L3 Fuel Requirements.

11.6.9.2.1.Fuel type – during the L3 phase, large cordwood pieces are used. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.9.2.2.L3 fuel loading structure: fuel shall be loaded in the direction specified by the fueling calculator.

11.6.9.2.3. L3 loading density: 5 lb. per cubic foot, +/- 5%. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.9.3. L3 Operational Parameters:

11.6.9.3.1.Open door upon completion of the L2 phase and load the maintenance-fire fuel charge.

11.6.9.3.2.L3 Load - L3 fuel loaded within 30 seconds of the door opening. Close the loading door immediately.

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11.6.9.4. L3 Fuel Adjustments: If there is a ten-minute period without weight change (0.1 lb) at any point during the L3-fire phase, a fuel adjustment shall be made to increase the burn rate. The door may be open for up to 30 seconds for fuel adjustments. Only two fuel adjustments may be made during this phase. If after the second fuel adjustment, another period of no weight change (0.1 lb) occurs, the run ends, and it is a failed test run.

11.6.9.5.L3 End of Phase – The L3-fire phase ends when the scale indicates that 90% of the maintenance-fire fuel mass has been consumed.

11.6.9.6.L3 Documentation - Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge.Photo documentation

11.6.10.*L4: Low burn rate phase* – L4 phase commences immediately after the L3- ends.

11.6.10.1.L4 Appliance Requirements.

11.6.10.1.1.Record the weight of the stove prior to loading the L4-fire fuel charge, the load of the fuel charge prior to loading, and the scale weight after loading the overnight-fire fuel charge. Alternatively, if the scale was zeroed prior to starting the test, record the scale weight before and after loading the overnight-fire fuel charge.

11.6.10.2.L4 Fuel requirements

11.6.10.2.1. L4 fuel type –a mix of small and large cordwood pieces are used. At least 50% of the fuel charge load, by the number of pieces, must be large pieces.

11.6.10.2.2.L4 Loading structure: fuel will be loaded in one direction.

11.6.10.2.3.L4 loading density: The fuel load calculator specifies a load volume of 12 lb/ft^3 .+/-5%. Fuel shall be loaded in a manner to maximize the number of pieces that will fit in the stove without using force.

11.6.10.3. L4 Operational Parameters:

11.6.10.3.1. Open the loading door upon completion of the L3 maintenance-fire phase.

11.6.10.3.2.Load the L4 fuel charge within two minutes (120 seconds).

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11.6.10.3.3.Keep the door in the 1" cracked position for five minutes from the beginning of the L4 phase.

11.6.10.3.4.Air controls shall be placed in the fully open position for the first ten minutes of the phase.

11.6.10.4.L4 Fuel Adjustments.

11.6.10.4.1.Unlimited fuel adjustments are allowed within the first five minutes of the phase. After ten minutes, air control(s) shall be moved to their lowest position. A picture of the air setting used must be included in the test report. The door may be open for up to 30 seconds for fuel adjustments.

11.6.10.4.2.If there is a ten-minute period without weight change (0.1 lb) during the first hour of the L4-phase, a fuel adjustment shall be made. The door may be open for up to 30 seconds for fuel adjustments.

11.6.10.4.3.Only two fuel adjustments may be made during the first hour. If after the second fuel adjustment, another periods of no weight change (0.1 lb) is observed, the run ends, and it is a failed test run.

11.6.10.4.4.No fuel adjustments are allowed after the first hour of the phase.

11.6.10.4.5.If there is no weight change for a consecutive period of 20 minutes at any point after the first hour of the phase, the unit has failed the test run.

11.6.10.5.L4 End of Phase – The L4 phase shall end when the scale indicates that 90% of the total L4 fuel mass has been consumed. If the fuel load does not burn to 90%, it is a failed test run.

11.6.10.6. L4 Documentation - Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge.

11.7. Test Run. A complete test run requires completion of all four burn phases and loads. For any appliance that will not accommodate the loading arrangement specified in this test method, the test facility personnel shall contact the Agency Administrator to obtain written approval for an alternative loading arrangement:

11.8. Test Run Requirements. The following describes the required parameters for each test run. Each emission test run shall include all phases of the operational and fueling protocol run in order as described.

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11.8.1. Consecutive Test Runs. Consecutive test runs may be conducted, provided that the following requirements are met:

11.8.1.1. Run 1 – The appliance shall have an internal and external starting temperature within +/- 2 °F (1.1°C) of laboratory ambient temperature at the beginning of Run 1

11.8.1.2. Run 2 – The second test run may commence 24 hours after the start of Run 1. Stove coals and ash can remain in the stove until 1 hour before conducting Run 2. All coals and ash shall be removed at least one hour prior to commencing Run 2.

11.8.1.3. Run 3 – The third test run may commence 24 hours after the start of Run 2. Stove coals and ash may remain in the stove until 1 hour before conducting Run 3. All coals and ash shall be removed at least one hour prior to commencing Run 2.

11.9. *Failure to Operate at All Test Conditions*

11.9.1. If the appliance fails two runs due to incomplete or failed test runs, it shall be determined that the appliance has failed the certification test and requires a modification to appliance design. All data for incomplete runs shall be reported. Incomplete failed test runs are defined as the following:

11.9.1.1. If a wood heater fails to complete all four phases of the test run, the run shall be considered an incomplete test run.

11.9.1.2. If there is no weight change for a consecutive period of 20 minutes at any point during the test, the unit has failed the test run.

11.9.1.3. If the wood heater fails to comply with test protocol parameters

11.9.2. If a test run violates the parameters of the test method, the run is invalid.

11.9.3. If during certification testing a critical component of the stove is damaged or breaks, the certification test will be stopped and considered invalid.

11.9.3.1. If damage is noted during a test, repairs shall be made by the manufacturer (or by laboratory personnel with written direction from the manufacturer). If the repair involves components that require aging, the appliance shall then undergo another round of wood heater aging as specified in section 10.6. Components requiring aging shall include but are not limited to catalyst elements, gaskets, and refractory components. Manufacturers have the option of aging these elements in other prototypes. The aging process is intended not only to 'cure' the stove but also to cycle parts that may fail with extended use. Alternate aging techniques may be approved by the administrator, depending on the nature of the failure, material, and critical nature.

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11.10. Test Run Completion. Once three valid runs have been completed, the testing is complete. No additional runs may be completed.

11.10.1. *Additional Test Runs*. If there is an invalid run, may attempt two additional runs to complete the test series. If more than three test runs are conducted, the results from all valid test runs shall be used in calculating the average emission rate. The measurement data and results of all test runs shall be reported regardless of which values are used in calculating the emission rate. No test run data can be eliminated from the reporting requirements of this method.

11.10.2. *Invalid Runs.* When a test run fails to meet one of the QA/QC criteria stipulated in the test method, the data are invalid and the run must be repeated. Data for the invalidated test run must be included in the test report but the data must not be used in calculation of average emission values.

11.10.3. *Incomplete Runs.* When an appliance cannot successfully complete all operational elements of the protocol specified in Section 11.6.7 through 11.6.10, it is an incomplete run.

11.11. Auxiliary Wood Heater Equipment Operation. If optional heat exchange blowers are sold for use with the wood heater, three runs with the fan and an additional run without the fan shall be completed. If emissions are more than 1 gram per higher with the fan on, an additional two runs must be completed with the fan on. Heat exchange blowers shall operate in the highest airflow setting. (Automatically operated blowers shall be operated as designed) during the entire test.

11.12. PM Data Recording.

11.13. All data shall be collected and recorded at intervals of no more than 1 minute. TEOM data shall be averaged up to 1-minute intervals for reporting. TEOM operation shall follow the procedures listed in NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

11.13.1. Data shall be reported in an Excel or compatible spreadsheet following the minimum data reporting requirements. All electronic files shall be submitted as part of the test report. Spreadsheet files shall be supplied as part of the publicly available test report.

11.13.2. Room PM measurement – TEOM. A TEOM shall be used to measure ambient lab air PM during the test, as configured in NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel. The sample flow shall be 2 LPM.

12. Quality Control Measures

12.1. Dilution tunnel - Conduct sampling equipment leak check and calibration pre- and post-test.

12.2. TEOM – Flow and Leak checks are done before and after every test run per NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

12.3. Volume Metering System Checks.

13. Data Analysis and Calculations. –

13.1. Emission Calculations. Particulate matter, carbon dioxide, and carbon monoxide shall be calculated using the following methodology and reported in grams per hour, grams per kilogram and pounds per million British Thermal Unit (BTU) heat output. All calculations shall be conducted using all decimal values provided by the instrumentation or recorded by the operator. No truncation of data is acceptable. Only the final calculation of the PM emissions rate shall be rounded, to three significant figures.

13.2. TEOM data shall be reported as follows.

13.2.1. Emissions from each of the 4 phases of the test shall be reported as individual results in grams per hour, grams per kilogram, and lb/MMBtu (heat output).

Emissions from the entire test run in grams per hour, grams per kilogram, and lb/MMBtu (heat output).

Nomenclature

AER = Ei/∑N
BR – average dry fuel burn rate, lb./min
$BR_{(x)}$ – Burn rate for specific phase, BR_{L1}, BR_{L2}, BR_{L3}, BR_{L4}
CO – Carbon Monoxide
CO_2 – Carbon Dioxide
H_2- Hydrogen
O_2 – Oxygen
BT = time of 90% of overnight load consumed – time of overnight loading
C_{steel} – Specific heat of steel (0.1 Btu/ lb., ˚F)
E_T – Total particulate emissions for the full test run in grams
$E_{g/MJ}$ – PM Emissions rate in grams per megajoule of heat output
$E_{g/kg}$ – PM Emissions factor in grams per kilogram of dry fuel burned
$E_{g/hr}$ – PM Emissions factor in grams per hour
E_{Rco} – CO emission rate, g/hr.
EIi – Average CO emission index for interval i
E_{ICO} – CO emission index, g/kg dry fuel
EIco,avg – Average CO emission index for the run
HHV – Higher heating value of fuel = Use accredited test results
LHV – Lower heating value of fuel = Use accredited test results
$\%M_d$ = Fuel moisture content, dry basis, percent.
$\%M_w$ = Average moisture in test fuel charge, wet basis, percent

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N = Total number of test runs.
PCTCO2– average CO_2 in the dry flue gas (%)
PPMco -average CO in the dry flue gas (ppm)
Q_{out} – Total heat output in BTU's (megajoules)
SC_i – Scale weight at specific time interval, lb.
$t_{(i)}$ – Data sampling interval in minutes
T1 – Surface Temperature 1 °F (°C)
T2 – Surface Temperature 2 °F (°C)
T3 – Surface Temperature 3 °F (°C)
T4 – Surface Temperature 4 °F (°C)
T5 – Surface Temperature 5 °F (°C)
T6 – Pre Catalyst Temperature 1 °F (°C)
T7 – Post Catalyst Temperature 2 °F (°C)
T8 – Tunnel Temperature °F (°C)
T9 - Flue Gas Temperature °F (°C)
T10 – Room Temperature °F (°C)
$TS_{avg(i)}$ – Initial Average Surface Temperature °F (°C)
$TS_{avg(f)}$ – Final Average Surface Temperature °F (°C)
W_{fuel} – Fuel charge weight in pounds (kg)
W_i – Weight of fuel in pounds (kg)
W_{app} – Weight of empty appliance in pounds (kg)
Θ – Total length of test run, hours
$\Theta_{(x)}$ – Total length of test run in hours per phase, X
$\%M_w = 100(\%M_d)/100+\%M_d$

13.3. Average Wood Heater Surface Temperatures. Calculate the average of the wood heater surface temperatures at the start of the phase (L4) and end at the end of the test (L4) of the test run.
L4 $TS_{avg(i)} = (T1 + T2 + T3 + T4 + T5) / 5$
L4 $TS_{avg(f)} = (T1 + T2 + T3 + T4 + T5) / 5$
Average surface temperatures at the start and end of any phase can be determined by averaging all five sensors at the beginning and end of each phase.
L_x $TS_{avg(i)} = (T1 + T2 + T3 + T4 + T5) / 5$
L_x $TS_{avg(f)} = (T1 + T2 + T3 + T4 + T5) / 5$

13.4. Burn Time Rating– A standardized burn time rating shall be determined by rounding the duration of the overnight-fire phase of the test up to the nearest 1 hour. Burn time shall be calculated as the time L4 is loaded into the stove until 90% of the fuel has been consumed. This provides an important rating for consumers and is not intended for any calculation purposes and shall be reported on the all manufacturers materials that provides specifications on appliance performance. Language such as "this stove has demonstrated a low setting burn time of x hours in official testing"

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13.5. Determine Burn Rates

BR_{L1} = not applicable
BR_{L2} = (L2 Initial SC_i – L2 Final SC_i) / $\Theta_{(L2)}$, lbs./hr
BR_{L3} = (L3 Initial SC_i – L3 Final SC_i) / $\Theta_{(L3)}$, lbs./hr
BR_{L4} = (L4 Initial SC_i – L4 Final SC_i) / $\Theta_{(L4)}$, lbs./hr

13.6. Emissions

13.6.1. Determine emission rates and emission factors as:

$E_{g/MJ} = E_T/(Q_{out} \times 0.001055)$, g/MJ
$E_{g/kg} = E_T/(W_{fuel}/(1+M\%M_d/100))$, g/dry kg
$E_{g/hr} = E_T/\Theta$, g/hr

13.7. Efficiency calculation.

Ultimate Analysis of dry fuel (% by weight)

Carbon – CA
Hydrogen – HY
Oxygen – OX
Moisture Content – mass of water per mass of dry fuel – Mcdb
Ambient Humidity Ratio – mass of water per unit mass of dry air – ω
Flue gas temperature (F) – Ts
Room temperature (F)-Tr
CO in the dry flue gas (ppm) – PPMco
CO2 in the dry flue gas (%) – PCTCO2
Higher heating value of the dry fuel (lb/MMBtu) – HHV

<u>Combustion Balance Equation:</u>

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

Where:

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

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[EMBED Equation.DSMT4] excess air parameter, e.g. if [EMBED Equation.DSMT4] 0.5 there is 50 % excess air

From this:

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

With flue gas CO and CO_2 measured, these two equations can be solved simultaneously for [EMBED Equation.DSMT4] and [EMBED Equation.DSMT4].

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

<u>Calculation of the Molar Coefficient for Each of the Products</u>

For the assumption of 100 kg of dry fuel, this is the number of moles of each product for the input conditions

[EMBED Equation.DSMT4] Molar Coefficient for CO

[EMBED Equation.DSMT4] Molar Coefficient for CO_2

[EMBED Equation.DSMT4] Molar Coefficient for H_2O

[EMBED Equation.DSMT4] Molar Coefficient for O_2

[EMBED Equation.DSMT4] Molar Coefficient for N_2

<u>Heat Capacity of Exhaust Products</u>

The general equation for representing how the heat capacity of the exhaust products varies with temperature is:

[EMBED Equation.DSMT4]

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THIS INTEGRATED-DUTY-CYCLE (IDC) PROTOCOL FOR WOOD STOVES IS THE PROPERTY OF THE NEW YORK STATE ENERGY RESEARCH AND DEVELOPMENT AUTHORITY (NYSERDA) AND CAN BE USED TO TEST TECHNOLOGIES IN A LABORATORY SETTING. ANY DEVIATIONS OR CHANGES TO THIS IDC PROTOCOL FOR WOOD STOVES ARE NOT APPROVED OR SANCTIONED BY NYSERDA.

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Where:

C = heat capacity J/mol K or kJ/kgmol K

A and B are constants

Tk = Temperature in °K

The values for A and B for the exhaust components are provided in the table below

Component	A	B
CO	.0056	27.162
CO2	.029	29.54
H2O	.0057	32.859
O2	.009	26.782
N2	.0062	26.626

For each component, heat capacity is calculated at the stack temperature and at room temperature. The average of these is used to calculate sensible heat loss.

<u>Calculation of Heat Losses for Efficiency Determination</u>

[EMBED Equation.DSMT4] Higher heating value in kJ/kg (conversion from Btu/lb)

[EMBED Equation.DSMT4] Latent heat of water vapor in kJ/kgmol

[EMBED Equation.DSMT4] Heat loss in latent heat of water vapor, % of input energy

[EMBED Equation.DSMT4] Heat loss in chemical energy in CO, % of input energy

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4] Heat loss in sensible heat in flue gas, % of input energy

[EMBED Equation.DSMT4] Stack loss efficiency, %

14. Reporting Requirements. The report shall include the following:

14.1.1. Introduction

14.1.2. Purpose of test: certification, audit, efficiency,

14.1.3. Name and location of the laboratory conducting the test.

14.1.4. Wood appliance identification – manufacturer, model number/name, design type, description of the appliance tested, stove condition, and date of receipt.

14.1.5. Test information – location of testing, date of tests, sampling methods used, number of test runs, a statement detailing any previous certification testing completed on the wood appliance.

14.1.6. A list of people who conducted research on the appliance, participated in testing preparation, or witnessed the certification testing. This list shall clearly specify their roles in the testing program for the appliance. The list shall include the participant's name, title, company, contact information and the purpose of their participation.

14.1.7. A statement that the test results apply only to the specific appliance tested.

14.2. Summary and Discussion of Results

14.2.1. Table of results to include test run number, average burn rate for entire run and each phase, carbon monoxide and particulate emission rate for full run, particulate and carbon monoxide emission rate for each load phase (L1, L2, L3, L4), efficiency for the full run and each phase, burn time for total run and each phase.

14.2.2. For each test run use the TEOM data and use real-time gas analyzer data for other emissions to report: Θ_1,Θ_2, Θ_3, CO, CO_2, PM, and efficiency for (1) L1 - the startup phase and (2) L2 - high-, (3) L3-maintenance-, and (4) L5 low burn rate fire phases. Calculated results for the emissions shall be reported as total emissions in grams, pounds per million Btu output, grams per MJ, grams per kilogram of dry fuel and grams per hour, and pounds per hour.

14.2.3. A narrative discussion detailing any issues or anomalies that arose during each test run and how those were handled, including comments about the fuel, and loading of the appliance.

14.2.4. A plot of CO emission rate in ppm vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.5. A plot of CO_2 emission rate in ppm vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.6. A plot of PM emission rate in grams/hour vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.7. A plot of PM emission rate in g/kg vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.8. Summary of other data – test facility conditions, surface temperature averages, catalyst temperature averages, pretest fuel weights, test fuel charge weights – total and by phase.

14.3. Discussion. Test run result, specific test run problems and solutions. Comments on fuel, loading, analysis, and anything that may impact the reported result(s).

14.3.1. Details of deviations from, additions to or exclusions from the test method, and their data quality implications on the test results (if any), as well as information on specific test conditions, such as environmental conditions. An explanation of the deviations, additions, or exclusions shall be provided along with an analysis as to why these elements had no impact.

14.4. Process description:

14.4.1. Data and drawings indicating the firebox size and location of the fuel charge.

14.4.2. Drawings and calculations used to determine firebox volume to include volume, height, width, and lengths, weight, and volume adjustments.

14.4.3. Firebox configuration – At a minimum to include air supply locations and operation, air supply introduction location, refractory location and dimensions, catalyst location, baffle and by-pass location and operation (include line drawings or photographs)

14.4.4. Appliance operation during the test – shall supply details on air supply settings and adjustments.

14.5. Test fuel properties – the report shall provide information on the species, density, fuel moisture, fuel temperature, and load details from the fuel load calculator to include all measurements including the number of pieces, individual piece weights, piece length, moisture content and weight.

14.6. Sampling

14.6.1. A description of the test procedures and test equipment, including a schematic or other drawing showing the location of all required test equipment. Also, a description of test fuel sourcing, handling and storage practices shall be included.

14.6.2. Describe the sampling location relative to the wood heater, include drawing or photographs.

14.6.3. Provide data on sampling blanks.

14.7. Quality Control and Assurance Procedures

14.7.1. Calibration procedures and results certification procedures, sample and analysis procedures.

14.7.2. Test method quality control procedures to include TEOM leak and flow checks, stratification (velocity) checks, tunnel flow range results, filter temperature range verification and dilution tunnel RH verification.

14.8. Appendices

14.8.1. Results and Example Calculations. Raw data and complete calculations for data included in summary tables.

14.8.2. Raw data. Copies of all files or sheets for sampling measurement, temperature records, and other materials used by lab related to testing.

14.8.3. Calibration Results. Summary of all calibrations, check, and audits pertinent to the certification.

14.8.4. Sampling and Operation Records. Copies of all uncorrected records of activities not included in

raw data sheets (e.g., wood heater door open, times and durations) as well as photographs of fuel loading and air flow settings.

14.8.5.Correspondence. Any correspondence to include written, electronic or verbal communications regarding appliance testing. Items shall include:

14.8.5.1.Request to conduct testing

14.8.5.2.Scheduling of testing

14.8.5.3. Notice to EPA to conduct test, and any modifications to that request.

14.8.5.4. Notice and submission of data to EPA after testing completed.

14.8.6.Test Facility Information. Report test facility temperature, air velocity, and humidity information.

14.8.7.Test Equipment Calibration and Audit Information. Report calibration and audit results for the platform scale, test fuel balance, test fuel moisture meter, and sampling equipment including volume metering systems and gaseous analyzers.

14.8.8.Pretest procedures. Report all pretest procedures conducted at the lab on the appliance to burns, rates, and amounts.

14.8.9.All required data for each test run shall be provided in spreadsheet format both in the printed report and in a computer file such that the data can be easily analyzed and calculations easily verified. Formulas used for all calculations shall be accessible for review.

14.8.10.For each test run: report TEOM flow and temperature and verification of all TEOM data validation parameters as required in NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

14.8.11.Raw data, calibration records, and other relevant documentation shall be retained by the laboratory for a minimum of 7 years.

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Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 5/28/2021 12:09:50 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
Subject: IDC protocol

Hi Stef, fyi, I removed oak fuel from the protocol since it is now down to maple, doug fir, and birch for the EPA testing. Please let me know if this is an issue for you.

Lisa

NESCAUM

Lisa Rector, Policy and Program Director at **NESCAUM**
89 South Street, Suite 602, Boston, Massachusetts, 02111 | 802.899.5306| 617.259.2095 | Fax: 617.742.9162
| lrector@nescaum.org

Message

From: George Allen [gallen@nescaum.org]
Sent: 11/16/2020 9:15:09 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]; Lisa Rector [lrector@nescaum.org]
CC: Toney, Mike [Toney.Mike@epa.gov]; Brashear, Angelina [Brashear.Angelina@epa.gov]; Garnett, Kim [Garnett.Kim@epa.gov]; Nash, Dave [Nash.Dave@epa.gov]
Subject: Re: Diluent stratification measurement in the dilution tunnel

Stef - thanks. I think using a few diff approaches is useful - CO2, optical pm, and the Teom as the gold standard.
George

At 04:04 PM 11/16/2020, Johnson, Steffan wrote:
George and Lisa,
Here is one thought for diluent measurement that would also provide insight into water vapor concentration(s).
https://gcc01.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.licor.com%2Fenv%2Fproducts%2Ftrace_gas%2FLI-7815&data=04%7C01%7CBrashear.Angelina%40epa.gov%7Cf19070ca13d2402748ae08d88a74b742%7C88b378b367484867acf976aacbeca6a7%7C0%7C0%7C637411581183050187%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C2000&sdata=UCS5PxKa%2F5R0Z025RFWBQfhrrKzNFfihKVxOvLr%2BCiU%3D&reserved=0

The advantage of this technology is that it has a very quick response time, and that aids in keeping traverse data meaningful.

Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 5/25/2021 2:33:26 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
Subject: FW: revised eom sop list for EPA
Attachments: 21-05-25 important dichot Teom SOP questions for EPA.docx

Stef, thanks to you and your team for taking the time to talk to us today. Attached is the list of questions for the TEOM SOP we discussed on today's call.

Lisa

Teom SOP comment summary
May 25, 2021

#2. *This procedure requires that dilution tunnel flows be at least 600 cfm to avoid condensation of water vapor in the sampling system.*
This is for stoves; need to higher for boilers/furnaces?

#4. Do we want to allow 3/8@ OD tube for the probe into the tunnel? Or stay w/ 1/4" od?

#5. *inlet tubing must be replaced or solvent-cleaned after every series of tests.*
Measure Catch? Do a solvent rinse/recovery? That=d require all SS tubing from tunnel to Teom inlet. It would require doing it on the heated down-tubes also. An alternative for the down-tubes would be to wire-brush them and measure the mass on the Teom filter, but this won=t capture condensed PM.

#8. There currently is no Azero-air@ stability test; it could be added as an overnight (12-h minimum, with clean filter) test before and after a set of tests. Not that important.

#13. *The mass transducer K0 (calibration factor) checks described here must be done before and after each set of test runs.*
Presumably also for the lab air Teom? Need some generic text describing what does/does not apply to lab air teom.

#15. *K0 mass transducer tolerance limits of 2%*:
Ideally the difference in the two K0 errors should ALSO be within 1% of each other to minimize the difference between channels B easier to meet the collo 5% limit. If +2 and -2%, you have a 4% error built in.

#16. *3. Noise: 3-minute running average of (100 x noise / concentration) is < 0.05*
This QC metric is preliminary and might be changed. Maybe 0.1?

#20. *These values must meet these criteria for TEOM data from a run to be valid, and assume the dilution tunnel is well-mixed.*
Some pass/fail run criteria may need to be relaxed to accommodate less than ideal mixing? Simple 7.5% run avg agreement.

#21. TBD: how to determine the tunnel is well mixed and not the cause of failing to meet these criteria. May need some Teom collo performance diagnostic tests.

#22. *Conversion to PM emission rates and other reporting metrics require data generated from other sources (wet STP tunnel flow, stove scale, and heat output data), and are not part of this SOP; those calculations are only noted below for completeness.*
Should these calcs be part of this SOP, or in the calcs section of the IDC SOP?

#28. *Results are not shown in column E unless there are valid data for both dichot TEOM*

channels and for the lab air PM TEOM data.
How should we handle cases where there is excessive missingness for just 1 dichot channel?
Example: from a bad filter change that does not get fixed.

Message

From: George Allen [gallen@nescaum.org]
Sent: 9/16/2020 8:28:01 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
CC: Holder, Amara [holder.amara@epa.gov]; Brashear, Angelina [Brashear.Angelina@epa.gov]; Toney, Mike [Toney.Mike@epa.gov]; Garnett, Kim [Garnett.Kim@epa.gov]; Nash, Dave [Nash.Dave@epa.gov]; lrector@nescaum.org
Subject: key changes to Teom SOP

Hi Stef - I want to be sure on a few key points from our discussions on operational details. If you're not sure on one, just note that and we will come back to it later, noted in the clean draft. There are a few pieces that need to wait for our Thermo conversation, including how to process the TeomB (pm-c) channel data and how to use the noise parameter in data validation.
Thanks - George

By the #s:

1a. Both Teom filters only get changed when % loading on either channel [eg, whichever hits 120 % first] reaches 120% [or when the flow setpoint can't be maintained, but that would point to a bad pump]. For reference, that's a delta-P across the filter of approx. 0.6 atm or ~ 18" Hg vacuum. Normally they should load almost [but not precisely] identically.

1b. For data validation, should we accept as valid all data with filter loading > 120% as long as the flow is within 5% of the setpoint? Eg, if they are late in changing them, how to validate those data?

2. Negative data due to normal filter dynamics are left as is - not set to 0, and not removed. Note that we have occasionally seen short periods with negative concentrations as much as 20 mg/m3 due to extreme filter dynamics.

3. "missing" data due to filter changes are left missing [or whatever term you prefer here].

4. Teom Temperature zones are fixed, always at 33 C year round.

5. Sample flow rate: fixed or within a range such as 0.5 to 2 lpm? If it's a fixed value, I'd go for 1.00 lpm. That's a face velocity of 12.5 cm/sec, and should be ok for most devices as long as tunnel flow is at least 500 cfm.

6. Presumably we are requiring Teom flow and leak checks before and after each test run - please confirm.

7a. Teom data are to be reported at 70F (21.1C) and 1 Atm, with dry sample flow. Need to confirm standard P of 1 Atm.

7b. I think we decided to use actual tunnel dewpoint data to "dry" the sample flow, but we could also re-plumb both Teom channels thru a dryer before the internal mass flowmeter. Please confirm how you'd like this to be done.

Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 3/30/2021 5:41:48 PM
To: cindy.heil@alaska.gov; Johnson, Steffan [johnson.steffan@epa.gov]; Toney, Mike [Toney.Mike@epa.gov]; Brashear, Angelina [Brashear.Angelina@epa.gov]
Subject: RE: revised protocol
Attachments: NYSERDA IDC Stove Protocol Version 7C 3 30 2021.pdf

Hi everyone, I was told that the previous file could not be opened so I have attached a new version of the protocol. Please note that the only change is in Section 3.29 (p4). In the fuel load definition, it should read 75% of fuel pieces, not 5% per the previous version. My apologies for the typo. No other changes were made.

Lisa

From: Lisa Rector
Sent: Tuesday, March 30, 2021 12:45 PM
To: cindy.heil@alaska.gov; Johnson, Steffan <johnson.steffan@epa.gov>; Toney.Mike@epa.gov; Brashear, Angelina <Brashear.Angelina@epa.gov>
Subject: revised protocol

Hi everyone, my apologies, the ATM has been revised to reflect the IDCs as run for our research, which is 75% of the fuel pieces must have bark. The previous version had a typo that said 5%.

NESCAUM

Lisa Rector, Policy and Program Director at **NESCAUM**
89 South Street, Suite 602, Boston, Massachusetts, 02111 | 802.899.5306| 617.259.2095 | Fax: 617.742.9162 | lrector@nescaum.org

THIS INTEGRATED-DUTY-CYCLE (IDC) PROTOCOL FOR WOOD STOVES IS THE PROPERTY OF THE NEW YORK STATE ENERGY RESEARCH AND DEVELOPMENT AUTHORITY (NYSERDA) AND CAN BE USED TO TEST TECHNOLOGIES IN A LABORATORY SETTING. ANY DEVIATIONS OR CHANGES TO THIS IDC PROTOCOL FOR WOOD STOVES ARE NOT APPROVED OR SANCTIONED BY NYSERDA.

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NYSERDA Integrated Duty Cycle Test Method for Certification of Wood-Fired Stoves Using Cordwood: Measurement of Particulate Matter (PM) and Carbon Monoxide (CO) Emissions and Heating Efficiency

Note: This method does not include all the specifications (e.g. equipment and supplies) and procedures (e.g., sample and analytical) essential to its performance. Some material is incorporated by reference from other methods. Therefore, to obtain reliable results, persons using this method shall have a thorough knowledge of at least the following EPA Tests

- Method 1- Sample and Velocity Traverses for Stationary Sources
- Method 2- Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube)
- Method 3 – Gas Analysis for the Determination of Dry Molecular Weight
- Method 4 – Determination of Moisture Content in Stack Gases
- Method 5G – Determination of Particulate Matter from Wood Heaters (Dilution Tunnel Sampling Location)
- Method 10 - Carbon Monoxide - Instrumental Analyzer
- Method 28 – Certification and Auditing if Wood Heaters

1. Scope and Application

1.1. This test method specifies operation and fueling for certification and auditing of manually operated wood-fired stoves and heaters.

1.2. This test method measures particulate matter (PM) emissions, carbon monoxide, and efficiency.

1.3. Particulate emissions are measured by the dilution tunnel method as specified in ASTM E2515 Standard Test Method for Determination of Particulate Matter Emissions Collected in a Dilution Tunnel using only Emfab Pallflex filters. Additional particulate matter emissions measurements may also use the Tapered Element Oscillating Microbalance (TEOM) continuous PM method, as detailed in this test method.

1.4. Analyte. Particulate matter (PM). No CAS number assigned. Carbon monoxide (CO). No CAS number assigned.

1.5. Applicability. This method is applicable for the certification and auditing of wood space heaters, which burn cordwood fuel. The test quantifies PM and CO emissions and provides overall efficiency ratings, maximum burn time, and heat output.

1.6. Data Quality Objectives. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods

1.7. Distinguishing features of appliances covered by this standard include:

1.7.1. Cordwood fuel is hand-fed into firebox.

1.7.2. A chimney or vent that exhausts combustion products from the appliance.

1.8. The values stated are to be regarded as the standard, whether in I-P or SI units. The values given in parentheses are for information only.

1.9. Data Quality Objectives.

1.9.1. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods.

1.9.2. Measurement of emissions and heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

1.9.3. This is a laboratory method intended to capture operating periods that are representative of actual field use without excessive test burden.

2. Referenced Methods

2.1. NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel

2.2. ASTM 2515: Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel.

3. Definitions

3.1. Appliance – a wood heater capable of and intended for space heating defined in the applicable regulation. Appliance includes combustion chamber, combustion air settings, operating controls, and a thermostat, if specified, and any other accessory required for standard operation, such as a barometric damper,

3.2. Catch - any mass from the sample probe system on the filter.

3.3. Certification or audit test - a series of at least three test runs conducted for certification or audit purposes that meets the specifications detailed in this protocol.

3.4. Chop – using a poker or another piece of wood to strike a piece of the fuel charge to break it into smaller pieces.

3.5. Coal-bed Stirring – prior to adding a new fuel charge, using a poker or piece of wood to stir or level the coal bed of the appliance for the sole purpose of ensuring ease of loading of the fuel

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charge. No special formations can be made, such as creating coal bed formations or pushing coals to one side or creating slopes with the coals.

3.6. East-west stove – a stove where the firebox dimension parallel to the loading door is greater or equal to the stove depth measurement. Logs are loaded so that they are viewed on the long length of the stove.

3.7. Emission factor – the emission of a pollutant expressed in mass per unit of energy (typically) output from the appliance.

3.8. Firebox - the portion of the chamber in the wood heater in which the test fuel charge is placed and combusted.

3.9. Firebox depth - the horizontal length of the fire chamber dimension measured perpendicular to the loading door. If the manufacturer believes that a portion of the firebox depth is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.10. Firebox Height - the vertical distance extending above the top of the firebox to the floor of the firebox. Firebox height is not necessarily uniform. The measurement must account for variations caused by internal baffles, air channels, or other permanent obstructions. If the manufacturer believes that a portion of the firebox height is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.11. Firebox width - the horizontal fire chamber dimension that is parallel to the loading door. If the manufacturer believes that a portion of the firebox width is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.12. Fuel Adjustment –manipulations to the fuel charge to reflect typical owner practices that allow the cordwood fuel to burn appropriately during the test period. A fuel adjustment does not include chopping the wood or stirring the coal bed.

3.13. Fuel load calculator – The locked excel spreadsheet tool that determines the allowable test fuel load weights and required piece sizes for each individual load.

3.14. Fuel loading direction – Fuel shall be loaded parallel to the greater of the width and depth dimensions for loads 2, 3 and 4. Criss-cross is allowed for startup phase and cannot be used as a load configuration for loads 2, 3 or 4. If the firebox length and width are within 2" fuel shall be loaded in an east/west fashion, parallel to the loading door.

3.15. Kindling pieces – small pieces of wood less than 1" in diameter. No bark or moisture requirements for these pieces, however kindling pieces shall not be dried or stored anywhere but in laboratory ambient conditions. Kindling length shall be of the same as the fuel charge length. and shall represent weights that would enable 8 to 12 pieces equal one pound.

3.16. Large fuel pieces – pieces that are larger for the appliance as defined by the fuel load calculator.

3.17. L1 – Start-up – period of the test when the unit has kindling and startup fuel under the conditions described in Section 11.6.7.

3.18. L2 – High-fire Phase – period of the test when the unit has a small coal bed and the stoves air settings are fully open. Intended to replicate period when homeowners are trying to quickly heat an area, shortly after starting or restarting the appliance.

3.19. L3 - Maintenance-fire phase– period of the test when a fire is maintained with a medium-sized coal bed, and a smaller batch of wood. This is intended to simulate a period when the operator is trying to maintain consistent heat output.

3.20. L4 - Low-burn Rate Phase – period of the test when the stove has a large coal bed, stove is fully loaded, and the adjustable air settings are set to produce the lowest possible burn rate and have the lowest air settings. Intended to simulate a period the operator is trying to maintain heat over a long period of time, such as overnight or while away for significant periods of time.

3.21. North-south stove: a firebox which has its longest dimension measurement perpendicular to the loading door. In this stove type, logs are loaded so that the ends of the fuel are viewed when loaded.

3.22. Phase – A distinct period in the test run with its own operational procedures and conditions.

3.23. Primary air supply – air supply that introduces air to the wood heater in the combustion chamber and is adjusted to target a desired burn rate. The wood heater manufacturer or test facility can document this through design drawings.

3.24. Secondary air supply - air supply that introduces air to the wood heater such that the burn rate is not altered by more than 10 percent when the secondary air supply is adjusted during the test run. The wood heater manufacturer or test facility can document this through design drawings that show the secondary air is introduced only into a mixing chamber or secondary chamber outside the firebox.

3.25. Small fuel pieces - pieces that are small for the appliance as defined by the fuel load calculator.

3.26. Starter fuel – pieces of cordwood that can be smaller than small and large pieces but larger than kindling, as defined by the fuel load calculator.

3.27. Test data– means the data for all test runs conducted on the wood heater, including any data collected during failed and invalid runs and includes records of preparation of standards, identification of equipment used and personnel present, records of calibrations, raw data sheets for field sampling, raw data sheets for field and laboratory analyses, chain-of-custody documentation, and example calculations for reported results.

3.28. Test facility - the area in which the wood heater is installed, operated, and sampled for emissions.

3.29. Test fuel charge - the collection of test fuel pieces used in each of the four phases of the test run. L2, L3, and L4 require that at least 75% of the individual pieces with at least 80% bark on one side of the fuel piece. Bark shall not be removed for certification testing. Any fuel charge that

suggests bark was purposely removed or shaped shall deem the certification test invalid. Examples of fuel piece manipulation are provided in Section 11

3.30. Test fuel load – the group of test fuel pieces that are loaded, as specified by phase, throughout the test run. Test fuel loading means the arrangement of the test fuel charge.

3.31. Test fuel loading density - the calculation that determines the weight of the as-fired test fuel load. The calculation is based on the usable volume of the firebox.

3.32. Test run - an individual emission test that includes the four operational phases required by the fueling protocol.

3.33. Usable firebox volume - the calculated volume of the firebox determined using its height, width, and depth as defined in this section. This calculation represents the area where wood is likely to be loaded. If the manufacturer claims that portions of the firebox may not be used in the calculation a justification must be submitted with the test report. If the justification is not approved, the test results will be deemed unrepresentative for certification purposes. It is highly recommended that manufacturers obtain regulatory approval if making claims that portions of the firebox are not appropriate for inclusion in the calculation.

3.34. Wood heater - an enclosed, wood-burning appliance capable of and intended for space heating or domestic water heating, as defined in the applicable regulation.

4. *Interferences*

None.

5. *Summary of Method*

5.1. Particulate matter emissions are measured from a wood heater burning cordwood test fuel in a test facility maintained at a set of prescribed ambient conditions. Procedures for operating the appliance, measuring PM and CO emission rates, and methods for reducing data and calculating results are provided.

5.2. *Dilution Tunnel.* A dilution tunnel following the specifications detailed in ASTM E2515-11 shall be used for particulate measurements.

5.3. *Particulate Matter:* PM emissions are measured in a dilution tunnel specified in ASTM 2515-11 *Standard Test Method for Determination of Particulate Matter Emissions Collected in a Dilution Tunnel* with exceptions as defined in Section 10.1. The flow rate in the dilution tunnel is maintained at a constant rate throughout the test cycle and accurately measured.

5.4. *Carbon Monoxide.* CO emissions are measured in the stack and used to calculate efficiency determination.

5.5. *Operation.* Appliance operation is conducted on a cold-to-hot test cycle, meaning that the appliance starts the first test run at room temperature and ends with the appliance in fully heated

state. The second and third test runs are started a slightly warmer temperature. The appliance is operated at a four operational phases representing start-up emissions, high heat demand, low heat demand, and refueling. To complete the certification test, the appliance shall complete three valid test runs that are averaged to determine the test results.

5.6. *Repeatability.* A series of at least three test runs comprised of six different heat demands or phases conducted for certification or audit purposes

6. Significance and Use

6.1. The measurement of particulate matter emission rates is an important test method widely used in the practice of air pollution control.

6.1.1. These measurements, when approved by state or federal agencies, are often required for the purpose of determining compliance with regulations and statutes.

6.1.2. The measurements made before and after design modifications are necessary to demonstrate the effectiveness of design changes in reducing emissions and make this standard an important tool in manufacturers' research and development programs.

6.2. Measurement of heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

7. Safety

7.1. Disclaimer. This method may involve hazardous materials, operations, and equipment. This test method may not address all the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to performing this test method.

7.2. These tests involve combustion of wood, which releases substantial amounts of heat and combustion products. The heating system also produces large quantities of very hot water and the potential for steam production and system pressurization. Appropriate precautions must be taken to protect personnel from burn hazards and respiration of products of combustion. Exposure of personnel to unsafe levels of carbon monoxide must be avoided, and the use of continuous ambient carbon monoxide monitoring is strongly recommended.

8. Equipment and Supplies. The following items are required for sample collection:

8.1. Anemometer. A device capable of detecting air velocities less than 0.10 m/sec (20 ft/min), for measuring air velocities near the test appliance.

8.2. Appliance Flue.

8.2.1. Steel flue pipe extending to 8.5 ±0.5 ft. (2.6 ±0.15 m) above the top of the platform scale, and above this level, insulated solid pack type chimney extending to 15 ±1 ft (4.6 ±0.3 m) above the

platform scale, and of the size specified by the appliance manufacturer. This applies to both freestanding and inserts type appliances.

8.2.2. Other chimney types (e.g., solid pack insulated pipe) may be used in place of the steel flue pipe if the appliance manufacturer's written appliance specifications require such chimney for home installation (e.g., zero clearance appliance inserts). Such alternative chimney or flue pipe must remain and be sealed with the appliance following the certification test.

8.2.3. Solid pack insulated chimneys shall have a minimum of 2.5 cm (1 in.) solid-pack insulating material surrounding the entire flue and possess a label demonstrating conformance to U.L. 103 (incorporated by reference—see §60.17).

8.3. Appliance Platform Scale and Monitor. For monitoring of fuel load weight change. The scale shall be capable of measuring weight to within 0.01 kg (0.02 lb.) and calibrated to NIST traceable standards at least annually.

8.4. Barometer. Aneroid or another barometer capable of measuring atmospheric pressure to within 0.1 in. Hg (2.5 mm Hg) with an uncertainty of +/- 0.05 in Hg (+/- 1.27 mm Hg).

8.5. Dilution Tunnel must meet the requirements of ASTM E2515, clauses 6.1.6 and 9.2.

8.6. Dilution Tunnel temperature and relative humidity measurement. A probe capable of measuring tunnel temperature to within 0.9 °F (0.5 °C)) and tunnel RH to within 2%, such as the Omega HX85-A or equivalent.

8.7. Draft Gauge. Electromanometer or other devices for the determination of flue draft or static pressure readable to within 0.005 in. H2O (1.2 Pa)

8.8. Flue Gas Temperature Measurement. A type K- thermocouple or equivalent located in the centroid of the stack located 8.0 +/- 0.5 ft (2.44 m +/- 150 mm) above the platform scale. Capable of measuring with an accuracy of 4.0°F (2.2°C) or 0.75% of reading, whichever is greater.

8.9. Flue Gas Composition Measurement. A sample probe and continuous infrared analyzer or equivalent capable of measuring span of carbon monoxide (CO) and carbon dioxide (CO_2) in the flue gas produced by the appliance tested. Continuous analyzers (or equivalent) shall have maximum zero and span drift, over a 24 h period, of 1% of full scale

8.10. Fuel Scale. Balance capable of weighing the test fuel charge to within 0.02 kg (0.05 lb.) and calibrated to NIST traceable standards at least annually.

8.11. Humidity Gauge. Psychrometer or hygrometer for measuring room humidity to within +/- 4% from 25 to 95% RH.

8.12. Moisture Meter. Calibrated electrical resistance meter for measuring test fuel moisture to within 2 percent moisture content.

8.13. Surface Temperatures. Capable of measuring temperature to within 1.5 percent of expected absolute temperatures with an accuracy of 4.0°F (2.2°C) or 0.75% of reading, whichever is greater.

8.14. Test Facility Temperature Monitor. A thermistor, RTD, or other equivalent device, located centrally in a vertically oriented 150 mm (6 in.) long, 50 mm (2 in.) diameter pipe shield that is open at both ends, capable of measuring temperature to within 1°F of expected temperatures.

8.15. TEOM – Thermo Fisher Scientific TEOM model 1405-D (Thermo part # 1405D-ANF, excluding models 1405, 1405-DF, or 1405-F) to measure and report continuous particulate matter (PM) measurements in an ASTM 2515 dilution tunnel or equivalent dilution method, and operated according to the NESCAUM Dichot TEOM Standard Operating Procedures.

9. Calibration and Standardizations

9.1. ASTM E2515-11. Perform all calibrations required by ASTM E2515-11.

9.2. Anemometer. Calibrate the anemometer as specified by the manufacturer's instructions before the first certification test and monthly thereafter.

9.3. Appliance Platform Scale. Perform a multi-point calibration (at least five points spanning the operational range) of the platform scale before its initial use. The scale manufacturer's calibration results are sufficient for this purpose. Before each certification test, audit the scale with the wood heater in place by weighing at least one calibration weight (Class F) that corresponds to between 20 percent and 80 percent of the expected test fuel charge weight. If the scale cannot reproduce the value of the calibration weight within 0.0045 kg (0.01 lb.) or 1 percent of the expected test fuel charge weight, whichever is greater, recalibrate the scale before use with at least five calibration weights spanning the operational range of the scale.

9.4. Barometer. Calibrate using a reference pressure monitor calibrator before the first certification test and semiannually after

9.5. Draft Gauge. Calibrate as per the manufacturer's instructions; a liquid manometer does not require calibration (but must be properly leveled, zeroed and the system leak checked).

9.6. Humidity Gauge. Calibrate as per the manufacturer's instructions before the first certification test and annually thereafter.

9.7. Fuel Scale. Calibrate as described in 9.2.

9.8. Moisture Meter. Calibrate as per the manufacturer's instructions before the first certification test and semiannually thereafter.

9.9. Temperature Sensors. Calibrate using at least five points within operating range within specification and in compliance with NIST Monograph 175. To be calibrated before the first certification test and semiannually thereafter.

9.10. Flue Gas Analyzers. In accordance with CSA B415.1-2010, C

10. Sampling, Test Specimens, and Test Appliances

10.1. Modifications to ASTM 2515 requirements.

10.1.1. Liquid water should not be present anywhere in the sampling system for a valid sample. The presence of condensed water anywhere in the sampling system invalidates the test run. All data from all invalid test runs shall be included in the report. The reviewing authority shall make a final determination on invalidated runs. Data from any invalidated test run shall not be used to calculate results. If the testing agency believes a run has been invalidated, the test run shall be repeated.

10.1.2. Dilution tunnel temperature and relative humidity shall be measured electronically and logged at one-minute intervals near the sample probe to calculate dewpoint. The temperature measurement method shall have an accuracy of 0.5 degrees C (type T-Special TC or a RTD).

10.1.3. The following section details test conditions that shall be maintained for a valid test run. A valid test shall have no more than two individual deviations from any of the conditions below to remain a valid run. An example of an individual deviations is a single, five-minute rolling average where the dilution tunnel exceeded temperature thresholds. Another five-minute period exceeding the tunnel temperature requirement shall be considered a second deviation.

10.1.3.1. Tunnel temperature shall not exceed 104 deg. F (40C) based on ten-minute rolling averages derived from one-minute data, excluding periods when the appliance door is open.

10.1.3.2. Tunnel relative humidity shall not exceed 90% based on ten-minute rolling averages derived from one-minute data excluding periods when the appliance door is open.

10.1.3.3. Tunnel dew point temperature shall be at least 2 deg. C less than filter temperature based on five-minute rolling averages derived from one-minute data.

10.1.3.4. A minimum tunnel flow of 500 CFM is required. Higher tunnel flows may be required to meet the parameters of 8.6.3.

10.1.3.5. All exceedances must be reported in the test anomalies section, even if deviations are within the test method tolerances.

10.2. Sample Collection. The following are required for sample collection:

10.2.1. Proportional Rate Variation shall meet the requirements of ASTM E2515 for all phases.

10.2.2. Particulate Matter Sampling for first-hour filter pull. This method provides two (2) options to obtain PM data for full runs and first-hour PM emissions data.

10.2.2.1. Option 1 – Uses three (3) ASTM 2515 sampling trains. Two trains are run through the entirety of the test to obtain full run data, and the third train obtains measurement for the first hour emissions.

10.2.2.1.1. Train 1 and 2 shall provide dual sampling trains that shall measure PM emissions from run start to run completion. Trains 1 and 2 must meet a precision requirement of 7.5% or lower, regardless of g/kg comparison.

10.2.2.1.1.1. Proportional rate variation shall meet ASTM 2515 requirements for all phases.

10.2.2.1.1.2. Filter conditions must be monitored, and filter changes are required to avoid filter clogging.

10.2.2.1.2. Train 3 will commence at the beginning of the test and cease measurement 60 minutes from the start of the test run.

10.2.2.1.2.1. Proportional rate variation shall meet ASTM 2515 requirements for all phases.

10.2.2.1.2.2. Filter conditions must be monitored, and filter changes are required to avoid filter clogging.

10.2.2.2. Option 2 – Uses two (2) ASTM 2515 sampling trains and a TEOM to obtain real-time data to include the first-hour emission rate. All measurements shall run through the entirety of the test to obtain full run data.

10.2.2.2.1. Train 1 and 2 shall provide dual sampling trains that shall measure PM emissions from run start to run completion. Trains 1 and 2 must meet a precision requirement of 7.5% or lower, regardless of g/kg comparison.

10.2.2.2.1.1. Proportional rate variation shall meet ASTM 2515 requirements for all phases.

10.2.2.2.1.2. Filter conditions must be monitored, and filter changes are required to avoid filter clogging.

10.2.2.2.2. TEOM data shall be colleted at 10-second intervals and averaged up to 1-minute intervals for reporting. TEOM operation shall follow the procedures listed on the most recent TEOM Standard Operating Procedures found on the NESCAUM website at www.nescaum.org/topics/testmethods.html

10.2.3. *Blanks.* Test reports shall measure and report data on blanks as follows

10.2.3.1. Lab blank, which is removed from each filter batch, stored in a protective environment, and weighed during each weighing session.

10.2.3.2. Room blank collected during every test run. The blank shall be placed within 10 feet of the intake for the dilution air

10.2.4. Weigh Room Conditions

10.2.4.1. The facility shall use an active ionizing air blower (or 210Polonium alpha sources) to neutralize charge associated with the filter. 210Polonium alpha sources must be replaced annually or more often.

10.2.4.2. Temperature range of 68 to 78 °F (20 to 25.6 °C).

10.2.4.3. Relative humidity shall be no higher than 45%.

10.2.5. Filter *equilibration / conditioning post sample collection.* Use of desiccation is not allowed. Equilibrate filters at a relative humidity between 30 and 40% for at least 24 hours. A saturated salt solution of magnesium chloride (33% RH) can be used. PREPARATION OF SALT SOLUTIONSU: Use only pure distilled water to make up the solution. Put 200 g of the salt into a beaker. Gradually add distilled water. Stir well after each addition, until the salt can absorb no more water, as will be evidenced by some free liquid on the surface of the mixture. For best results keep the excess liquid to a minimum. The mixture should be slushy but must have a small amount of liquid water on the surface. Put this slushy mixture in the desiccant tray of the equilibration chamber. After equilibration, the chamber RH should measure 33% +/- 3%.

10.2.6. *Probe catch.* Report sampling system catch as a separate number from front and rear filter catch.

10.2.7. Filter *weight measurements.* The test report shall contain the following filter measurements for all filter weights.

10.2.7.1. Day zero – initial filter measurement before going into the equilibrium chamber.

10.2.7.2. Final filter measurement or day-seven measurement, whichever measurement comes first.

10.2.8. *TEOM filters (optional).* Teflon coated glass fiber filters as supplied by the TEOM manufacturer for use with the TEOM model 1405-D. These are Pallflex Emfab (TX40) with an exposed diameter of 13 mm, without organic binder, exhibiting at least 99.95 percent efficiency.

10.3. *Test Specimens.* Appliances shall be supplied as complete systems, including all controls and accessories necessary for installation at the test facility. A full set of specifications, designs, and assembly drawings shall be provided when the product is placed under certification of a third-party agency.

10.4. Preparation of Apparatus

10.4.1. Wood Heater Installation for Certification Testing. Assemble the wood heater appliance and parts in conformance with the manufacturer's provided User Guide. These instructions must match all instructions materials developed by the manufacturer and/or their distributors. Place the wood heater on the platform scale and connect the chimney to the appliance. Clean the flue with an appropriately sized, wire chimney brush before initiating Run 1 of the certification test. Test documentation should include the date and time of flue cleaning.

10.4.2. Wood Heater Temperature Monitors.

10.4.2.1. For catalyst-equipped wood heaters, locate a temperature monitor (optional) about 25 mm (1 in.) upstream of the catalyst at the centroid of the catalyst face area, and locate a temperature monitor (mandatory) that will indicate the catalyst exhaust temperature. This temperature monitor is centrally located within 25 mm (1 in.) downstream at the centroid of the catalyst face area. Record these locations.

10.4.2.2. Locate wood heater surface temperature monitors at five locations on the wood heater firebox exterior surface. Position the temperature monitors centrally on the top surface, centrally on two sidewall surfaces, and centrally on the bottom and back surfaces. Position the monitor sensing tip on the exterior of the firebox surface inside of any heat shield, room air circulation walls, or other wall or shield separated from the firebox exterior surface. Surface temperature locations for unusual design shapes (e.g., spherical, etc.) shall be positioned so that there are four surface temperature monitors in

10.5. Conditioning

10.5.1. Wood Heater Aging Prior to Certification Testing. A wood heater of any type shall be aged at least 50 hours before initiating a certification test. The aging procedure shall be conducted by the manufacturer prior to sending the appliance to the testing laboratory. The certification lab cannot be involved with wood heater aging in any manner. The appliance shall be operated at a variety of burn rates. Documentation for wood heating aging must be included in the test report to include data on individual hour burn rates. The testing laboratory shall not conduct any firing of the appliance prior to conducting the certification test.

10.5.1.1. The manufacturer shall supply wood heater aging information for the final test reports. Aging data that shall be reported include all fuel parameters (species, moisture content, load weights, piece amounts, and size), air settings used, time spent in each air setting phase, amount of fuel burned, and appliance burn rates.

10.5.1.2. If an appliance uses a catalytic combustor, it must be engaged according to the manufacturer's instructions and operate with the catalyst engaged for at least 50 hours during the break-in period. In addition to the reporting requirements listed in 8.1.1, catalytic appliances shall also report hourly catalyst exit temperature data to include the dates and hours of operation.

11. Procedure

11.1. Test Facility Conditions. The test facility shall meet the following requirements during testing.

11.1.1. Shall conform to 9.7 of ASTM 2515-11.

11.1.2. The test facility temperature shall be maintained between 55 and 90°F (13 and 32°C) during each test run.

11.1.3. The flue shall discharge into the same space or into a space freely communicating with the test facility. Any hood or similar device used to vent combustion products shall not induce a draft greater than 0.005 in. H_2O (1.25 Pa) on the wood heater measured when the wood heater is not operating.

11.1.4. For test facilities with artificially induced barometric pressures (e.g., pressurized chambers), the barometric pressure in the test facility shall not exceed 30.5 in. Hg (775 mm Hg) during any test run.

11.1.5. Locate the test facility temperature monitor on the horizontal plane that includes the primary air intake opening for the wood heater. Locate the temperature monitor 3 to 6 ft. (1 to 2 m) from the front of the wood heater in the 90° sector in front of the wood heater.

11.1.6. Use an anemometer, to measure the air velocity. Measure and record the room air velocity before the ignition period in L1 Startup and once immediately following the test run completion. Air velocities within 0.6 m (2 ft) of the test appliance and exhaust system shall be less than 0.25 m/sec (50 ft/min) without fire in the unit.

11.1.7. Measure and record the test facility's ambient relative humidity, barometric pressure, and temperature before and after each test run using equipment as specified in Section 6.

11.2. Wood Heater Firebox Volume.

11.2.1. Determine the firebox volume using the definitions for height, width, and length. Volume adjustments due to the presence of firebrick and other permanent fixtures may be necessary. All adjustments shall be detailed in the test report. Include areas adjacent to and above a baffle.

11.2.2. If a manufacturer deems certain areas of the firebox as unusable for fuel load calculations, written documentation stating the basis for that claim and supporting photographic image(s) must be provided and approved by the regulatory authority prior to conducting the certification test. If approval is not granted prior to the test, then the test may be invalidated if the reviewing agency determines the firebox volume is inaccurate.

11.3. Test Fuel. The test fuel shall conform to the following requirements and meet specifications as required by the fuel loading calculator:

11.3.1. Fuel Species. Untreated, air-dried, cordwood fuel.

11.3.1.1. Allowable species: maple (big leaf, red, silver), oak (red or white), or white birch.

11.3.1.2. Kiln-dried fuel is not permitted.

11.3.1.3. Fuel shall be free of decay, fungus, or other contaminants.

11.3.2. Fuel Moisture.

11.3.2.1. Determine fuel moisture for each fuel piece by averaging four moisture meter readings, one from each of three sides, measured parallel to the wood grain.

11.3.2.2. The test fuel load shall have an average moisture content from 19% to 25%, dry basis.

11.3.2.3. Average individual piece moisture content shall have an average moisture content 18% to 27%.

11.3.2.4. The addition of moisture to previously dried wood is not allowed.

11.3.2.5. It is recommended that the test fuel be stored in a temperature and humidity-controlled room.

11.3.2.6.Fuel moisture shall be measured within 24 hours of using the fuel for the test and shall be stored in a humidity-controlled environment until 2 hours prior to testing.

11.3.3. Fuel Temperature. The test fuel shall be at the test facility temperature of 13 to 32°C (55 to 90°F).

11.3.4. Fuel Dimensions. The dimensions of each test fuel piece shall conform to definitions specified by the protocols using the fuel load calculator.

11.3.4.1.Fuel length:

11.3.4.1.1.The length of the fuel pieces will be determined by the fuel load calculator.

11.3.4.1.2.Measurements shall be taken, and the length of the test fuel will be determined by entering the firebox dimensions, which calculates the length for all the fuel pieces into a generally available commercial size (14, 16, 18, 20 or 22 inches in length).

11.3.4.1.3.Piece length specified by the fuel calculator shall be communicated and specified for use in the owner's manual and website. Piece size shall be within 0.5" of the log length determined by the calculator, as measured on the shortest length measurement.

11.3.5.Fuel Loading Direction

11.3.5.1.Fuel loading direction shall be determined by the firebox measurement.

11.3.5.1.1.Stoves with a depth measurement greater than two inches from the width measurement shall be tested with the fuel in a north-south configuration and may not test with fuel in an east/west or crisscross configuration in any load other than Load 1 and Load 2.

11.3.5.1.2.Stoves with a width measurement greater than the depth measurement or a width measurement within two inches of the depth measurement shall be tested with the fuel loaded in an east-west configuration and may not test with fuel in a north/south configuration or crisscross configuration in any load other than Load 1 and Load 2.

11.3.6.Fuel piece weight for each phase of the protocol shall be determined by the fuel load calculator.

11.3.6.1.Kindling –shall be:

11.3.6.1.1.pieces of wood less than or equal to 1" in diameter.

11.3.6.1.2.No bark requirements for kindling fuel

11.3.6.1.3.Fuel species may be any species allowed in 7.2.1.1.

11.3.6.1.4.No moisture requirements.

11.3.6.1.5.Length of kindling shall be the fuel length specified by the fuel load calculator.

11.3.6.1.6.Kindling fuel shall conform to the rule that 7 to 12 pieces of kindling equal 1 pound of kindling fuel (+/- 10%).

11.3.6.2. Starter fuel: pieces of cordwood shall be used during the startup phase. Individual piece weight for starter fuel shall be determined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall be not be used in testing (see Figure 1). Pieces that have squared cross sections shall be split to represent the typical triangle nature of wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible and fuel load pieces shall be composed to include different shapes of wood if using any trapezoidal pieces. .

11.3.6.3.Small fuel pieces: smaller pieces of cordwood by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall not be used (see figure 1). Pieces that have square cross-sections shall be split to represent the typical triangle nature of wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible. No more than 2 small fuel pieces can be trapezoidal in shape (Figure 2) per fuel load.

11.3.6.4.Large fuel pieces: larger pieces of cordwood, by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall be not be used (see figure 1). Pieces that have square cross sections shall be split to represent the typical triangle nature of wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible. No more than 1 large fuel pieces can be trapezoidal in shape (Figure 2) per fuel load.

Figure 1. Schematic of unacceptable cross-sectional profiles

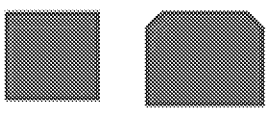


Figure 2.

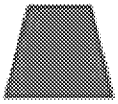
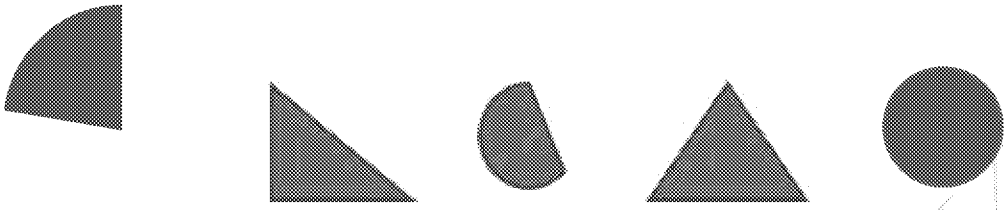


Figure 3. Schematics of acceptable cross-sectional profiles



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11.4. Sampling Equipment.

11.4.1. Prepare the PM and ambient sampling equipment.

11.4.2. Prepare all other equipment as defined by method EPA Method 1, 2, 3, 4, ASTM 2515, and CSA B415.

11.5. Manufacturer participation in certification testing

11.5.1. A representative of the manufacturer may observe testing but may not provide instructions to the certification lab, in any form, with testing staff or equipment once the certification tests begin. The names of testing witnesses cannot be withheld as confidential business information (CBI).

11.6. Test Run Procedure.

11.6.1. Before each test series, the firebox shall be vacuumed. Testing shall begin without any ash or other materials in the appliance.

11.6.2. Before initiating the compliance test, clean the flue and dilution tunnel with an appropriately sized wire chimney brush before each certification test. Test documentation should include the date and time of flue cleaning.

11.6.3. Record fuel weight data, temperature measurements, and gas concentrations at 1-minute intervals.

11.6.4. Wood Heater Operation and Adjustments. Record all adjustments made to the air supply controls, adjustments to and additions or subtractions of fuel, and any other changes to wood heater operations that occur during the test period.

11.6.5. The weight of fuel remaining at the end of the test run is determined as the difference between the weight of the wood heater with the remaining coals and fuel and the weight after loading the fuel charge. The starting weight is the tare weight of the cleaned, dry wood heater.

11.6.6. All runs shall be videotaped in their entirety. Video tape shall be of sufficient quality to determine fuel characteristics, fuel loading procedures, and firebox conditions during any testing or aging conducted by the test lab. The testing lab shall have the capacity to allow appropriate agencies the opportunity to remotely witness the test.

11.6.7.L1: Start-up Phase.

11.6.7.1.L1 Appliance requirements.

11.6.7.1.1. Stove temperature: internal and external stove temperature must not be greater than the ambient temperature +/- 2°F (1.1°C) for Run 1. There is no stove starting temperature requirement for Runs 2 and 3 except in the case of a failed first run. In this case, if Run 1 is invalid or incomplete and, the stove must meet Run 1 conditions for at least one valid run. Temperature measurements for the external and internal temperatures shall be taken within 15 minutes before starting the test and shall be reported in the test report.

11.6.7.1.2. Tare the appliance scale before starting the test. Record appliance scale weights at the start and end of L1 phase

11.6.7.2.L1 Fuel requirements.

11.6.7.2.1.L1 Fuel type – during the startup phase newspaper (optional up to six full sheets traditional newspaper size), kindling, and starter fuel pieces are used. No other additions are allowed.

11.6.7.2.2.L1 loading density

11.6.7.2.2.1. Kindling loading density: 1 lb. per cubic foot for dry kindling, +/- 5%. The fuel load calculator determines the amount of kindling that can be used.

11.6.7.2.2.2. Starter Fuel loading density: 3 lb. per cubic foot, +/- 5%. The fuel load calculator will determine the minimum piece weight that can be used as starter fuel.

11.6.7.2.3.L1 fuel loading structure: The loading structure of the fire shall be a bottom-up configuration with newspaper on the bottom, kindling on top of the paper, and starter fuel on top of the kindling. Kindling and starter fuel shall be loaded in a crisscross configuration.

11.6.7.3.L1 Operational parameters.

11.6.7.3.1.All kindling, starter fuel, and newspaper must be in the firebox for light off.

11.6.7.3.2.Air settings are fully open.

11.6.7.3.3.Light the fire with a torch for a period of no more than 30 seconds.

11.6.7.3.4.Immediately after lighting the fire and completing the photo requirement, the appliance door shall be moved to a cracked open position. Cracked open position is defined as opening no more than one inch. The appliance door shall be closed 5 minutes after ignition.

11.6.7.4.L1 Fuel Adjustments: up to three fuel adjustments are allowed in the startup phase. The door may be open for 30 seconds during each fuel adjustment.

11.6.7.5.L1 End of Phase – the end of the startup phase is defined by the weight specified by the fuel load calculator.

11.6.7.6. L1 Documentation – Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge.

11.6.8. *L2: High-fire Phase* – the high-fire phase commences immediately after the startup phase ends.

11.6.8.1.L2 Appliance requirements.

11.6.8.1.1.Record the weight of the stove prior to loading the L2 fuel charge, the weight of the fuel charge prior to loading, and the scale weight after loading the L2 fuel charge.

11.6.8.2. L2 Fuel requirements.

11.6.8.2.1. L2 piece size – during the high-fire phase, small cordwood pieces by weight, as defined by the fuel load calculator, are used.

11.6.8.2.2. L2 loading density: 7 lb. per cubic foot, +/- 5%. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.8.3.L2 Operational parameters: Open the door upon completion of the startup phase and load the L2 fuel load within 60 seconds. Once the fuel has been loaded, the appliance doors shall be closed immediately. Air settings shall be left fully open. When 50% of the L2 fuel load mass has been consumed, the air settings shall be moved to the lowest settings.

11.6.8.4.L2 Fuel Adjustments.

11.6.8.4.1.One fuel adjustment may be made during the high-fire phase prior to moving the primary air control(s) to their lowest setting. The door shall remain open for 30 seconds for fuel adjustments.

11.6.8.4.2.Additional fuel adjustments shall be made if there is a five-minute period without a weight change of 0.1 pounds at any point during the high-fire phase.

11.6.8.4.3.if there is a five-minute period without a weight change at any point during the high-fire phase. The door may only be open for 30 seconds for fuel adjustments.

11.6.8.4.4.All fuel adjustments must be documented in the test report notes and summary.

11.6.8.5.End of L2 Phase –The high-fire phase ends when the scale indicates that 90% of the high-fire fuel mass has been consumed.

11.6.8.6. L2 Documentation - – Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge.

11.6.9. *L3: Maintenance-fire Phase* – the L3 maintenance-fire phase commences immediately after the L2 high-fire phase ends.

11.6.9.1.L3 Appliance Requirements.

11.6.9.1.1. Record the weight of the stove prior to loading the maintenance-fire fuel charge, the weight of the fuel charge prior to loading, and the scale weight after loading the maintenance-fire fuel charge.

11.6.9.2.L3 Fuel Requirements.

11.6.9.2.1.Fuel type – during the L3 phase, large cordwood pieces are used. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.9.2.2.L3 fuel loading structure: fuel shall be loaded in the direction specified by the fueling calculator.

11.6.9.2.3. L3 loading density: 5 lb. per cubic foot, +/- 5%. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.9.3. L3 Operational Parameters:

11.6.9.3.1.Open door upon completion of the L2 phase and load the maintenance-fire fuel charge.

11.6.9.3.2.L3 Load - L3 fuel loaded within 30 seconds of the door opening. Close the loading door immediately.

11.6.9.4. L3 Fuel Adjustments: Fuel Adjustments: If there is a ten-minute period without weight change (0.1 lb) at any point during the L3-fire phase, a fuel adjustment shall be made to increase the burn rate. The door may be open for up to 30 seconds for fuel adjustments. Only two fuel adjustments may be made during this phase. If after the second fuel adjustment, another period of no weight change (0.1 lb) occurs, the run ends, and it is a failed test run.

11.6.9.5.L3 End of Phase – The L3-fire phase ends when the scale indicates that 90% of the maintenance-fire fuel mass has been consumed.

11.6.9.6.L3 Documentation – Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge.

11.6.10.*L4: Low burn rate phase* – L4 phase commences immediately after the L3- ends.

11.6.10.1.L4 Appliance Requirements.

11.6.10.1.1.Record the weight of the stove prior to loading the L4-fire fuel charge, the load of the fuel charge prior to loading, and the scale weight after loading the overnight-fire fuel charge. Alternatively, if the scale was zeroed prior to starting the test, record the scale weight before and after loading the overnight-fire fuel charge.

11.6.10.2.L4 Fuel requirements

11.6.10.2.1. L4 fuel type –a mix of small and large cordwood pieces are used. At least 50% of the fuel charge load, by the number of pieces, must be large pieces.

11.6.10.2.2.L4 Loading structure: fuel will be loaded in one direction.

11.6.10.2.3.L4 loading density: The fuel load calculator specifies a load volume of 12 lb/ft^3 .+/-5%. Fuel shall be loaded in a manner to maximize the number of pieces that will fit in the stove without using force.

11.6.10.3. L4 Operational Parameters:

11.6.10.3.1. Open the loading door upon completion of the L3 maintenance-fire phase.

11.6.10.3.2.Load the L4 fuel charge within two minutes (120 seconds).

11.6.10.3.3.Keep the door in the 1" cracked position for five minutes from the beginning of the L4 phase.

11.6.10.3.4.Air controls shall be placed in the fully open position for the first ten minutes of the phase.

11.6.10.4.L4 Fuel Adjustments.

11.6.10.4.1.Unlimited fuel adjustments are allowed within the first five minutes of the phase. After ten minutes, air control(s) shall be moved to their lowest position. A picture of the air setting used must be included in the test report. The door may be open for up to 30 seconds for fuel adjustments.

11.6.10.4.2.If there is a ten-minute period without weight change (0.1 lb) during the first hour of the L4-phase, a fuel adjustment shall be made. The door may be open for up to 30 seconds for fuel adjustments.

11.6.10.4.3.Only two fuel adjustments may be made during the first hour. If after the second fuel adjustment, another periods of no weight change (0.1 lb) is observed, the run ends, and it is a failed test run.

11.6.10.4.4.No fuel adjustments are allowed after the first hour of the phase.

11.6.10.4.5.If there is no weight change for a consecutive period of 20 minutes at any point after the first hour of the phase, the unit has failed the test run.

11.6.10.5.L4 End of Phase – The L4 phase shall end when the scale indicates that 90% of the total L4 fuel mass has been consumed. If the fuel load does not burn to 90%, it is a failed test run.

11.6.10.6. L4 Documentation - Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed and fire when the door is closed

sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge.

11.7. Test Run. A complete test run requires completion of all four burn phases and loads. For any appliance that will not accommodate the loading arrangement specified in this test method, the test facility personnel shall contact the Agency Administrator to obtain written approval for an alternative loading arrangement:

11.8. Test Run Requirements. The following describes the required parameters for each test run. Each emission test run shall include all phases of the operational and fueling protocol run in order as described.

11.8.1. Consecutive Test Runs. Consecutive test runs may be conducted, provided that the following requirements are met:

11.8.1.1. Run 1 – The appliance shall have an internal and external starting temperature within +/- 2 °F (1.1°C) of laboratory ambient temperature at the beginning of Run 1

11.8.1.2. Run 2 – The second test run may commence 24 hours after the start of Run 1. Stove coals and ash can remain in the stove until 1 hour before conducting Run 2. All coals and ash shall be removed at least one hour prior to commencing Run 2.

11.8.1.3. Run 3 – The third test run may commence 24 hours after the start of Run 2. Stove coals and ash may remain in the stove until 1 hour before conducting Run 3. All coals and ash shall be removed at least one hour prior to commencing Run 2.

11.9. *Failure to Operate at All Test Conditions*

11.9.1. If the appliance fails two runs due to incomplete or invalid test runs, it shall be determined that the appliance has failed the certification test and requires a modification to appliance design. All data for incomplete runs shall be reported. Incomplete failed test runs are defined as the following:

11.9.1.1. If a wood heater fails to complete all four phases of the test run, the run shall be considered a failed test run.

11.9.1.2. If there is no weight change for a consecutive period of 20 minutes at any point during the test, the unit has failed the test run.

11.9.1.3. If the wood heater fails to comply with test protocol parameters

11.9.2. If a test run violates the parameters of the test method, the run is invalid.

11.9.3. If during certification testing a critical component of the stove is damaged or breaks, the certification test will be stopped and considered invalid.

11.9.3.1. If damage is noted during a test, repairs shall be made by the manufacturer (or by laboratory personnel with written direction from the manufacturer). If the repair involves components that would need aging, the appliance shall then undergo another round of wood heater aging as specified in section 10.6. These components may include but are not limited to catalyst elements, gaskets, and refractory components. The aging process is intended not only to 'cure' the stove but also to cycle parts that may fail with extended use. Alternate aging techniques may be approved by the administrator, depending on the nature of the failure, material, and critical nature.

11.10. Test Run Completion. Once three valid runs have been completed, the testing is complete. No additional runs may be completed.

11.10.1. *Additional Test Runs*. If there is an invalid run, may attempt two additional runs to complete the test series. If more than three test runs are conducted, the results from all valid test runs shall be used in calculating the average emission rate. The measurement data and results of all test runs shall be reported regardless of which values are used in calculating the emission rate. No test run data can be eliminated from the reporting requirements of this method.

11.10.2. *Invalid Runs.* When a test run fails to meet one of the QA/QC criteria stipulated in the test method, the data are invalid and the run must be repeated. Data for the invalidated test run must be included in the test report but the data must not be used in calculation of average emission values.

11.11. Auxiliary Wood Heater Equipment Operation. If optional heat exchange blowers are sold for use with the wood heater, three runs with the fan and an additional run without the fan shall be completed. If emissions are more than 1 gram per higher with the fan on, an additional two runs must be completed with the fan on. Heat exchange blowers shall operate in the highest airflow setting. (Automatically operated blowers shall be operated as designed) during the entire test.

11.12. PM Data Recording.

11.12.1. For tests using TEOM. All data shall be collected and recorded at intervals of no more than 1 minute. TEOM data shall be averaged up to 1-minute intervals for reporting. TEOM operation shall follow the procedures listed in NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

11.12.2. For tests using ASTM 2515 filter pulls

11.12.3. Data shall be reported in an Excel or compatible spreadsheet following the minimum data reporting requirements. All electronic files shall be submitted as part of the test report. Spreadsheet files shall be supplied as part of the publicly available test report.

12. Quality Control Measures

12.1. Dilution tunnel - Conduct sampling equipment leak check and calibration pre- and post-test.

12.2. TEOM – Flow and Leak checks are done before and after every test run per NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

12.3. Volume Metering System Checks.

13. Data Analysis and Calculations. –

NOTE: If a TEOM is used for PM measurement, proportioning of emission factors and rates per phase according to Appendix A, variables shall have subscript added to determine the relevancy of phase i.e. $E_{T(P1)}$ indicates Total particulate emissions for Phase 1 and $E_{g/hr(P2)}$ indicates emissions factor in grams per hour for Phase 2.

13.1. Emission Calculations. Particulate matter, carbon dioxide, and carbon monoxide shall be calculated using the following methodology and reported in grams per hour, grams per kilogram and pounds per million British Thermal Unit (BTU) heat output. All calculations shall be conducted using all decimal values provided by the instrumentation or recorded by the operator. No truncation of data is acceptable. Only the final calculation of the PM emissions rate shall be rounded, to three significant figures.

13.2. TEOM data shall be reported as follows.

13.2.1. Emissions from each of the 4 phases of the test shall be reported as individual results in grams per hour, grams per kilogram, and lb/MMBtu (heat output).

Emissions from the entire test run in grams per hour, grams per kilogram, and lb/MMBtu (heat output).

Nomenclature

$AER = Ei/\sum N$

BR – average dry fuel burn rate, lb./min

$BR_{(x)}$ – Burn rate for specific phase, BR_{L1}, BR_{L2}, BR_{L3}, BR_{L4}

CO – Carbon Monoxide

CO_2 – Carbon Dioxide

H_2- Hydrogen

O_2 – Oxygen

BT = time of 90% of overnight load consumed – time of overnight loading

C_{steel} – Specific heat of steel (0.1 Btu/ lb., °F)

E_T – Total particulate emissions for the full test run in grams

$E_{g/MJ}$ – PM Emissions rate in grams per megajoule of heat output
$E_{g/kg}$ – PM Emissions factor in grams per kilogram of dry fuel burned
$E_{g/hr}$ – PM Emissions factor in grams per hour
E_{Rco} – CO emission rate, g/hr.
EIi – Average CO emission index for interval i
E_{ICO} – CO emission index, g/kg dry fuel
EIco,avg – Average CO emission index for the run
HHV – Higher heating value of fuel = Use accredited test results
LHV – Lower heating value of fuel = Use accredited test results
$\%M_d$ = Fuel moisture content, dry basis, percent.
$\%M_w$ = Average moisture in test fuel charge, wet basis, percent
N = Total number of test runs.
PCTCO2– average CO_2 in the dry flue gas (%)
PPMco -average CO in the dry flue gas (ppm)
Q_{out} – Total heat output in BTU's (megajoules)
SC_i – Scale weight at specific time interval, lb.
$t_{(i)}$ – Data sampling interval in minutes
T1 – Surface Temperature 1 °F (°C)
T2 – Surface Temperature 2 °F (°C)
T3 – Surface Temperature 3 °F (°C)
T4 – Surface Temperature 4 °F (°C)
T5 – Surface Temperature 5 °F (°C)
T6 – Pre Catalyst Temperature 1 °F (°C)
T7 – Post Catalyst Temperature 2 °F (°C)
T8 – Tunnel Temperature °F (°C)
T9 - Flue Gas Temperature °F (°C)
T10 – Room Temperature °F (°C)
$TS_{avg(i)}$ – Initial Average Surface Temperature °F (°C)
$TS_{avg(f)}$ – Final Average Surface Temperature °F (°C)
W_{fuel} – Fuel charge weight in pounds (kg)
W_i – Weight of fuel in pounds (kg)
W_{app} – Weight of empty appliance in pounds (kg)
Θ – Total length of test run, hours
$\Theta_{(x)}$ – Total length of test run in hours per phase, X
$\%M_w = 100(\%M_d)/100+\%M_d$

13.3. Average Wood Heater Surface Temperatures. Calculate the average of the wood heater surface temperatures at the start of the phase (L4) and end at the end of the test (L4) of the test run.
L4 $TS_{avg(i)}$ – (T1 + T2 + T3 + T4 + T5) / 5
L4 $TS_{avg(f)}$ – (T1 + T2 + T3 + T4 + T5) / 5
Average surface temperatures at the start and end of any phase can be determined by averaging all

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five sensors at the beginning and end of each phase.

$L_x\ TS_{avg(i)} - (T1 + T2 + T3 + T4 + T5) / 5$

$L_x\ TS_{avg(f)} - (T1 + T2 + T3 + T4 + T5) / 5$

13.4. Burn Time Rating– A standardized burn time rating shall be determined by rounding the duration of the overnight-fire phase of the test up to the nearest 1 hour. Burn time shall be calculated as the time L4 is loaded into the stove until 90% of the fuel has been consumed. This provides an important rating for consumers and is not intended for any calculation purposes and shall be reported on the all manufacturers materials that provides specifications on appliance performance. Language such as "this stove has demonstrated a low setting burn time of x hours in official testing"

13.5. Determine Burn Rates

BR_{L1} = not applicable

$BR_{L2} = (L2\ Initial\ SC_i - L2\ Final\ SC_i) / \Theta_{(L2)}$, lbs./hr

$BR_{L3} = (L3\ Initial\ SC_i - L3\ Final\ SC_i) / \Theta_{(L3)}$, lbs./hr

$BR_{L4} = (L4\ Initial\ SC_i - L4\ Final\ SC_i) / \Theta_{(L4)}$, lbs./hr

13.6. Emissions

13.6.1. Determine emission rates and emission factors as:

$E_{g/MJ} = E_T/(Q_{out} \times 0.001055)$, g/MJ

$E_{g/kg} = E_T/(W_{fuel}/(1+M\%M_d/100))$, g/dry kg

$E_{g/hr} = E_T/\Theta$, g/hr

13.7. Efficiency calculation.

Ultimate Analysis of dry fuel (% by weight)

Carbon – CA

Hydrogen – HY

Oxygen – OX

Moisture Content – mass of water per mass of dry fuel – Mcdb

Ambient Humidity Ratio – mass of water per unit mass of dry air – ω

Flue gas temperature (F) – Ts

Room temperature (F)-Tr

CO in the dry flue gas (ppm) – PPMco

CO2 in the dry flue gas (%) – PCTCO2

Higher heating value of the dry fuel (lb/MMBtu) – HHV

<u>Combustion Balance Equation:</u>

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$$C_xH_yO_z + (1+\alpha)\bullet\gamma(O_2 + 3.76N_2) + \left[\omega\bullet\left(\frac{(1+\alpha)\bullet\gamma\bullet(32+3.76\bullet 28)}{18}\right) + \frac{Mcdb}{18}\right]H_2O$$

$$\rightarrow (x-\beta)\,CO_2 + \beta CO + (\alpha\bullet\gamma + \frac{\beta}{2})\,O_2 + (1+\alpha)\bullet\gamma\bullet 3.76\,N_2 + \left[\frac{y}{2} + \omega\bullet\left(\frac{(1+\alpha)\bullet\gamma\bullet(32+3.76\bullet 28)}{18}\right) + \frac{Mcdb}{18}\right]H_2O$$

Where:

$x = CA/12$

$y = HY$

$z = OX/16$

$\gamma = (x + \frac{y}{4} - \frac{z}{2})$

$\alpha =$ excess air parameter, e.g. if $\alpha =$ 0.5 there is 50 % excess air

From this:

$$PPMco = \frac{1E6\square\beta}{x + \left(\alpha\square\gamma + \frac{\beta}{2}\right) + (1+\alpha)\square\gamma\square 3.76}$$

$$PCTCO2 = \frac{100\square(x-\beta)}{x + \left(\alpha\square\gamma + \frac{\beta}{2}\right) + (1+\alpha)\square\gamma\square 3.76}$$

With flue gas CO and CO_2 measured, these two equations can be solved simultaneously for β and α.

$$\beta = \frac{100\square x\square PPMco}{1E6\square PCTCO2\square + 100\square PPMco}$$

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$$\alpha = \frac{\frac{100 \cdot (x-\beta)}{PCTCO2} - x - \frac{\beta}{2} - 3.76 \cdot \gamma}{4.76 \cdot \gamma}$$

Calculation of the Molar Coefficient for Each of the Products

For the assumption of 100 kg of dry fuel, this is the number of moles of each product for the input conditions

$MFCO = \beta$ Molar Coefficient for CO

$MFCO2 = x - \beta$ Molar Coefficient for CO_2

$MFH2O = \frac{\gamma}{2} + \frac{Mcdb}{18} + \frac{\omega \cdot (1+\alpha) \cdot \gamma \cdot (32+3.76 \cdot 28)}{18}$ Molar Coefficient for H_2O

$MFO2 = \alpha \cdot \gamma + \frac{\beta}{2}$ Molar Coefficient for O_2

$MFN2 = (1+\alpha) \cdot \gamma \cdot 3.76$ Molar Coefficient for N_2

Heat Capacity of Exhaust Products

The general equation for representing how the heat capacity of the exhaust products varies with temperature is:

$C = A \cdot Tk + B$

Where:

C = heat capacity J/mol K or kJ/kgmol K

A and B are constants

Tk = Temperature in °K

The values for A and B for the exhaust components are provided in the table below

Component	A	B

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CO	.0056	27.162
CO2	.029	29.54
H2O	.0057	32.859
O2	.009	26.782
N2	.0062	26.626

For each component, heat capacity is calculated at the stack temperature and at room temperature. The average of these is used to calculate sensible heat loss.

Calculation of Heat Losses for Efficiency Determination

$HHVJ = HHV \square 2.326$ Higher heating value in kJ/kg (conversion from Btu/lb)

$LHWV = 43969$ Latent heat of water vapor in kJ/kgmol

$Llat = MFH2O \square LHWV / HHVJ$ Heat loss in latent heat of water vapor, % of input energy

$Lco = MFCO \square 282993 / HHVJ$ Heat loss in chemical energy in CO, % of input energy

$Lsens = (MFCO \square C\_COm + MFCO2 \square C\_CO2m + MFH2O \square C\_H2Om + MFO2 \square C\_O2m$

$+ MFN2 \square C\_N2) / HHVJ$ Heat loss in sensible heat in flue gas, % of input energy

$Efficiency = 100 - Llat - Lco - Lsens$ Stack loss efficiency, %

14. Reporting Requirements. The report shall include the following:

14.1.1. Introduction

14.1.2. Purpose of test: certification, audit, efficiency,

14.1.3. Name and location of the laboratory conducting the test.

14.1.4. Wood appliance identification – manufacturer, model number/name, design type, description of the appliance tested, stove condition, and date of receipt.

14.1.5. Test information – location of testing, date of tests, sampling methods used, number of test runs, a statement detailing any previous certification testing completed on the wood appliance.

14.1.6. A list of people who conducted research on the appliance, participated in testing preparation, or witnessed the certification testing. This list shall clearly specify their roles in the testing program

for the appliance. The list shall include the participant's name, title, company, contact information and the purpose of their participation.

14.1.7. A statement that the test results apply only to the specific appliance tested.

14.2. Summary and Discussion of Results

14.2.1. Table of results to include test run number, average burn rate for entire run and each phase, carbon monoxide and particulate emission rate for full run, particulate and carbon monoxide emission rate for each load phase (L1, L2, L3, L4), efficiency for the full run and each phase, burn time for total run and each phase. First hour PM emissions for each test run shall also be reported.

14.2.2. For each test run and pollutant with real-time data to include: Θ_1,Θ_2, Θ_3, CO, CO_2, PM, and efficiency for (1) L1 - the startup phase and (2) L2 - high-, (3) L3-maintenance-, and (4) L5 low burn rate fire phases. Calculated results for the emissions shall be reported as total emissions in grams, pounds per million Btu output, grams per MJ, grams per kilogram of dry fuel and grams per hour, and pounds per hour.

14.2.3. A narrative discussion detailing any issues or anomalies that arose during each test run and how those were handled, including comments about the fuel, and loading of the appliance.

14.2.4. A plot of CO emission rate in ppm vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.5. A plot of CO_2 emission rate in ppm vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.6. If a TEOM used:

14.2.6.1. a plot of PM emission rate in grams/hour vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.6.2. A plot of PM emission rate in g/kg vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.7. Summary of other data – test facility conditions, surface temperature averages, catalyst temperature averages, pretest fuel weights, test fuel charge weights – total and by phase.

14.3. Discussion. Test run result, specific test run problems, and solutions. Comments on fuel, loading, analysis, and anything that may impact the reported result(s).

14.3.1. Details of deviations from, additions to or exclusions from the test method, and their data quality implications on the test results (if any), as well as information on specific test conditions, such as environmental conditions. An explanation of the deviations, additions, or exclusions shall be provided along with an analysis as to why these elements had no impact.

14.4. Process description:

14.4.1. Data and drawings indicating the firebox size and location of the fuel charge.

14.4.2. Drawings and calculations used to determine firebox volume to include volume, height, width, and lengths, weight, and volume adjustments.

14.4.3. Firebox configuration – At a minimum to include air supply locations and operation, air supply introduction location, refractory location and dimensions, catalyst location, baffle and by-pass location and operation (include line drawings or photographs)

14.4.4. Appliance operation during the test – shall supply details on air supply settings and adjustments.

14.5. Test fuel properties – the report shall provide information on the species, density, fuel moisture, fuel temperature, and load details from the fuel load calculator to include all measurements including the number of pieces, individual piece weights, piece length, moisture content and weight.

14.6. Sampling

14.6.1. A description of the test procedures and test equipment, including a schematic or other drawing showing the location of all required test equipment. Also, a description of test fuel sourcing, handling and storage practices shall be included.

14.6.2. Describe the sampling location relative to the wood heater, include drawing or photographs.

14.6.3. Provide data on sampling blanks.

14.7. Quality Control and Assurance Procedures

14.7.1. Calibration procedures and results certification procedures, sample and analysis procedures.

14.7.2. Test method quality control procedures to include TEOM leak and flow checks, stratification (velocity) checks, tunnel flow range results, filter temperature range verification and dilution tunnel RH verification.

14.8. Appendices

14.8.1. Results and Example Calculations. Raw data and complete calculations for data included in summary tables.

14.8.2. Raw data. Copies of all files or sheets for sampling measurement, temperature records, and other materials used by lab related to testing.

14.8.3. Calibration Results. Summary of all calibrations, check, and audits pertinent to the certification.

14.8.4. Sampling and Operation Records. Copies of all uncorrected records of activities not included in raw data sheets (e.g., wood heater door open, times and durations) as well as photographs of fuel loading and air flow settings.

14.8.5. Correspondence. Any correspondence to include written, electronic or verbal communications regarding appliance testing. Items shall include:

14.8.5.1. Request to conduct testing

14.8.5.2. Scheduling of testing

14.8.5.3. Notice to EPA to conduct test, and any modifications to that request.

14.8.5.4. Notice and submission of data to EPA after testing completed.

14.8.6. Test Facility Information. Report test facility temperature, air velocity, and humidity information.

14.8.7. Test Equipment Calibration and Audit Information. Report calibration and audit results for the platform scale, test fuel balance, test fuel moisture meter, and sampling equipment including volume metering systems and gaseous analyzers.

14.8.8. Pretest procedures. Report all pretest procedures conducted at the lab on the appliance to burns, rates, and amounts.

14.8.9. All required data for each test run shall be provided in spreadsheet format both in the printed report and in a computer file such that the data can be easily analyzed and calculations easily verified. Formulas used for all calculations shall be accessible for review.

14.8.10. For each test run: report TEOM flow and temperature and verification of all TEOM data validation parameters as required in NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

14.8.11. Raw data, calibration records, and other relevant documentation shall be retained by the laboratory for a minimum of 7 years.

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Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 5/28/2021 2:13:42 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]; Burkhard, Ellen G (NYSERDA) [Ellen.Burkhard@nyserda.ny.gov]
Subject: FW: protocol
Attachments: NYSERDA IDC Stove protocol EPA Research 5 28 21 clean-GA-LR-GA secured.pdf

Does this one work?

THIS INTEGRATED-DUTY-CYCLE (IDC) PROTOCOL FOR WOOD STOVES IS THE PROPERTY OF THE NEW YORK STATE ENERGY RESEARCH AND DEVELOPMENT AUTHORITY (NYSERDA) AND CAN BE USED TO TEST TECHNOLOGIES IN A LABORATORY SETTING. ANY DEVIATIONS OR CHANGES TO THIS IDC PROTOCOL FOR WOOD STOVES ARE NOT APPROVED OR SANCTIONED BY NYSERDA. DO NOT CITE, COPY, or DISTRIBUTE THIS IDC PROTOCOL FOR WOOD STOVES WITHOUT THE WRITTEN PERMISSION OF NYSERDA

NYSERDA Integrated Duty Cycle Test Method for Certification of Wood-Fired Stoves Using Cordwood: Measurement of Particulate Matter (PM) and Carbon Monoxide (CO) Emissions and Heating Efficiency

Note: This method does not include all the specifications (e.g. equipment and supplies) and procedures (e.g., sample and analytical) essential to its performance. Some material is incorporated by reference from other methods. Therefore, to obtain reliable results, persons using this method shall have a thorough knowledge of at least the following EPA Tests:

- Method 1- Sample and Velocity Traverses for Stationary Sources
- Method 2- Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube)
- Method 3 – Gas Analysis for the Determination of Dry Molecular Weight
- Method 4 – Determination of Moisture Content in Stack Gases
- Method 5G – Determination of Particulate Matter from Wood Heaters (Dilution Tunnel Sampling Location)
- Method 10 - Carbon Monoxide - Instrumental Analyzer
- Method 28 – Certification and Auditing of Wood Heaters

1. Scope and Application

1.1. This test method specifies operation and fueling for certification and auditing of manually operated wood-fired stoves and heaters.

1.2. This test method measures particulate matter (PM) emissions, carbon monoxide, and efficiency.

1.3. Particulate emissions are measured in the dilution tunnel method as specified in ASTM E2515, Standard Test Method for Determination of Particulate Matter Emissions Collected in a Dilution Tunnel, using the Tapered Element Oscillating Microbalance (TEOM) continuous PM method as detailed in this test method.

1.4. Analyte. Particulate matter (PM). No CAS number assigned. Carbon monoxide (CO). No CAS number assigned.

1.5. Applicability. This method is applicable for the certification and auditing of wood space heaters, which burn cordwood fuel. The test quantifies PM and CO emissions and provides overall efficiency ratings, maximum burn time, and heat output.

1.6. Data Quality Objectives. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods.

1.7. Distinguishing features of appliances covered by this standard include:

ED_005942D_00000047-00001

1.7.1. Cordwood fuel is hand-fed into firebox.

1.7.2. A chimney or vent that exhausts combustion products from the appliance.

1.8. The values stated are to be regarded as the standard, whether in I-P or SI units. The values given in parentheses are for information only.

1.9. Data Quality Objectives.

1.9.1. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods.

1.9.2. Measurement of emissions and heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

1.9.3. This is a laboratory method intended to capture operating periods that are representative of actual field use without excessive test burden.

2. Referenced Methods

2.1. NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel

2.2. ASTM 2515: Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel.

3. Definitions

3.1. Appliance – a wood heater capable of and intended for space heating defined in the applicable regulation. The appliance includes a combustion chamber, combustion air settings, operating controls, and a thermostat if specified, and any other accessory required for standard operation, such as a barometric damper,

3.2. Catch - any mass from the sample probe system on the filter.

3.3. Certification or audit test - a series of at least three test runs conducted for certification or audit purposes that meets the specifications detailed in this protocol.

3.4. Chop – using a poker or another piece of wood to strike a piece of the fuel charge to break it into smaller pieces.

3.5. Coal-bed Stirring – prior to adding a new fuel charge, using a poker or piece of wood to stir or level the coal bed of the appliance for the sole purpose of ensuring ease of loading of the fuel charge. No special formations can be made, such as creating coal bed formations or pushing coals to one side or creating slopes with the coals.

3.6. East-west stove – a stove where the firebox dimension parallel to the loading door is greater or equal to the stove depth measurement. Logs are loaded so that they are viewed on the long length of the stove.

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3.7. Emission factor – the emission of a pollutant expressed in mass per unit of energy (typically) output from the appliance.

3.8. Firebox - the portion of the chamber in the wood heater in which the test fuel charge is placed and combusted.

3.9. Firebox depth - the horizontal length of the fire chamber dimension measured perpendicular to the loading door. If the manufacturer believes that a portion of the firebox depth is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.10. Firebox Height - the vertical distance extending above the top of the firebox to the floor of the firebox. Firebox height is not necessarily uniform. The measurement must account for variations caused by internal baffles, air channels, or other permanent obstructions. If the manufacturer believes that a portion of the firebox height is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.11. Firebox width - the horizontal fire chamber dimension that is parallel to the loading door. If the manufacturer believes that a portion of the firebox width is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.12. Fuel Adjustment – manipulations to the fuel charge to reflect typical owner practices that allow the cordwood fuel to burn appropriately during the test period. A fuel adjustment includes minor changes in fuel placement. It does not include chopping the wood, stirring the coal bed, or reorganizing fuel placement.

3.13. Fuel load calculator – The locked excel spreadsheet tool that determines the allowable test fuel load weights and required piece sizes for each individual load.

3.14. Fuel loading direction – For loads 2, 3, and 4 fuel shall be loaded based parallel to the dimension with the largest value. If the firebox length and width are within 2", fuel shall be loaded in an east/west fashion, parallel to the loading door. A crisscross configuration is allowed for L1 but cannot be used as a load configuration for loads 2, 3, or 4.

3.15. Kindling pieces – small pieces of wood less than 1" in diameter. No bark or moisture requirements for these pieces, however kindling pieces shall not be dried or stored anywhere but in laboratory ambient conditions. Kindling length shall be of the same wood species as the fuel charge length. Individually kindling pieces may weigh no less than 1.5 ounces.

3.16. Large fuel pieces – pieces that are larger for the appliance as defined by the fuel load calculator.

3.17. L1 – Start-up – period of the test when the unit has kindling and startup fuel under the conditions described in Section 11.6.7.

3.18. L2 – High-fire Phase – period of the test when the unit has a small coal bed and the stoves air settings are fully open. It is intended to replicate periods when homeowners are trying to quickly heat an area, shortly after starting or restarting the appliance.

3.19. L3 - Maintenance-fire phase– period of the test when a fire is maintained with a medium-sized coal bed, and a smaller batch of wood made up of two large pieces. This is intended to simulate a period when the operator is trying to maintain consistent heat output.

3.20. L4 - Low-burn Rate Phase – period of the test when the stove has a large coal bed, the stove is fully loaded, and the adjustable air settings are set to produce the lowest possible burn rate and have the lowest air settings. It is intended to simulate when the operator is trying to maintain heat over a long time, such as overnight or while away for significant periods of time.

3.21. North-south stove: a firebox that has its longest dimension measurement perpendicular to the loading door. In this stove type, logs are loaded so that the ends of the fuel are viewed when loaded.

3.22. Phase – A distinct period in the test run with its own operational procedures and conditions.

3.23. Primary air supply – air supply that introduces air to the wood heater in the combustion chamber and is adjusted to target a desired burn rate. The wood heater manufacturer or test facility can document this through design drawings.

3.24. Secondary air supply - air supply that introduces air to the wood heater such that the burn rate is not altered by more than 10 percent when the secondary air supply is adjusted during the test run. The wood heater manufacturer or test facility can document this through design drawings that show the secondary air is introduced only into a mixing chamber or secondary chamber outside the firebox.

3.25. Significant figure – is any digit that is necessary to define the specific value or quantity. Zeros may be used either to indicate a specific value, like any other digit, or to indicate the magnitude of a number.

3.26. Small fuel pieces - pieces that are small for the appliance as defined by the fuel load calculator.

3.27. Starter fuel – pieces of cordwood that can be smaller than small and large pieces but larger than kindling, as defined by the fuel load calculator.

3.28. Test data– means the data for all test runs conducted on the wood heater, including any data collected during failed and invalid runs and includes records of preparation of standards, identification of equipment used and personnel present, records of calibrations, raw data sheets for field sampling, raw data sheets for field and laboratory analyses, chain-of-custody documentation, and example calculations for reported results.

3.29. Test facility - the area in which the wood heater is installed, operated, and sampled for emissions.

3.30. Test fuel charge - the collection of test fuel pieces used in each of the four phases of the test run. L2, L3, and L4 recommend that at least 75% of the individual pieces with at least 80% bark on one side of the fuel piece. Bark shall not be removed for certification testing. Any fuel charge that suggests bark was purposely removed or shaped shall deem the certification test invalid. Examples of fuel piece manipulation are provided in Section 11. If 75% of the fuel load pieces for L2, L3, and L4 do not have bark, document in the test report.

3.31. Test fuel load – the group of test fuel pieces that are loaded, as specified by phase, throughout the test run.

3.32. Test fuel loading – the arrangement of the test fuel charge.

3.33. Total run fuel load – the amount of wood burned during the entire test run.

3.34. Test fuel loading density – the calculation that determines the weight of the as-fired test fuel load. The calculation is based on the usable volume of the firebox.

3.35. Test run – an individual emission test that includes the four operational phases required by the fueling protocol.

3.36. Usable firebox volume – the calculated volume of the firebox determined using its height, width, and depth as defined in this section. This calculation represents the area where wood is likely to be loaded. If the manufacturer claims that portions of the firebox may not be used in the calculation, a justification must be submitted with the test report. If the justification is not approved, the test results will be deemed unrepresentative for certification purposes. It is highly recommended that manufacturers obtain regulatory approval if making claims that portions of the firebox are not appropriate for inclusion in the calculation.

3.37. Wood heater – an enclosed, wood-burning appliance capable of and intended for space heating or domestic water heating, as defined in the applicable regulation.

4. Interferences

None.

5. Summary of Method

5.1. Particulate matter emissions are measured from a wood heater burning cordwood test fuel in a test facility maintained at a set of prescribed ambient conditions. Procedures for operating the appliance, measuring PM and CO emission rates, and methods for reducing data and calculating results are provided.

5.2. *Dilution Tunnel*. A dilution tunnel following the specifications detailed in ASTM E2515-11 shall be used for particulate measurements.

5.3. *Particulate Matter:* PM emissions are measured in a dilution tunnel with a Thermo model 1405-D 2-channel TEOM using NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel, with a dilution tunnel as specified in ASTM 2515 with modifications discussed in Section 10.

5.4. *Carbon Monoxide*. The CO is measured in the stack and is used to calculate efficiency determination.

5.5. *Operation*. Appliance operation is conducted on a cold-to-hot test cycle, meaning that the appliance starts the first test run at room temperature and ends with the appliance in a heated state. The second and third test runs may start at a slightly warmer temperature if the appliance is designed to retain the heat from the first run. The appliance is operated at operational phases

representing start-up emissions, high heat demand, low heat demand, changing air conditions, and refueling. To complete the certification test, the appliance shall complete three valid test runs that are averaged to determine the test results.

5.6. *Repeatability.* A series of at least three test runs conducted for certification or audit purposes.

6. Significance and Use

6.1. The measurement of particulate matter emission rates is an important test method widely used in the practice of air pollution control.

6.1.1. These measurements, when approved by state or federal agencies, are often required for the purpose of determining compliance with regulations and statutes.

6.1.2. The measurements made before and after design modifications are necessary to demonstrate the effectiveness of design changes in reducing emissions and make this standard an important tool in manufacturers' research and development programs.

6.2. Measurement of heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

7. Safety

7.1. Disclaimer. This method may involve hazardous materials, operations, and equipment. This test method may not address all the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to performing this test method.

7.2. These tests involve combustion of wood, which releases substantial amounts of heat and combustion products. The heating system also produces large quantities of very hot water and the potential for steam production and system pressurization. Appropriate precautions must be taken to protect personnel from burn hazards and respiration of products of combustion. Exposure of personnel to unsafe levels of carbon monoxide must be avoided, and the use of continuous ambient carbon monoxide monitoring is strongly recommended.

8. ***Equipment and Supplies.*** The following items are required for sample collection:

8.1. Anemometer. A device capable of detecting air velocities less than 0.10 m/sec (20 ft/min), for measuring air velocities near the test appliance.

8.2. *Appliance Flue.*

8.2.1. Steel flue pipe extending to 8.5 ±0.5 ft. (2.6 ±0.15 m) above the top of the platform scale, and above this level, insulated solid pack type chimney extending to 15 ±1 ft (4.6 ±0.3 m) above the platform scale, and of the size specified by the appliance manufacturer. This applies to both freestanding and inserts type appliances.

8.2.2. Other chimney types (e.g., solid pack insulated pipe) may be used in place of the steel flue pipe if the appliance manufacturer's written appliance specifications require such chimney for home installation (e.g., zero clearance appliance inserts). Such alternative chimney or flue pipe must remain and be sealed with the appliance following the certification test. This applies only to appliances requiring a specialized chimney.

8.2.3. Solid pack insulated chimneys shall have a minimum of 2.5 cm (1 in.) solid-pack insulating material surrounding the entire flue and possess a label demonstrating conformance to U.L. 103 (incorporated by reference—see §60.17).

8.3. Appliance Platform Scale and Monitor. For monitoring of fuel load weight change. The scale shall be capable of measuring weight to within 0.01 kg (0.02 lb.) and calibrated to NIST traceable standards at least annually.

8.4. Barometer. Aneroid or another barometer capable of measuring atmospheric pressure to within 0.1 in. Hg (2.5 mm Hg) with an uncertainty of +/- 0.05 in. Hg (+/- 1.27 mm Hg).

8.5. Dilution Tunnel must meet the requirements of ASTM E2515, clauses 6.1.6 and 9.2.

8.6. Dilution Tunnel temperature and relative humidity measurement. A probe with analog or digital data outputs capable of measuring tunnel temperature to within 0.5 °C (1.0 °F) and tunnel RH to within 2% between 5 and 95% RH at maximum tunnel temperatures, such as the Omega HX85A or equivalent. The probe should also report calculated dewpoint.

8.7. Draft Gauge. Electromanometer or other devices for the determination of flue draft or static pressure readable to within 0.005 in. H2O (1.2 Pa)

8.8. Flue Gas Temperature Measurement. A type K thermocouple or equivalent located in the centroid of the stack located 8.0 +/- 0.5 ft (2.44 m +/- 150 mm) above the platform scale, capable of measuring with an accuracy of 4.0°F (2.2°C) or 0.75% of reading, whichever is greater.

8.9. Flue Gas Composition Measurement. A sample probe and continuous infrared analyzer or equivalent capable of measuring span of carbon monoxide (CO) and carbon dioxide (CO_2) in the flue gas produced by the appliance tested. Continuous analyzers (or equivalent) shall have maximum zero and span drift, over a 24 h period, of 1% of full scale.

8.10. Fuel Scale. Balance capable of weighing the test fuel charge to within 0.02 kg (0.05 lb.) and calibrated to NIST traceable standards at least annually.

8.11. Humidity Gauge. Psychrometer or hygrometer for measuring room humidity to within +/- 4% from 25 to 95% RH.

8.12. Moisture Meter. Calibrated electrical resistance meter for measuring test fuel moisture to within 2 percent moisture content.

8.13. Surface Temperatures. Capable of measuring temperature to within 1.5 percent of expected absolute temperatures with an accuracy of 4.0°F (2.2°C) or 0.75% of reading, whichever is greater.

8.14. Test Facility Temperature Monitor. A thermistor, RTD, Type T-Special thermocouple, or other equivalent device, located centrally in a vertically oriented 150 mm (6 in.) long, 50 mm (2 in.) diameter pipe shield that is open at both ends, capable of measuring temperature to within 1°F of expected temperatures.

8.15. TEOM – Thermo Fisher Scientific TEOM model 1405-D (Thermo part # 1405D-ANF, excluding models 1405, 1405-DF, or 1405-F) to measure and report continuous particulate matter (PM) measurements in an ASTM 2515 dilution tunnel or equivalent dilution method, and operated according to the NYSERDA Dichot TEOM Standard Operating Procedures. For lab air PM measurements, Thermo Fisher Scientific TEOM model 1405 (Thermo part # 1405-ANF, excluding model 1405-F), operated according to the NYSERDA Dichot TEOM Standard Operating Procedures.

9. Calibration and Standardizations

9.1. Anemometer. Calibrate the anemometer as specified by the manufacturer's instructions before the first certification test every six months thereafter.

9.2. Appliance Platform Scale. Perform a multipoint calibration (at least five points spanning the operational range) of the platform scale before its initial use. The scale manufacturer's calibration results are sufficient for this purpose. Before each certification test, audit the scale with the wood heater in place by weighing at least one calibration weight (Class F) that corresponds to between 20 percent and 80 percent of the expected test fuel charge weight. If the scale cannot reproduce the value of the calibration weight within 0.0045 kg (0.01 lb.) or 1 percent of the expected test fuel charge weight, whichever is greater, recalibrate the scale before use with at least five calibration weights spanning the operational range of the scale.

9.3. Barometer. Calibrate using a reference pressure monitor calibrator before the first certification test and semiannually after.

9.4. Draft Gauge. Calibrate as per the manufacturer's instructions; a liquid manometer does not require calibration (but must be properly leveled, zeroed, and the system leak checked).

9.5. Humidity Gauge. Calibrate as per the manufacturer's instructions before the first certification test and annually thereafter.

9.6. Fuel Scale. Calibrate as described in 9.2.

9.7. Moisture Meter. Calibrate as per the manufacturer's instructions before the first certification test and semiannually thereafter.

9.8. Temperature Sensors. Calibrate using at least five points within operating range within specification and in compliance with NIST Monograph 175. To be calibrated before the first certification test and semiannually thereafter.

10. Sampling, Test Specimens, and Test Appliances

10.1. Modifications to ASTM 2515 requirements.

10.1.1. Liquid water should not be present anywhere in the sampling system for a valid sample. The presence of condensed water anywhere in the sampling system invalidates the test run. All data from all invalid test runs shall be included in the report. The reviewing authority shall make a final determination on invalidated runs. Data from any invalidated test run shall not be used to calculate results. If the testing agency believes a run has been invalidated, the test run shall be repeated.

10.1.2. Dilution tunnel temperature and relative humidity shall be measured electronically and logged at one-minute intervals near the sample probe to calculate dewpoint.

10.1.3. The following section details test conditions that shall be maintained for a valid test run. A valid test shall have no more than two individual deviations from any of the conditions below to remain a valid run. An example of an individual deviation is a single, ten-minute rolling average where the dilution tunnel exceeded temperature thresholds. Another ten-minute period exceeding the tunnel temperature requirement shall be considered a second deviation.

10.1.3.1. Tunnel temperature shall not exceed 104 deg. F (40 deg. C) based on ten-minute rolling averages derived from one-minute data, excluding periods when the appliance door is open.

10.1.3.2. Tunnel relative humidity shall not exceed 90% based on ten-minute rolling averages derived from one-minute data excluding periods when the appliance door is open.

10.1.3.3. A minimum tunnel flow of 600 CFM is required. Higher tunnel flows may be required to meet the parameters of Section 10.1.3.

10.1.3.4. All exceedances must be reported in the test anomalies section, even if deviations are within the test method tolerances.

10.2. Sample Collection. The following are required for sample collection:

10.2.1. Teflon coated glass fiber filters as supplied by the TEOM manufacturer for use with the TEOM model 1405-D. These are Pallflex Emfab (TX40) with an exposed diameter of 13 mm, without organic binder, exhibiting at least 99.95 percent efficiency.

10.2.2. *Test Specimens.* Appliances shall be supplied as complete systems, including all controls and accessories necessary for installation at the test facility. A full set of specifications, designs, and

assembly drawings shall be provided when the product is placed under certification of a third-party agency.

10.3. Preparation of Apparatus

10.3.1. Wood Heater Installation for Certification Testing. Assemble the wood heater appliance and parts in conformance with the manufacturer's provided User Guide. These instructions must match all instructions materials developed by the manufacturer and/or their distributors. Place the wood heater on the platform scale and connect the chimney to the appliance. Clean the flue with an appropriately sized, wire chimney brush before initiating Run 1 of the certification test. Test documentation should include the date and time of flue cleaning.

10.3.2. Wood Heater Temperature Monitors.

10.3.2.1. For catalyst-equipped wood heaters, locate a temperature monitor (optional) about 25 mm (1 in.) upstream of the catalyst at the centroid of the catalyst face area, and locate a temperature monitor (mandatory) that will indicate the catalyst exhaust temperature. This temperature monitor is centrally located within 25 mm (1 in.) downstream at the centroid of the catalyst face area. Record these locations.

10.3.2.2. Locate wood heater surface temperature monitors at five locations on the wood heater firebox exterior surface. Position the temperature monitors centrally on the top surface, centrally on two sidewall surfaces, and centrally on the bottom and back surfaces. Position the monitor sensing tip on the exterior of the firebox surface inside of any heat shield, room air circulation walls, or other wall or shield separated from the firebox exterior surface. Surface temperature locations for unusual design shapes (e.g., spherical, etc.) shall be positioned so that there are four surface temperature monitors positioned to average stove temperature across various points on the appliance.

10.4. Conditioning

10.4.1. Wood Heater Aging Prior to Certification Testing. A wood heater of any type shall be aged at least 50 hours before initiating a certification test. The aging procedure shall be conducted by the manufacturer or a manufacturer's agent prior to sending the appliance to the testing laboratory. The certification lab cannot be involved with wood heater aging in any manner.

During aging, the appliance shall be operated at a variety of burn rates. Documentation for wood heating aging must be included in the test report to include data on individual hourly burn rates. The testing laboratory shall not conduct any firing of the appliance prior to conducting the certification test.

10.4.1.1. The manufacturer shall supply wood heater aging information for the final test reports. Aging data that shall be reported include all fuel parameters (species, moisture content, load weights,

piece amounts, and size), air settings used, time spent in each air setting phase, amount of fuel burned, and appliance burn rates.

10.4.1.2. If an appliance uses a catalytic combustor, it must be engaged according to the manufacturer's instructions and operate with the catalyst engaged for at least 50 hours during the break-in period. In addition to the reporting requirements listed in 8.1.1, catalytic appliances shall also report hourly catalyst exit temperature data to include the dates and hours of operation.

11. Procedure

11.1. Test Facility Conditions. The test facility shall meet the following requirements during testing.

11.1.1. The test facility temperature shall be maintained between 55 and 87 °F (13 and 30.6 °C) during each test run.

11.1.2. The flue shall discharge into the same space or into a space freely communicating with the test facility. Any hood or similar device used to vent combustion products shall not induce a draft greater than 0.005 in. H_2O (1.25 Pa) on the wood heater measured when the wood heater is not operating.

11.1.3. For test facilities with artificially induced barometric pressures (e.g., pressurized chambers), the barometric pressure in the test facility shall not exceed 30.5 in. Hg (775 mm Hg) during any test run.

11.1.4. Locate the test facility temperature monitor on the horizontal plane that includes the primary air intake opening for the wood heater. Locate the temperature monitor 3 to 6 ft. (0.9 to 1.8 m) from the front of the wood heater in the 90° sector in front of the wood heater.

11.1.5. Use an anemometer, or equivalent device, to measure the air velocity. Measure and record the room air velocity before the ignition period in L1 Startup and once immediately following the test run completion. Air velocities within 0.6 m (2 ft) of the test appliance and exhaust system shall be less than 0.25 m/sec (50 ft/min) without fire in the unit.

11.1.6. Measure and record the test facility's ambient relative humidity, barometric pressure, and temperature before and after each test run using equipment as specified in Section 6.

11.2. Wood Heater Firebox Volume.

11.2.1. Determine the firebox volume using the definitions for height, width, and length. Volume adjustments due to the presence of firebrick and other permanent fixtures may be necessary. All adjustments shall be detailed in the test report and shall conform to the definition of usable firebox volume contained in this test method. Measurements shall include areas adjacent to and above a baffle.

11.2.2. If a manufacturer deems certain areas of the firebox as unusable for fuel load calculations, written documentation stating the basis for that claim and supporting photographic image(s) must

be provided and approved by the regulatory authority prior to conducting the certification test. If approval is not granted prior to the test, then the test may be invalidated if the reviewing agency determines the firebox volume is inaccurate.

11.3. Test Fuel. The test fuel shall conform to the following requirements and meet specifications as required by the fuel loading calculator:

11.3.1. Fuel Species. Untreated, air-dried, cordwood fuel.

11.3.1.1.For EPA research purposes, allowable species: maple (big leaf, red, silver), or birch (black, white, yellow, paper).

11.3.1.2.Kiln-dried fuel is not permitted. Kiln-dried fuel includes elevating air temperature settings.

11.3.1.3.Fuel shall be free of decay, fungus, or other contaminants.

11.3.2. Fuel Moisture.

11.3.2.1.Determine fuel moisture for each fuel piece by averaging four moisture meter readings, one from each of three sides, measured parallel to the wood grain.

11.3.2.2.The test fuel load shall have an average moisture content from 19% to 25%, dry basis.

11.3.2.3.Average individual piece moisture content shall have an average moisture content 18% to 27% dry basis.

11.3.2.4.The addition of moisture to previously dried wood is not allowed.

11.3.2.5.It is recommended that the test fuel be stored in a temperature and humidity-controlled room.

11.3.2.6. Fuel moisture shall be measured within 24 hours of using the fuel for the test and shall be bagged or stored in a humidity-controlled environment until 2 hours prior to testing. A humidity-controlled environment is one where fuel is not subject to conditions that would remove moisture from the fuel, such as fans or a heating source, and maintain relative humidity levels greater than 75%.

11.3.3.Fuel Temperature. The test fuel shall be at the test facility temperature of 55 to 87 °F (13 to 30.6 °C) +/-2 °F.

11.3.4. Fuel Dimensions. The dimensions of each test fuel piece shall conform to definitions specified by the protocols using the fuel load calculator.

11.3.4.1.Fuel length:

11.3.4.1.1.The length of the fuel pieces will be determined by the fuel load calculator.

11.3.4.1.2.Measurements shall be taken, and the length of the test fuel will be determined by entering the firebox dimensions, which calculates the length for all the fuel pieces into a generally available commercial size (14, 16, 18, 20, or 22 inches in length).

11.3.4.1.3.Piece length specified by the fuel calculator shall be communicated and specified for use in the owner's manual and website. Piece size shall be within 0.5" of the log length determined by the calculator, as measured on the shortest length measurement.

11.3.5.Fuel Loading Direction

11.3.5.1.Fuel loading direction shall be determined by the firebox measurement.

11.3.5.1.1.Stoves with a depth measurement greater than two inches from the width measurement shall be tested with the fuel in a north-south configuration and may not test with fuel in an east/west or crisscross configuration in any load other than Load 1 and Load 2.

11.3.5.1.2.Stoves with a width measurement greater than the depth measurement or a width measurement within two inches of the depth measurement shall be tested with the fuel loaded in an east-west configuration and may not test with fuel in a north/south configuration or crisscross configuration in any load other than Load 1 and Load 2.

11.3.6.Fuel piece weight for each phase of the protocol shall be determined by the fuel load calculator.

11.3.6.1.Kindling – shall be:

11.3.6.1.1.Pieces of wood less than or equal to 1" in diameter.

11.3.6.1.2.No bark requirements for kindling fuel.

11.3.6.1.3.Fuel species may be any species allowed in 7.2.1.1.

11.3.6.1.4.No moisture requirements.

11.3.6.1.5.Length of kindling shall be the fuel length specified by the fuel load calculator.

11.3.6.1.6.Kindling fuel shall conform to the rule that 7 to 10 pieces of kindling equal 1 pound of kindling fuel (+/- 5%).

11.3.6.2. Starter fuel: pieces of cordwood shall be used during the startup phase. Individual piece weight for starter fuel shall be determined by the fuel load calculator. Each piece shall be

triangular, irregular, or circular in cross-section. Square pieces shall be not be used in testing (see Figure 1). Pieces that have squared cross sections shall be split to represent the typical triangle nature of wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible and fuel load pieces shall be composed to include different shapes of wood if using any trapezoidal pieces. .

11.3.6.3.Small fuel pieces: smaller pieces of cordwood by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall not be used (see figure 1). Pieces that have square cross-sections shall be split to represent the typical triangle nature of wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible. No more than two (2) small fuel pieces can be trapezoidal in shape (Figure 2) per fuel load.

11.3.6.4.Large fuel pieces: larger pieces of cordwood, by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall be not be used (see figure 1). Pieces that have square cross-sections shall be split to represent the typical triangle nature of wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible. No more than one (1) large fuel piece can be trapezoidal in shape (Figure 2) per fuel load.

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Figure 1. Schematic of unacceptable cross-sectional profiles

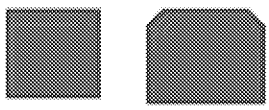


Figure 2. Schematic of undesirable and limited use shapes

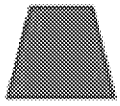
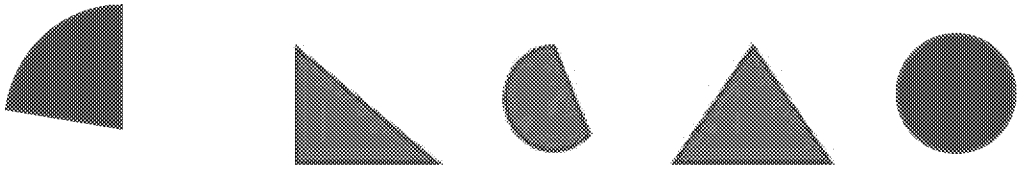


Figure 3. Schematics of acceptable cross-sectional profiles



11.4. Sampling Equipment.

11.4.1. Prepare the tunnel and lab air PM sampling equipment as defined by the TEOM Protocol.

11.4.2. Prepare all other equipment as defined by method EPA Method 1, 2, 3, 4, and ASTM 2515 (dilution tunnel specifications only).

11.5. Manufacturer participation in certification testing.

11.5.1. A representative of the manufacturer may observe testing but may not provide instructions to the certification lab, in any form, with testing staff or equipment once the certification tests begin. The names of testing witnesses cannot be withheld as confidential business information (CBI).

11.6. Test Run Procedure.

11.6.1. Before each test series, the firebox shall be vacuumed. Testing shall begin without any ash or other materials in the appliance.

11.6.2. Before initiating the compliance test series, clean the flue and dilution tunnel with an appropriately sized wire chimney brush before each certification test. Test documentation should include the date and time of flue cleaning.

11.6.3. Record fuel weight data, temperature measurements, and gas concentrations at 1-minute intervals.

11.6.4. Wood Heater Operation and Adjustments. Record all adjustments made to the air supply controls, adjustments to and additions or subtractions of fuel, and any other changes to wood heater operations that occur during the test period.

11.6.5. Appliance operation -bypass operation for catalytic and hybrid models shall follow operational instructions contained in the appliances owner's manual.

11.6.6. The weight of fuel remaining at the end of the test run is determined as the difference between the weight of the wood heater with the remaining coals and fuel and the weight after loading the fuel charge. The starting weight is the tare weight of the cleaned, dry wood heater.

11.6.7. All runs shall be video-recorded in their entirety. Video shall be of sufficient quality to determine fuel characteristics, fuel loading procedures, and firebox conditions during any testing or aging conducted by the test lab. The testing lab shall have the capacity to allow appropriate agencies the opportunity to remotely witness the test.

11.6.8.L1: Start-up Phase.

11.6.8.1.L1 Appliance requirements.

11.6.8.1.1.Stove temperature: internal and external stove temperature must not be greater than the ambient temperature +/- 2˚F (1.1˚C) for Run 1. There is no stove starting temperature requirement for Runs 2 and 3 except in the case of a failed first run. In this case, if Run 1 is invalid or incomplete, the stove must meet Run 1 conditions for at least one valid run. Temperature measurements for the external and internal temperatures shall be taken within 15 minutes before starting the test and shall be reported in the test report.

11.6.8.1.2.Tare the appliance scale before starting the test. Record appliance scale weights at the start and end of L1 phase.

11.6.8.2.L1 Fuel requirements.

11.6.8.2.1.L1 Fuel type – during the startup phase newspaper (optional up to six full sheets traditional newspaper size), kindling, and starter fuel pieces are used. No other additions are allowed.

11.6.8.2.2.L1 loading density

11.6.8.2.2.1.Kindling loading density: 1 lb. per cubic foot for dry kindling, +/- 5%. The fuel load calculator determines the amount of kindling that can be used.

11.6.8.2.2.2.Starter Fuel loading density: 3 lb. per cubic foot, +/- 5%. The fuel load calculator will determine the minimum piece weight that can be used as starter fuel.

11.6.8.2.3.L1 fuel loading structure: The loading structure of the fire shall be a bottom-up configuration with newspaper on the bottom, kindling on top of the paper, and starter fuel on top of the kindling. Kindling and starter fuel shall be loaded in a crisscross configuration.

11.6.8.3.L1 Operational parameters.

11.6.8.3.1.All kindling, starter fuel, and newspaper must be in the firebox for light off.

11.6.8.3.2.Air settings are fully open.

11.6.8.3.3.Light the fire with a torch for a period of no more than 30 seconds.

11.6.8.3.4. Immediately after lighting the fire and completing the photo requirement, the appliance door shall be moved to a cracked open position. Cracked open position is defined as opening no more than one inch. The appliance door shall be closed 5 minutes after ignition.

11.6.8.4.L1 Fuel Adjustments: up to three fuel adjustments are allowed in the startup phase. The door may be open for 30 seconds during each fuel adjustment.

11.6.8.5.L1 End of Phase – the end of the startup phase is defined by the weight specified by the fuel load calculator.

11.6.8.6. L1 Documentation – Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed, and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge.

11.6.9. *L2: High-fire Phase* – the high-fire phase commences immediately after the startup phase ends.

11.6.9.1.L2 Appliance requirements.

11.6.9.1.1.Record the weight of the stove prior to loading the L2 fuel charge, the weight of the fuel charge prior to loading, and the scale weight after loading the L2 fuel charge.

11.6.9.2. L2 Fuel requirements.

11.6.9.2.1. L2 piece size – during the high-fire phase, small cordwood pieces by weight, as defined by the fuel load calculator, are used.

11.6.9.2.2. L2 loading density: 7 lb. per cubic foot, +/- 5%. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.9.3.L2 Operational parameters: Open the door upon completion of the startup phase and load the L2 fuel load within 60 seconds. Once the fuel has been loaded, the appliance doors shall be closed immediately. Air settings shall be left fully open. When 50% of the L2 fuel load mass has been consumed, the air settings shall be moved to the lowest settings.

11.6.9.4.L2 Fuel Adjustments.

11.6.9.4.1.One fuel adjustment shall be made during the high-fire phase prior to moving the primary air control(s) to their lowest setting. The fuel adjustment shall optimize fuel placement for burn conditions. The door shall remain open for 30 seconds for fuel adjustments.

11.6.9.4.2.Additional fuel adjustments shall be made if there is a five-minute period without a weight change of 0.1 pounds at any point during the high-fire phase.

11.6.9.4.3.if there is a five-minute period without a weight change at any point during the high-fire phase. The door may only be open for 30 seconds for fuel adjustments.

11.6.9.4.4.All fuel adjustments must be documented in the test report notes and summary.

11.6.9.5.End of L2 Phase –The high-fire phase ends when the scale indicates that 90% of the high-fire fuel mass has been consumed.

11.6.9.6. L2 Documentation – Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed, and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge prior to loading.

11.6.10. *L3: Maintenance-fire Phase* – the L3 maintenance-fire phase commences immediately after the L2 high-fire phase ends.

11.6.10.1.L3 Appliance Requirements.

11.6.10.1.1. Record the weight of the stove prior to loading the maintenance-fire fuel charge, the weight of the fuel charge prior to loading, and the scale weight after loading the maintenance-fire fuel charge.

11.6.10.2.L3 Fuel Requirements.

11.6.10.2.1.Fuel type – during the L3 phase, large cordwood pieces are used. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.10.2.2.L3 Fuel loading structure: fuel shall be loaded in the direction specified by the fueling calculator.

11.6.10.2.3. L3 loading density: 5 lb. per cubic foot, +/- 5%. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.10.3. L3 Operational Parameters:

11.6.10.3.1.Open door upon completion of the L2 phase and load the maintenance-fire fuel charge.

11.6.10.3.2.Air controls shall be placed in the fully open position for the first five minutes of the phase, and then returned to the low air setting.

11.6.10.3.3.L3 Load - L3 fuel loaded within 30 seconds of the door opening. Close the loading door immediately.

11.6.10.4. L3 Fuel Adjustments: Fuel Adjustments: If there is a ten-minute period without weight change (0.10 lb.) at any point during the L3-fire phase, a fuel adjustment shall be made to increase the burn rate. The door may be open for up to 30 seconds for fuel adjustments. Only two

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fuel adjustments may be made during this phase. If after the second fuel adjustment, another ten-minute period of no weight change (0.10 lb.) occurs, the run ends, and it is a failed test run.

11.6.10.5.L3 End of Phase – The L3-fire phase ends when the scale indicates that 90% of the maintenance-fire fuel mass has been consumed.

11.6.10.6.L3 Documentation – Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed, and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge prior to loading.

11.6.11.*L4: Low burn rate phase* – L4 phase commences immediately after the L3-fire ends.

11.6.11.1.L4 Appliance Requirements.

11.6.11.1.1.Record the weight of the stove prior to loading the L4-fire fuel charge, the load of the fuel charge prior to loading, and the scale weight after loading the overnight-fire fuel charge. Alternatively, if the scale was zeroed prior to starting the test, record the scale weight before and after loading the overnight-fire fuel charge.

11.6.11.2.L4 Fuel requirements

11.6.11.2.1. L4 fuel type –a mix of small and large cordwood pieces are used. At least 50% of the fuel charge load, by the number of pieces, must be large pieces.

11.6.11.2.2.L4 Loading structure: fuel will be loaded in one direction.

11.6.11.2.3.L4 loading density: The fuel load calculator specifies a load volume of 12 lb/ft^3 +/-5%. Fuel shall be loaded in a manner to maximize the number of pieces that will fit in the stove without using force.

11.6.11.3. L4 Operational Parameters:

11.6.11.3.1. Open the loading door upon completion of the L3 maintenance-fire phase.

11.6.11.3.2.Load the L4 fuel charge within two minutes (120 seconds).

11.6.11.3.3.Keep the door in the 1" cracked position for five minutes from the beginning of the L4 phase.

11.6.11.3.4.Air controls shall be placed in the fully open position for the first ten minutes of the phase, and then returned to the low air setting.

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11.6.11.4.L4 Fuel Adjustments.

11.6.11.4.1.Unlimited fuel adjustments are allowed within the first five minutes of the phase. After ten minutes, air control(s) shall be moved to their lowest position. A picture of the air setting used must be included in the test report. The door may be open for up to 30 seconds for fuel adjustments.

11.6.11.4.2.If there is a ten-minute period without weight change (0.10 lb.) during the first hour of the L4- phase, a fuel adjustment shall be made. The door may be open for up to 30 seconds for fuel adjustments.

11.6.11.4.3.Only two fuel adjustments may be made during the first hour. If after the second fuel adjustment, another period of no weight change (0.10 lb.) is observed, the run ends, and it is a failed test run.

11.6.11.4.4.No fuel adjustments are allowed after the first hour of the phase.

11.6.11.4.5.If there is no weight change for a consecutive period of 20 minutes at any point after the first hour of the phase, the unit has failed the test run.

11.6.11.5.L4 End of Phase – The L4 phase shall end when the scale indicates that 90% of the total L4 fuel mass has been consumed. If the fuel load does not burn to 90%, it is a failed test run.

11.6.11.6. L4 Documentation - Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed, and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge prior to loading.

11.7. Test Run. A complete test run requires the completion of all four burn phases and loads. For any appliance that will not accommodate the loading arrangement specified in this test method, the test facility personnel shall contact the Agency Administrator to obtain written approval for an alternative loading arrangement.

11.8. Test Run Requirements. The following describes the required parameters for each test run. Each emission test run shall include all phases of the operational and fueling protocol run in order as described.

11.8.1.Consecutive Test Runs. Consecutive test runs may be conducted, provided that the following requirements are met:

11.8.1.1.Run 1 – The appliance shall have an internal and external starting temperature within +/- 2 °F (1.1°C) of ambient laboratory temperature at the beginning of Run 1.

11.8.1.2. Run 2 – The second test run may commence 24 hours after the start of Run 1. Stove coals and ash can remain in the stove until 1 hour before conducting Run 2. All coals and ash shall be removed at least one hour prior to commencing Run 2.

11.8.1.3. Run 3 – The third test run may commence 24 hours after the start of Run 2. Stove coals and ash may remain in the stove until 1 hour before conducting Run 3. All coals and ash shall be removed at least one hour prior to commencing Run 2.

11.9. *Failure to Operate at All Test Conditions*

11.9.1. If the appliance fails two runs due to incomplete or invalid test runs, it shall be determined that the appliance has failed the certification test and requires a modification to appliance design. All data for incomplete runs shall be reported. Incomplete failed test runs are defined as the following:

11.9.1.1. If a wood heater fails to complete all four phases of the test run, the run shall be considered a failed test run.

11.9.1.2. If there is no weight change, defined as 0.10 lb., for a consecutive period of 20 minutes at any point during the test, the unit has failed the test run.

11.9.2. If a test run violates the test method parameters, the run is invalid.

11.9.3. If during certification testing a critical component of the stove is damaged or breaks, the certification test will be stopped and considered invalid.

11.9.3.1. If damage is noted during a test, repairs shall be made by the manufacturer (or by laboratory personnel with written direction from the manufacturer). If the repair involves components that would need aging, the appliance shall then undergo another round of wood heater aging as specified in section 10.6. These components may include but are not limited to catalyst elements, gaskets, and refractory components. The aging process is intended not only to 'cure' the stove but also to cycle parts that may fail with extended use. Alternate aging techniques may be approved by the administrator, depending on the nature of the failure, material, and critical nature.

11.10. Test Run Completion. Once three valid runs have been completed, the testing is complete. No additional runs may be completed.

11.10.1. *Additional Test Runs*. If there is an invalid run, two additional runs may be attempted to complete the test series. If more than three test runs are conducted, the results from all valid test runs shall be used in calculating the average emission rate. The measurement data and results of all test runs shall be reported regardless of which values are used in calculating the emission rate. No test run data can be eliminated from the reporting requirements of this method.

11.10.2. *Invalid Runs.* When a test run fails to meet one of the QA/QC criteria stipulated in the test method, the data are invalid, and the run must be repeated. Data for the invalidated test run must be included in the test report, but the data must not be used in the calculation of average emission values.

11.10.3. *Incomplete Runs:* When an appliance cannot successfully complete all operational elements of the protocol specified in Section 11.6.7 through 11.6.10, it is an incomplete run

11.11. Auxiliary Wood Heater Equipment Operation. If optional heat exchange blowers are sold for use with the wood heater, three runs with the fan and an additional run without the fan shall be completed. If emissions are more than 1 gram per higher with the fan on, an additional two runs must be completed with the fan on. Heat exchange blowers shall operate in the highest airflow setting. (Automatically operated blowers shall be operated as designed) during the entire test.

11.12. PM Data Recording.

11.12.1. All data shall be collected and recorded at intervals of no more than 1 minute. TEOM operation shall follow the procedures listed in NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

11.12.2. Data shall be reported in an Excel or compatible spreadsheet following the minimum data reporting requirements. All electronic files, including raw instrument data, shall be submitted as part of the test report. Spreadsheet files shall be supplied as part of the publicly available test report.

11.12.3. Room PM measurement – TEOM. A single channel TEOM shall be used to measure ambient lab air PM during the test, as configured in NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel. The sample flow shall be 3 LPM.

12. Quality Control Measures

12.1. Dilution tunnel - Conduct sampling equipment leak check and calibration pre- and post-test.

12.2. TEOM – Flow and Leak checks are done before and after every test run per NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel. Additional quality control measures are included in the TEOM Operating Procedure.

13. Data Analysis and Calculations.

Proportioning of emission factors and rates per phase according to Appendix A, variables shall have subscript added to determine the relevancy of phase, i.e. $E_{T(P1)}$ indicates Total particulate emissions for Phase 1 and $E_{g/hr(P2)}$ indicates emissions factor in grams per hour for Phase 2.

13.1. Emission Calculations. Particulate matter, carbon dioxide, and carbon monoxide shall be calculated using the following methodology and reported in grams per hour, grams per kilogram and pounds per million British Thermal Unit (BTU) heat output.

13.2. Rounding

13.2.1. All calculations shall be conducted using all decimal values provided by the instrumentation or recorded by the operator.

13.2.2. No truncation of data is acceptable until the final result has been calculated.

13.2.3. Only the final calculation of the PM emissions rate shall be rounded to three significant figures.

13.2.4. When rounding off a figure, the following procedure should be used. If the first digit to be discarded is less than five, the last digit retained should not be changed. When the first digit discarded is greater than five, or if it is a five followed by at least one digit other than zero, the last figure retained should be increased by one unit. When the first digit discarded is exactly five, followed only by zeros, the last digit retained should be rounded upward if it is an odd number, but no adjustment made if it is an even number.

13.3. TEOM data shall be reported as follows.

13.3.1. Emissions from each of the 4 phases of the test shall be reported as individual results in grams per hour, grams per kilogram, and lb/MMBtu (heat output). Calculations shall use Section 7 of the NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM NYSERDA TEOM protocol.

Emissions from the entire test run in grams per hour, grams per kilogram, and lb/MMBtu (heat output).

Nomenclature

BR – average dry fuel burn rate, lb/hour
$BR_{(x)}$ – Burn rate for specific phase, BR_{L1}, BR_{L2}, BR_{L3}, BR_{L4}
CO – Carbon Monoxide
CO_2 – Carbon Dioxide
BT = time of 90% of overnight load consumed – time of overnight loading
C_{steel} – Specific heat of steel (0.1 Btu/ lb., ˚F)1
E_T – Total particulate emissions for the full test run in grams
$E_{g/MJ}$ – PM Emissions rate in grams per megajoule of heat output
$E_{g/kg}$ – PM Emissions factor in grams per kilogram of dry fuel burned

1 The value of 0.1 for the specific heat of steel is taken from EPA M28WHH.

$E_{g/hr}$ – PM Emissions factor in grams per hour
HHV – Higher heating value of dry fuel (Btu/lb), measured ASTM E711.
$\%M_d$ = Fuel moisture content, dry basis, percent.
$\%M_w$ = Average moisture in test fuel charge, wet basis, percent
PCTCO2– average CO_2 in the dry flue gas (%)
PPMco -average CO in the dry flue gas (ppm)
Q_{out} – Total heat output in BTU's (megajoules)
SC_i – Scale weight at specific time interval, lb.
T1 – Surface Temperature 1 °F (°C)
T2 – Surface Temperature 2 °F (°C)
T3 – Surface Temperature 3 °F (°C)
T4 – Surface Temperature 4 °F (°C)
T5 – Surface Temperature 5 °F (°C)
T6 - Flue Gas Temperature °F (°C)
T7 – Room Temperature °F (°C)
$TS_{avg(i)}$ – Initial Average Surface Temperature °F (°C)
$TS_{avg(f)}$ – Final Average Surface Temperature °F (°C)
W_{fuel} – Fuel charge weight in pounds (kg)
Θ – Total length of test run, hours
$\Theta_{(x)}$ – Total length of test run in hours per phase, X
$\%M_w = 100(\%M_d)/100+\%M_d$

13.4. Average Wood Heater Surface Temperatures. Calculate the average of the wood heater surface temperatures at the start of the phase (L4) and end at the end of the test (L4) of the test run.
L4 $TS_{avg(i)}$ – (T1 + T2 + T3 + T4 + T5) / 5
L4 $TS_{avg(f)}$ – (T1 + T2 + T3 + T4 + T5) / 5
Average surface temperatures at the start and end of any phase can be determined by averaging all five sensors at the beginning and end of each phase.
L_x $TS_{avg(i)}$ – (T1 + T2 + T3 + T4 + T5) / 5
L_x $TS_{avg(f)}$ – (T1 + T2 + T3 + T4 + T5) / 5

13.5. Burn Time Rating– A standardized burn time rating shall be determined by rounding the duration of the overnight-fire phase of the test up to the nearest 1 hour. Burn time shall be calculated as the time L4 is loaded into the stove until 90% of the fuel has been consumed. This provides an important rating for consumers and is not intended for any calculation purposes and shall be reported by all manufacturers materials that provide specifications on appliance performance. Language such as "this stove has demonstrated a low setting burn time of x hours in official testing."

13.6. Determine Burn Rates

BR_{L1} = not applicable
BR_{L2} = (L2 Initial SC_i – L2 Final SC_i) / $\Theta_{(L2)}$, lbs./hr

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BR_{L3} = (L3 Initial SC_i – L3 Final SC_i) / $\Theta_{(L3)}$, lbs./hr
BR_{L4} = (L4 Initial SC_i – L4 Final SC_i) / $\Theta_{(L4)}$, lbs./hr

13.7. Emissions

13.7.1. Determine emission rates and emission factors as:

$E_{g/MJ} = E_T/(Q_{out} \times 0.001055)$, g/MJ
$E_{g/kg} = E_T/(W_{fuel}/(1+M\%M_d/100))$, g/dry kg
$E_{g/hr} = E_T/\Theta$, g/hr

13.8. Efficiency calculation.

The following nomenclature is defined specifically for the efficiency calculation in this section.
Ultimate Analysis of dry fuel (% by weight, ASTM D5373)
Carbon – CA
Hydrogen – HY
Oxygen – OX
Moisture Content – mass of water per mass of dry fuel – Mcdb
Ambient Humidity Ratio[1] – mass of water per unit mass of dry air – ω
Flue gas temperature (F) – Ts
Room temperature (F)-Tr
CO in the dry flue gas (ppm) – PPMco
CO2 in the dry flue gas (%) – PCTCO2
Higher heating value of the dry fuel (lb/MMBtu, ASTM E711) – HHV

1. Humidity ratio is a commonly used term to express the moisture content in air. It can be determined from ambient temperature and relative humidity using, for example, a Psychrometric Chart. [ASHRAE Handbook of Fundamentals, Chapter 1, p. 1.15, American Society of Heating, Refrigeration, and Air Conditioning Engineers (2017)] For example, air at 65°F and 70% relative humidity has a humidity ratio of .0092 lb of water vapor per pound of dry air.

<u>Combustion Balance Equation:</u>

$$C_xH_yO_z + (1+\alpha)*\gamma(O_2 + 3.76N_2) + \left[\omega * \left(\frac{(1+\alpha)\bullet\gamma\bullet(32 + 3.76\bullet 28)}{18}\right) + \frac{Mcdb}{18}\right] H_2O$$

$$\rightarrow (x-\beta)\,CO_2 + \beta CO + (\alpha\bullet\gamma + \frac{\beta}{2})\,O_2 + (1+\alpha)\bullet\gamma \bullet 3.76N_2 + \left[\frac{y}{2} + \omega\bullet\left(\frac{(1+\alpha)\bullet\gamma\bullet(32 + 3.76\bullet 28)}{18}\right) + \frac{Mcdb}{18}\right] H_2O$$

Where:

$x = CA/12$

$y = HY$

$z = OX/16$

$\gamma = (x + \frac{y}{4} - \frac{z}{2})$

α = excess air parameter, e.g. if $\alpha = 0.5$, there is 50 % excess air

From this:

$$PPMco = \frac{1E6 * \beta}{x + \left(\alpha * \gamma + \frac{\beta}{2}\right) + (1 + \alpha) * \gamma * 3.76}$$

$$PCTCO2 = \frac{100 * (x - \beta)}{x + \left(\alpha * \gamma + \frac{\beta}{2}\right) + (1 + \alpha) * \gamma * 3.76}$$

With flue gas CO and CO_2 measured, these two equations can be solved simultaneously for β and α.

$$\frac{100 * x * PPMco}{1E6 * PCTCO2 + 100 * PPMco}$$

$$\alpha = \frac{\frac{100 * (x - \beta)}{PCTCO2} - x - \frac{\beta}{2} - 3.76 * \gamma}{4.76 * \gamma}$$

<u>Calculation of the Molar Coefficient for Each of the Products</u>

For the assumption of 100 kg of dry fuel, this is the number of moles of each product for the input conditions

$MFCO = \beta$ Molar Coefficient for CO

$MFCO2 = x - \beta$ Molar Coefficient for CO_2

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$MFH2O = \frac{\gamma}{2} + \frac{Mcdb}{18} + \frac{\omega * (1+\alpha) * \gamma * (32+3.76*28)}{18}$ Molar Coefficient for H_2O

$MFO2 = \alpha * \gamma + \frac{\beta}{2}$ Molar Coefficient for O_2

$MFN2 = (1+\alpha) * \gamma * 3.76$ Molar Coefficient for N_2

Conversion of Molar Coefficients to Mass of Products per Unit Mass of Dry Fuel

$MCO = MFCO * 28/100$ kg CO in flue products per kg dry fuel fired

$MCO2 = MFCO2 * 44/100$ kg CO_2 in flue products per kg dry fuel fired

$MH2O = MFH2O * 18/100$ kg H_2O in flue products per kg dry fuel fired

$MO2 = MFO2 * 32/100$ kg O_2 in flue products per kg dry fuel fired

$MN2 = MFN2 * 28/100$ kg N_2 in flue products per kg dry fuel fired

Heat Capacity of Exhaust Products

The general equation for representing how the heat capacity of the exhaust products varies with temperature is:

$C = A * Tk + B$

Where:

C = heat capacity J/mol K or kJ/kgmol K

A and B are constants

Tk = Temperature in °K

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The values for A and B for the exhaust components are provided in the table below

Component	A	B
CO	.0056	27.162
CO2	.029	29.54
H2O	.0057	32.859
O2	.009	26.782
N2	.0062	26.626

For each component, heat capacity is calculated at the stack temperature and at room temperature. The average of these is used to calculate sensible heat loss.

<u>Calculation of Heat Losses for Efficiency Determination</u>

$HHVJ = HHV * 2.326$ Higher heating value in kJ/kg (conversion from Btu/lb)

$LHWV = 43969$ Latent heat of water vapor in kJ/kgmol

$Llat = MFH2O * LHWV/HHVJ$ Heat loss in latent heat of water vapor, % of input energy

$Lco = MFCO * 282993/HHVJ$ Heat loss in chemical energy in CO, % of input energy

$Lsens = (MFCO * C_{COm} + MFCO2 * C_{CO2m} + MFH2O * C_{H2Om} + MFO2 * C\_O2m$

$+MFN2 * C\_N2)/HHVJ$ Heat loss in sensible heat in flue gas, % of input energy

<u>Note – T6 and T7 in this expression must be expressed in °C or K.</u>

$Efficiency = 100 - Llat - Lco - Lsens$ Stack loss efficiency, %

14. ***Reporting Requirements.*** The report shall include the following:

14.1.1. Introduction

14.1.2. Purpose of test: certification, audit, efficiency,

14.1.3. Name and location of the laboratory conducting the test.

14.1.4. Wood appliance identification – manufacturer, model number/name, design type, description of the appliance tested, stove condition, and date of receipt.

14.1.5. Test information – location of testing, date of tests, sampling methods used, number of test runs, a statement detailing any previous certification testing completed on the wood appliance.

14.1.6. A list of people who conducted research on the appliance, participated in testing preparation, or witnessed the certification testing. This list shall clearly specify their roles in the testing program for the appliance. The list shall include the participant's name, title, company, contact information and the purpose of their participation.

14.1.7. A statement that the test results apply only to the specific appliance tested.

14.2. Summary and Discussion of Results

14.2.1. Table of results to include test run number, average burn rate for entire run and each phase, carbon monoxide and particulate emission rate for full run, particulate and carbon monoxide emission rate for each load phase (L1, L2, L3, L4), efficiency for the full run and each phase, burn time for total run and each phase.

14.2.2. For each test run and pollutant with real-time data to include: Θ_1,Θ_2, Θ_3, CO, CO_2, PM, and efficiency for (1) L1 - the startup phase and (2) L2 - high-, (3) L3-maintenance-, and (4) L4 low burn rate fire phases. Calculated results for the emissions shall be reported as total emissions in grams, pounds per million Btu output, grams per MJ, grams per kilogram of dry fuel and grams per hour, and pounds per hour.

14.2.3. A narrative discussion detailing any issues or anomalies that arose during each test run and how those were handled, including comments about the fuel, and loading of the appliance.

14.2.4. PM Plots

14.2.4.1. A plot of PM emission rate in grams/hour vs. time at 1-minute intervals, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.5. Summary of other data – test facility conditions, surface temperature averages, catalyst temperature averages, pretest fuel weights, test fuel charge weights – total and by phase.

14.3. Discussion. Test run result, specific test run problems, and solutions. Comments on fuel, loading, analysis, and anything that may impact the reported result(s).

14.3.1. Details of deviations from, additions to or exclusions from the test method, and their data quality implications on the test results (if any), as well as information on specific test conditions, such as environmental conditions. An explanation of the deviations, additions, or exclusions shall be provided along with an analysis as to why these elements had no impact.

14.4. Process description:

14.4.1. Data and drawings indicating the firebox size and location of the fuel charge.

14.4.2. Drawings and calculations used to determine firebox volume to include volume, height, width, and lengths, weight, and volume adjustments.

14.4.3. Firebox configuration – At a minimum to include air supply locations and operation, air supply introduction location, refractory location and dimensions, catalyst location, baffle and by-pass location and operation (include line drawings or photographs)

14.4.4. Appliance operation during the test – shall supply details on air supply settings and adjustments.

14.5. Test fuel properties – the report shall provide information on the species, density, fuel moisture, fuel temperature, and load details from the fuel load calculator to include all measurements including the number of pieces, individual piece weights, piece length, moisture content and weight.

14.6. Sampling

14.6.1. A description of the test procedures and test equipment, including a schematic or other drawing showing the location of all required test equipment. Also, a description of test fuel sourcing, handling and storage practices shall be included.

14.6.2. Describe the sampling location relative to the wood heater, include drawing or photographs.

14.6.3. Provide data on sampling blanks.

14.7. Quality Control and Assurance Procedures

14.7.1. Calibration procedures and results certification procedures, sample and analysis procedures.

14.7.2. Test method quality control procedures to include TEOM leak and flow checks, stratification (velocity) checks, tunnel flow range results, filter temperature range verification and dilution tunnel RH verification.

14.8. Appendices

14.8.1. Results and Example Calculations. Raw data and complete calculations for data included in summary tables.

14.8.2. Raw data. Copies of all files or sheets for sampling measurement, temperature records, and other materials used by lab related to testing.

14.8.3. Calibration Results. Summary of all calibrations, check, and audits pertinent to the certification.

14.8.4. Sampling and Operation Records. Copies of all uncorrected records of activities not included in raw data sheets (e.g., wood heater door open, times and durations) as well as photographs of fuel loading and air flow settings.

14.8.5. Correspondence. Any correspondence to include written, electronic or verbal communications regarding appliance testing. Items shall include:

14.8.5.1. Request to conduct testing

14.8.5.2. Scheduling of testing

14.8.5.3. Notice to EPA to conduct test, and any modifications to that request.

14.8.6. Test Facility Information. Report test facility temperature, air velocity, and humidity information.

14.8.7. Test Equipment Calibration and Audit Information. Report calibration and audit results for the platform scale, test fuel balance, test fuel moisture meter, and sampling equipment including volume metering systems and gaseous analyzers.

14.8.8. Pretest procedures. Report all pretest procedures conducted at the lab on the appliance to burns, rates, and amounts.

14.8.9. All required data for each test run shall be provided in spreadsheet format both in the printed report and in a computer file such that the data can be easily analyzed and calculations easily verified. Formulas used for all calculations shall be accessible for review.

14.8.10. For each test run: report TEOM flow and temperature and verification of all TEOM data validation parameters as required in NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

14.8.11. Raw data, calibration records, and other relevant documentation shall be retained by the laboratory for a minimum of 7 years.

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Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 5/28/2021 7:37:46 PM
To: Burkhard, Ellen G (NYSERDA) [Ellen.Burkhard@nyserda.ny.gov]; Johnson, Steffan [johnson.steffan@epa.gov]
Subject: FW: Teom SOP for docket
Attachments: NYSERDA DRAFT TEOM 1405-Dichot SOP 21-05-28 clean for docket-secured.pdf

This time with the TEOM protocol attached.

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NYSERDA Standard Operation Procedures for Thermo Scientific 1405-D TEOM™ for use in a dilution tunnel

DRAFT, May 28, 2021

Section 1. Introduction

This document covers operation concepts and procedures for use of the Thermo Scientific model 1405-D TEOM to measure and report continuous particulate matter (PM) concentration measurements in an EPA Method 5G dilution tunnel or equivalent dilution method. The TEOM is designed for ambient real-time PM measurements, and is an inertial microbalance - a true continuous mass measurement method with resolution of 0.01 µg (0.00001 mg). The TEOM operating parameters are highly configurable, allowing the instrument to be set up to best meet the needs of a specific application.

The version of the TEOM used here for measurement of PM in the dilution tunnel is the "Dichotomous" (Dichot) 2-channel configuration (custom configuration, 1405D Base unit without Accessories), without any inlet hardware, virtual impactor, flow splitter, pump, T/RH sensor, or sample conditioning options such as "FDMS". For this application, the TEOM flows, temperatures, and timing settings are changed from the normal ambient settings to allow for fast filter changes with minimal data loss (typically four to five minutes). The second ("PM-coarse") TEOM channel is used as a co-located PM measurement for quality control purposes, similar to the paired filter train in ASTM-2515. Instrument configuration settings are the same for each channel. There are no hardware modifications needed. Instrument manuals, Microsoft Windows instrument software, and related support information are available from the Thermo web site.[1] Technical support is available during eastern time business hours by calling the main Thermo Scientific number: 866 282 0430.

Note: This procedure requires that dilution tunnel flows be at least 600 cfm to avoid condensation of water vapor in the sampling system.

Instrument Software

Thermo provides two Microsoft Windows programs for the TEOM that can be obtained from the 1405 web page. "RPComm" (the serial port interface program) can be used to display the last 15 minutes of data on a graph, download data, and quickly read all key operating parameters during a test run. It is also used to document the instrument settings. "ePort" (the ethernet interface program) is used to control the instrument remotely and to download data. Both programs can be used at the same time. Instrument control and data can be accessed remotely using any program that provides remote PC access.

Instrument Installation.

[1]The TEOM manual, revision of 15Feb2008, is referenced in this SOP, and is available here: https://www.thermofisher.com/order/catalog/product/TEOM1405D

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The TEOM must be positioned close to the dilution tunnel sample port location. The length of the sample lines from the tunnel wall to the TEOM inlets must be no more than 18 inches. Consistent with ASTM-2515, samples are taken no more than 1 inch from the tunnel center line, and there must be at least 1 inch distance between the two sample line ends. Sample tubing must be conductive (either metal or conductive flexible tubing) with ¼" ID. A short piece of ¼" OD x 3/16" ID metal tubing must be used for insertion into the tunnel. All of the inlet tubing must be replaced or solvent-cleaned after every series of tests.

The laboratory temperature at the location of the TEOM must be kept sufficiently cool enough to keep the instrument's Case temperature reading from exceeding 0.1 ºC of the setpoint. This requires that the laboratory temperature at the TEOM be at least 1 and ideally 1.5 to 2 ºC lower than the Case temperature setpoint.

The TEOM does NOT have any clear visual warning that the filter needs changing due to loading. The TEOM digital outputs (relay contact closures, page 3-31 of the TEOM manual) must be used to trigger an external audible alarm at 115% filter loading, as shown in the alarm configuration instructions at the end of this SOP.

<u>Supplies and Parts needed for this test method:</u>
1405D Dual TEOM Base unit without Accessories, Thermo p/n 1405D-ANF
1405 Single TEOM Base unit without Accessories, Thermo p/n 1405-ANF
Teom filters, 6 to 8 per test, ordered from Thermo, p/n 57-007225-0020 (box of 20 filters)
Black sample filter change tool, Thermo, p/n 55-002013-0001
Mass transducer calibration kit, Thermo p/n 59-008298 and 1 refill, p/n 59-008299
TEOM sample tube brush, Thermo p/n 30-002227
Particle filter for zero-air tests and transducer calibration
Vacuum pump for 5 lpm at 20" vacuum (connects to TEOMs with 3/8" plastic tubing)
3/8" or 1/4" conductive inlet tubing (metal or conductive plastic[2])
(2) 1/2" to 3/8" swage SS reducing union for inlet tubing
NIST-traceable flowmeter for 0.9 to 3.3 lpm at 20 ºC and 1 Atm, accuracy of 2% or better.
Windows PC for RPComm (with a USB to serial port adaptor) and EPort (ethernet connection)
Filter change alarm parts: a DB25 male breakout connector, alarm, and alarm power supply

Lab air PM is also measured with a TEOM without any particle size cut, with the inlet of the probe located within 10 feet of the bottom of the tunnel's hood and an inlet line using conductive tubing of at least ¼" ID and no longer than 5 feet. This TEOM can be a single channel TEOM (1405). It can use the same pump as the dilution tunnel TEOM, and is configured the same way except for the following settings to increase sensitivity:

Inlet flow = 3.0 lpm
MRMC and MassAVG times set to 120 seconds

The filter for the lab air TEOM must be changed before the start of a series of test runs and whenever filter loading exceeds 80% before the start of a test day. All other operating

[2]Available from Freelin-Wade, Static Dissipative 90A Plastic Tubing - 90A-452, p/n 1J-452-90-01

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parameters and procedures are the same as for the dilution tunnel dichot TEOM. Lab air PM concentrations are subtracted from tunnel PM concentrations before any other calculations are performed.

Section 2. Routine Operation Procedures for Thermo 1405-D TEOM

This section is a summary of routine operating procedures.

A. *Quality Assurance checks to be completed before and after each set of test runs for tunnel and lab air TEOMs:*

1. Modify system settings as detailed in Section 8 (initial installation only).
2. Perform K0 mass transducer verification checks on both channels as detailed in Section 4 of this procedure.
3. Document the system settings listed below using the Thermo RPComm program to display and save the values to a text file. Instrument time (PRC90) is in Unix Epoch format (seconds since 1/1/70, valid through 2037). This example is at May 14, 2021 1:59:05 PM (instrument clock time, not UTC). TEOMA (left sensor) is PM2.5 and TEOMB (right sensor) is PM-coarse. K0 values are calibration constants specific to each of the two TEOM mass transducers.

PRC	Name	Value
1	serial number	1405A247642010
2	instrument firmware version	1.74
3	instrument model	TEOM 1405-D
4	Instrument model variant	Dichot
28	system wait time	0
35	mass average time	30
74	average temperature set point	20.000000
75	standard temperature set point	25.000000
76	average pressure set point	1.000000
77	standard pressure set point	1.000000
78	volumetric flow control	1
79	mass conc reporting	1
91	bypass flow mass set point	0.000000
259	TEOMA K0	15317.000000
343	TEOMB K0	17551.000000
390	instrument time	1621000745
392	MRMC average time	30
407	TEOMA mass constant A	0.000000
408	TEOMA mass constant B	1.000000
409	TEOMB mass constant A	0.000000
410	TEOMB mass constant B	1.000000

Other key instrument operating parameters are always recorded in the data file and thus are not listed here.

B. *Routine procedures before every test run to be conducted 1-2 hours prior to testing.*

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1. Check the TEOM time for both the tunnel and lab air instruments, and set as needed to be within 5 seconds of laboratory time. Changing the time causes an instrument reboot and loss of up to an hour of data. See notes section below. Verify that the 1-minute data records are being recorded with time-stamps within 5 seconds of the top of the minute. If they are not, reboot the instrument and re-check after the top of the next hour.

2. Before installing new tunnel TEOM filters, perform a leak test and flow check on both tunnel TEOM channels using the procedures in section 3 of the SOP. The leak test net results shall be no greater than 0.05 lpm. The flow checks must be performed with a traceable calibration standard. If either measured flow is greater than 2% different than the reported flow, a flow calibration shall be performed using the procedures in section 3.

3. Tunnel TEOM Initial filter change.
Install a clean filter for each channel before each test run and put 2 clean filters on the storage pins inside the sensor. See section 5 for the filter change procedure, including confirmation of proper operation after the filter change.

4. Lab-air TEOM
Verify that the lab-air 1405 TEOM is operating properly and that the filter loading is less than 80%. Change the filter if needed to ensure it does not overload during the test run. Flow and leak check tests are only needed after a filter change and after completion of a set of test runs.

C. Operation During Testing (tunnel TEOM only)

1. Before initiating the test, run the TEOM while sampling dilution tunnel air (with tunnel flow) for at least 10 minutes. The change of pressure in the tunnel can cause a large transient TEOM response which would invalidate the data for several minutes.

2. TEOM filter changes during a test run must be done when any of the following conditions are met, using the "Advanced" filter change mode and the procedure in Section 5. Filters for both channels must always be changed at the same time.

   a. Near the end of burn phases 2 and 3, when 80% of the fuel charge has been burned. This is sufficiently in advance of loading the next fuel charge to allow the TEOM to stabilize after completion of the filter change procedure, and ensures that valid data are available when the next fuel charge is loaded.
   b. Percent loading reaches 115% for <u>either</u> TEOM channel
   c. When the sample flow drops more than 5% of the flow setpoint for either channel.

   (b) will not normally trigger a filter change on a low-emitting device, and (c) should never occur without (b) unless there is a problem with the pump. Note that filter "plugging" does not end the test run – it triggers a filter change and the run continues.

   Proper operation of the TEOM must always be confirmed after a filter change as detailed

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in the section 5 filter change procedure.

Note that if the flow starts to drop from the setpoint before 115% is reached, that is an indication of a vacuum pump problem. Vacuum is usually between 0.25 and 0.35 atm as read on the "System Status" TEOM display screen. If it exceeds 0.40 atm, the pump must be serviced.

Detailed information on performing filter changes during testing is provided in Section 5 of this document.

3. At the end of the test, perform external leak and flow checks on both channels as detailed in Section 3 and record the results. For valid results, leak checks shall be no more than 0.05 lpm, and flow checks shall be within 2.0 % of the TEOM flow reading.

4. Download the test data using either the Thermo ePort software (preferred), RPComm, or to a USB thumb drive. Note: the data format may be different depending on how the data are downloaded; the TEOM data template is based on downloading data using the ePort software.

Notes:

- The instrument "Status" code is not normally used for data validation. If the ambient T/RH sensors are not used, a status code of 8 will be present. Other than status codes of 134,217,728 (TeomA) and 524,288 (TeomB) when the % loading is greater than 90%, 8 (for the ambient T/RH sensor) is normally the only allowable "warning" status once the system is operational and running properly. The "8" status will cause the warning triangle on the TEOM display to show all the time.

- When the TEOM is first turned on or rebooted, no data are recorded until the top of the next hour. Other than after a reboot, data will be recorded even when no concentration data is displayed on the screen.

- **After EVERY instrument power on or Reboot:** confirm data are being recorded after the top of the hour. Occasionally the TEOM doesn't store any data after a reboot, even though all operational parameters are normal and concentrations are reported to RPComm and the TEOM display. If this occurs, Stop and Start the instrument to start data storage. A filter change using the Wizard is a Stop and Start cycle.

- When the time is changed, the instrument reboots (after many seconds of being hung, with no information on the screen). When it reboots, no data are recorded until after the top of the next hour (see above).

- TEOM PM concentrations are in micrograms per cubic meter, at EPA STP (20.0 °C and 1.00 atmosphere) with the instrument configuration used in this procedure. Filter mass loading is reported in micrograms, with a resolution of 0.01 micrograms (10^{-8} grams).

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Section 3. Leak and Flow Checks and Flow Calibration for the 1405-D TEOM

A traceable flow standard capable of displaying flow at standard conditions of 20.0 ºC and 1.00 atm shall be used for all flow checks and flow calibrations. Facing the front of the TEOM, the left channel is PM2.5 (TeomA) and the right channel is PM-coarse (TeomB). The lab air TEOM leak and flow checks are done at the start of every set of test runs, whenever the filter is changed, and at the completion of every set of test runs.

Leak Checks

A leak test measures the net flow as reported by the TEOM's flow sensors with no flow. Leak checks shall be done for both channels before the start and after the end of every test run. The TEOM leak test flow readings must be corrected for the TEOM flowmeter's zero offsets. To conduct a flow check, follow the procedures below for each channel:

1. With the TEOM warmed up for at least 30 minutes, read the TEOM reported flow for both channels with the pump turned off or with the TEOM in Stop mode. This is the flowmeter zero reading.
2. Close off the inlets to the TEOM sample train.
3. Turn on the TEOM pump, or set the TEOM to Run mode.
4. Wait one minute and read the flows reported by the TEOM.
5. The leak test values are the difference between the reading without and with flow.
6. The leak tests must be no greater than 0.05 lpm (net value).
7. Open the inlet to the TEOM sample train.

Flow Checks.

The TEOM sample flows for each channel shall be set to 1.00 lpm (at 20.0 C and 1.00 atm). The TEOM must be warmed up for at least 30 minutes before checking or adjusting the sample flows. The sample flows must be measured at the sample train inlet with an external NIST-traceable flow meter that reads in STP (20.0 C and 1.00 atm); measured flows must be within 2.0 % of the flow as indicated on the TEOM display for each of the two channels.

Flow Calibrations.

Flows must be calibrated for each channel with a NIST-traceable flowmeter that reads STP flow at 20.0 C and 1.00 Atm, using the TEOM wizard at Service, Calibration, Flow Calibration (page 5-41 of the Dichot TEOM manual); select "Direct Flow Device" (not FTS). A Flow Check shall be performed immediately after every flow calibration.

Flow Troubleshooting.

When a flow calibration fails, use RPComm to report the "flow offset" and "flow span" parameters [PRC 228, 229 for TeomA, and PRC 312, 313 for TeomB]. If they are not close to 0 and 1 respectively, reset the instrument's flow calibration to 0 and 1 by doing a flow cal routine but just hit "next" without entering any flows. Once that is reset, perform a normal flow calibration and then record the new offset and span parameters.

NOTE: In buildings where heavy electrical equipment is operated, the actual TEOM flows might be unstable even though the reported flow appears to be stable. This can cause erratic and poor

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agreement in the PM between the two TEOM channels. For that reason it is recommended to use a constant voltage power supply for this instrument rather than a direct 120VAC wall outlet.

Section 4. TEOM Mass Transducer K0 Check Procedure for the 1405-D TEOM

The mass transducer K0 (calibration factor) checks described here must be done before and after each set of test runs for both TEOM channels and for the lab air TEOM.

K0 Checks

K0 checks confirm the calibration factor for the tapered element mass transducer in use by the TEOM by weighing a clean TEOM calibration filter of known mass (nominally 0.09 grams) as supplied by Thermo. To prevent contamination of calibration filters, the red filter change tool must only be used with calibration filters, and the black filter change tool must never be used with the calibration filters

K0 verifications must be done before and after every set of test runs using the K0 Wizard. See page 5-53 of the Dichot TEOM manual. Verify that the K0 values in use by the instrument are the same as the values on the mass transducer sticker, and document the serial number of the mass transducer. The PM2.5 K0 is on the left, and the PM-coarse K0 is on the right. The transducer serial number is on the far right in the example below; the last four digits are the YYMM of manufacturer. If either of the K0 values in use are different than the original values, the date of calibration and the new values must be recorded.

Record the calibration filter ID, the calibration date, and the average mass value of the calibration filter. Document K0 checks with an ePort screenshot of the result as shown below. If results are greater than 2% different from the values currently being used by the TEOM, or if the difference between the two dichot TEOM channels is greater than 2%, repeat the check. If repeated checks fail either of these criteria, repeat the check with a second calibration filter. If the difference persists, the K0 values in the instrument may need to be changed from the manufacturer's value supplied with the instrument, but this must not be done without clear and robust evidence such as multiple calibrations with multiple filters that the K0 value is out of

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tolerance. The new values must be documented and stored with the instrument for future reference.

K0 Verification Results

The K0 Verification Wizard has completed successfully. The instrument will be put in Run mode when this wizard is finished.

PM-2.5 (left) TEOM:
K0: 14523.0 Audit K0: 14592.7
Percent difference: 0.48
Initial frequency: 344.6019
Final frequency: 248.6712

PM-Coarse (right) TEOM:
K0: 15825.0 Audit K0: 15871.9
Percent difference: 0.30
Initial frequency: 364.9166
Final frequency: 260.5874

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Section 5. Filter Change Procedure for the 1405-D TEOM

The TEOM measures the pressure drop across the filter as % of maximum (115 %), and is shown on the instrument display screen. A clean filter has a loading of about 5 % at 1.00 lpm. Tunnel TEOM filter lifetime will vary widely depending on the PM concentrations and nature of the smoke being sampled. Under typical sampling conditions, lifetime is an hour or more with concentrations in the 20 to 50 mg/m^3 range, but at very high PM concentrations (several hundred mg/m^3), filter lifetime may be less than 30 minutes. With care, filter changes can be done such that only a few minutes of data are lost. A video showing the TEOM filter change procedure is on the Thermo TEOM web page. This video does not use the "Advanced User Mode" that is required by this SOP, but is useful for training purposes. The Dichot TEOM manual has illustrated procedures for filter changes starting on page 5-6.

Note: Both tunnel TEOM filters must always be changed at the same time, even if only one channel triggers a filter change event.

Filter change procedure.

The following are filter handling procedures that shall be followed:

A. Unused clean filters must be stored in the original box and plastic bag, with the silica gel desiccant in the bag.
B. Two clean filters must be stored in the mass transducer on the posts provided.
C. Filters must only be handled with the black filter change tool.

Minimize the time the mass transducer is open to reduce the time needed to re-stabilize temperatures after the filter change.

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1. The filter change menu can be located by choosing Service, Maintenance, Replace Filter. Select the "Advanced" option, and then Next to proceed. This turns off the oscillating element which makes filter seating easier.

2. Open the TEOM cabinet door, open the box of clean filters, and open the mass transducer. Remove the old filters by sliding the filter tool onto the filter and pulling straight out. Do not twist the tool (to prevent damage to the glass tapered element).

3. For each channel, pick up a new filter that has been stored inside the mass transducer with the tool. Position it directly over the tapered element and push the filter on gently. Once the filter is on, remove the tool from the filter and fully seat the filter by pushing firmly straight down on the filter with the bottom of the tool with approximately 1 pound of force for at least two seconds (see the TEOM manual and video for more information). The filter should have a small amount of horizontal play when this is done; if not, the filter may be wedged between the tapered element and the side of the opening for the element. Store two new filters in the mass transducer (this equilibrates them to the sensor temperature).

4. Close the mass transducer, replace the filter box cover, and close the cabinet door. Restart the TEOM by completing the filter change wizard with Next, Finish. The TEOM is not restarted until the Wizard is closed with "Finish", and the Maintenance screen is shown.

5. Proper operation of the TEOM must always be confirmed after a filter change. For the PM2.5 channel, the RPComm PM plot can be used; there must not be excessive noise or large and erratic negative data. The TEOM's PM2.5 and PM-Coarse display (PM-10 is not used) as shown below is used to verify proper operation for both channels as follows.

<u>1-minute</u> after the filter change is completed:
a. Frequencies for both channels must be greater than 200 Hz.

<u>5-minutes</u> after the filter change:
b. Filter mass values for both channels must be similar and not any more negative than -1 μg.
c. Noise values for both channels must be small (< 2 ug) or if larger because of high PM concentrations, similar.

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	PM-2.5	PM-Coarse
MC (µg/m³):	0.00	8.66
30-Min MC (µg/m³):	0.00	0.00
1-Hr MC (µg/m³):	0.00	0.00
2-Hour value (µg/m³):	0.00	0.00
12-Hr MC (µg/m³):	0.00	0.00
24-Hr MC (µg/m³):	0.00	0.00
Total mass (µg):	0.07	0.11
Filter loading:	3.68 %	5.51 %
Frequency:	257.9879 Hz	270.8600 Hz
Noise:	0.028 µg	0.129 µg

If the filter change fails, the filter may need to be reseated or is defective, or the sensor latch may not be closed properly. Repeat the filter change "advanced" procedure and take the filter off and re-seat it. Push it on firmly with the back of the filter tool and make sure the sensor is properly closed and latched. If the problem persists after another 5 minutes, restart the procedure with another new filter.

Note: the PM2.5 concentrations on the TEOM display will read 0.0 after a filter change until the top of the next hour. When valid data are being collected, the RPComm graph will indicate PM2.5 concentration, and the "Total Mass" on the TEOM display will read something other than "0.00" for both channels.

Section 6: Data Storage and Download

The TEOM shall be set to store data every 60 seconds. There is storage for more than a year of data at this storage interval. Data can be downloaded while the TEOM is running.

Data are usually downloaded with the ePort software, with the "use old column names" option unchecked. If needed, data can also be downloaded to a USB thumb drive or with the RPComm TEOM software. The data file is in .CSV format for importing into a spreadsheet.

The TEOM shall be configured to record data parameters as follows. There is a limit of 20 parameters (not including the Date and Time, which are always recorded). For the lab air TEOM the list is the same but without the PM-Coarse parameters.

0. Date, Time
1. Operating mode
2. PM-2.5 raw MC
3. PM-Coarse raw MC
4. PM-2.5 total mass
5. PM-Coarse total mass
6. Case temperature

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7. Cap temperature
8. PM-2.5 flow rate
9. PM-2.5 air tube temperature
10. PM-2.5 TEOM filter load
11. PM-2.5 TEOM filter pressure
12. PM-2.5 TEOM noise
13. PM-2.5 TEOM frequency
14. PM-Coarse flow rate
15. PM-Coarse air tube temperature
16. PM-Coarse filter load
17. PM-Coarse TEOM noise
18. PM-Coarse TEOM frequency
19. Vacuum pump pressure
20. System status

The key parameters for data validation are:

1. Date and Time – reported as the end of the average interval.
2. Mode – must be 3 or 4 for valid data.
3. PM2.5 raw and PM-Coarse raw Mass Concentration in $\mu g/m^3$. A zero value or a repeating value for Mass Concentration indicates no data. These are always reported even when they are invalid. This minimizes loss of data after a filter change but also requires manual QC of the data file to remove invalid PM concentrations based on review of the data and critical parameters listed below.
4. PM2.5 and PM-Coarse total mass – the mass loading on the TEOM filter in µg since the last instrument reset, filter change, or Stop/Start cycle. A zero value indicates no data.
5. PM2.5 and PM-Coarse flow rate – Flow is lpm at 20.0 C and 1.00 atm.
6. PM2.5 and PM-coarse TEOM filter load – filter loading as % of maximum.
7. Case temperature, in degrees C. Cap and Air Tube temperatures are not normally used for validation.
8. PM2.5 and PM-coarse "Noise" is a mass transducer stability metric and should normally be less than 0.50 µg when PM concentrations are low or zero.
9. Agreement between the PM2.5 and PM-coarse channel PM concentration data in the data processing spreadsheet template meets QC criteria.

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Section 7. Data Validation and Calculations

TEOM data are recorded every 60 seconds. Data validation and conversion to PM rate (g/h, using "wet" STP tunnel flow) is performed on the 60 second TEOM data. PM rate data are averaged up to longer intervals for reporting use as required. A valid test run must have at least 95% data capture at the 1-minute level.

One-minute TEOM PM concentration data for each channel (and for the lab air TEOM) are valid only when all of the following parameters are met:

1. Flow reported by the instrument is within 5% of the flow setpoint (between 0.950 and 1.050 lpm)
2. Operating mode (not system status): 3 or 4
3. Noise: 3-minute running average of (100 x noise / concentration) is < 0.10
4. Case temperature: +/- 0.10 C of setpoint (32.90 to 33.10 C)
5. Concentration is not 0.00
6. Total Mass for is not 0.00
7. Concentration is different from the preceding interval.
8. Lab air PM data are available and valid.

Items 5, 6, and 7 are usually covered by item 2 (Mode) but there can be cases such as a failed filter change where mode indicates valid data but some of these parameters indicate invalid data.

When a filter change is done during a test run, the TEOM data may skip a time interval. The time sequence during a filter change must be examined using the data processing spreadsheet and corrected if needed.

Since the "wait time" is set to 0 to minimize data loss during a filter change, the TEOM never invalidates any data. Thus the data must always be reviewed and validated manually using the criteria above and the data processing spreadsheet. 1-minute intervals during the test run that do not have valid data are represented using empty spreadsheet cells for those intervals. Any longer interval calculated from the 1-minute data (such as a burn-phase) must have 75% of the possible 1-minute values. Example: a 20-minute interval must have at least 15 minutes of valid data to be valid.

Note that negative TEOM PM concentration data are considered valid data. This can occur when there is substantial mass on the TEOM filter and the burn cleans up. The filter can lose mass when this occurs, and that results in negative PM being reported.

The output of the TEOM is PM concentration in $\mu g/m^3$ at 20.0 °C and 1.00 Atmosphere (29.92 inches Hg) pressure. The TEOM flow is "wet" e.g., not dried. The tunnel flow used to convert PM concentration into PM emission rate must also be "wet", without any water vapor correction.

Run validation parameters.

The Excel dichot TEOM data template calculates the following parameters for the entire run from the PM concentration data for the two channels. These values must meet these criteria for TEOM data from a run to be valid, and assume the dilution tunnel is well-mixed.

%D of run-average PM: no more than 7.5%

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Calculations.

The final product of this SOP is valid 1-minute TEOM PM concentrations using the average of both channels and with lab air PM subtracted. An Excel spreadsheet data template is provided to facilitate TEOM PM concentration calculations and TEOM data validation steps described in this section.

The 1405-D TEOM does not report the actual PM-coarse channel (TeomB) concentration because it is designed for use with a dichotomous sampler virtual impactor inlet system. The PM concentrations for the PM-Coarse channel must be calculated as follows:

PM-Coarse raw MC * (16.67/PM-Coarse flow).

For 1.00 lpm flow, the calculation is:

PM-Coarse channel ($\mu g/m^3$) = 16.67 * PM-Coarse raw MC.

The PM2.5 TEOM channel does not need any additional calculations.

Conversion to PM emission rates and other reporting metrics require data generated from other sources (wet STP tunnel flows, stove scale weights, and heat output data).

The final 1-minute TEOM PM concentrations are converted into grams/hour using the wet STP tunnel flow as follows:

g/h = 0.000001699 * (tunnel flow in wet CFM) * (net PM concentration in $\mu g/m^3$)

The values used for tunnel flow must be the actual (wet) measured values corrected to STP, at intervals of no greater than 10 minutes, except as follows. If the range of 10 minute tunnel flow measurements (100*(Max - Min) / average) is no greater than 5.0% of the run-average tunnel flow, the run average tunnel flow can be used for these calculations. Note that proportionality of TEOM flow to tunnel flows does not need to be maintained since emission rate data are calculated on a 1-minute basis rather than on a run-average basis, and then averaged up to the time period of interest.

For calculation of lbs/MMBtu or grams/kg, total grams PM emitted is calculated by multiplying the average g/h rate for the test period of interest times the duration (in hours) of that test period. Grams are converted to lbs by dividing grams by 453.6. Heat output calculations are in the main IDC protocol.

Section 8: TEOM Configuration Changes for Fast Response and High PM Concentrations, and List of TEOM Parameter Configuration Values.

These settings are for the 1405-D TEOM as used in this application that are different from instrument default settings. See the 1405-D manual for detailed information on how to change these values. Settings that are different for the lab air TEOM are noted in steps 2 and 3.

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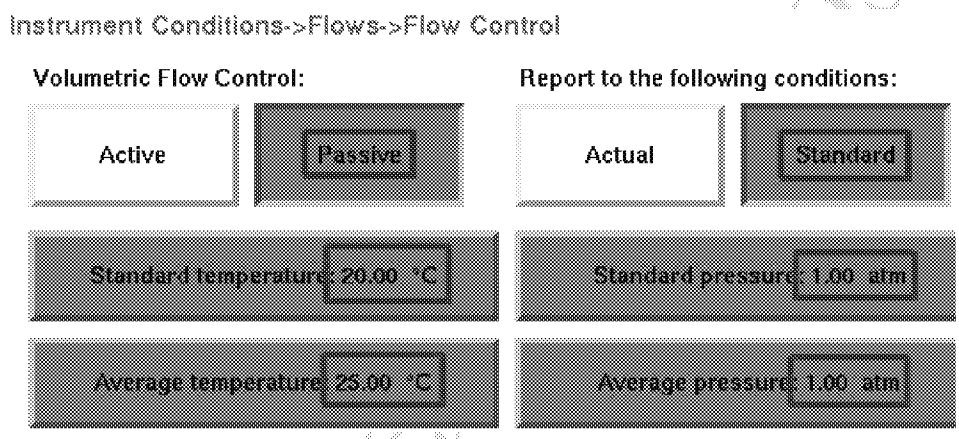
1. For both channels (TEOMA and TEOMB), confirm that all of the "Mass Constants" A and B factors are set as follows: The 3 "Mass Constant A" values are set to 0.0, and the 3 "Mass Constant B" values are set to 1.00.

2. Change system signal filtering and wait time settings:
Mass Avg time from 750 to 30 seconds (120 for lab air TEOM)
MR-MC (Mass Rate/Mass Conc) Avg time from 750 to 30 seconds (120 for lab air TEOM)
System Wait Time from 1800 to 0 seconds (disabled)

3. Change the sample flow from 3.00 to 1.00 lpm for the PM2.5 channel (3.00 lpm for lab air TEOM), and from 1.67 to 1.00 lpm for the PM-Coarse channel. Change the bypass flow to 0.00.

4. Change all four temperature zones [Case, Cap, PM2.5 Air, and PM-Coarse Air] to 33 C.

5. Set the Flow Control to Passive, and Reporting conditions to Standard. Change T/P values to 20.0 (Std) and 25 (Avg) C and 1 atm as shown below.



6. Change the Data Storage interval to 60 seconds.

A complete list of 1405-D TEOM Settings that are modified from instrument defaults are shown below. TEOMA is the PM2.5 (left) channel, and TEOMB is the "Coarse PM" (right) channel.

PRC*	Description	Value	Unit	Notes
12	storage interval	60	Sec	
28	system wait time	0	Sec	Always reports data
35	mass average time**	30	Sec	See also PRC392 (MRMC Avg)
48	case T	33.00	°C	
59	cap T	33.00	°C	
74	average T	20.0	°C	For reporting PM at 20 °C

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75	standard T	25.0[3]	ºC	For reporting PM at 20 ºC
76	average P	1.00	ATM	For reporting PM at 29.92 "Hg
77	standard P	1.00	ATM	For reporting PM at 29.92 "Hg
115	TEOMA air tube T	33.00	ºC	
225	TEOMA flow rate**	1.00	lpm	
309	TEOMB flow rate	1.00	lpm	
321	TEOMB air tube T	33.00	ºC	
392	MRMC average time**	30	Sec	See also PRC35 (Mass Avg)
407	TEOMA mass constant A	0.0	µg	Intercept
408	TEOMA mass constant B	1.00		Slope
409	TEOMB mass constant A	0.0	µg	Intercept
410	TEOMB mass constant B	1.00		Slope

* TEOM Program Register Code
** Different for lab air TEOM (3.0 lpm and 120 seconds)

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[3] 25C is correct here for data at 20 °C

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1405-dichot TEOM filter change alarm setup.

This configuration uses the TEOM contact closure ("digital") outputs, and triggers alarms when either Teom channel exceeds the filter loading threshold. The male DB25 connector goes on the TEOM USER I/O connector. See pages 3-31 to 3-33 of the dichot TEOM manual.

Any kind of low voltage alarm can be used, typically a 6 to 12 volt DC alarm. The TEOM interface is only a contact closure - it does not supply any alarm power, so an external alarm power supply must be used.

Parts needed.

1. DB25-male breakout connector, such as Mouser p/n 651-2761622, Phoenix Contact p/n 2761622 https://www.mouser.com/ProductDetail/Phoenix-Contact/2761622/?qs=p6trItWzfMXZ%2FKY9Mkeclg%3D%3D or equivalent. Thermo p/n 102562-00 is a DB25 male connector cable that goes to a DB25 breakout board where you can connect alarm and power wires.

2. A low DC voltage alarm (6 to 24 volts).

3. DC power supply for alarm

Alarm wiring.

DB25 pins 12 and 13 both go to DC power positive
DB25 pin 24 and 25 both go to alarm positive power connection
DC power negative to alarm negative power connection

1405-dichot Teom contact closure alarm config:

Settings->Analog & Digital Outputs->Contact Closure

	Instrument Variable:	Compare Operator:	Compare Value:
#1:	PM-2.5 TEOM filter load	>	115.00
#2:	PM-Coarse TEOM filter load	>	115.00

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Data processing and validation review Excel Template for 1405-D dichot TEOM

The TEOM data file includes PM concentrations and related operational parameters as specified in the TEOM 1405-D SOP. The SOP contains a list of parameter limits used to determine if a 1-minute data record is valid or not. An Excel spreadsheet template is used to format the raw data output from the instrument, to remove invalid data during filter change periods, calculate PM-coarse channel PM concentrations, and to check for missing data records. The resulting 1-minute data are then manually screened to identify any additional problems. The template also generates an assessment of how well the two dichot TEOM channels agree based on 10-minute block average data. This assessment is used to determine if the run data meet specified data quality objectives.

The operator must manually review the spreadsheet data to verify that limits for flow, temperature, and instrument "noise" are met; charts are generated in the template to facilitate this review. The template also generates a "reconstructed" column of time records to facilitate the check for missing data records. The following steps are to be followed for this data review process.

1. Open the dichot tunnel TEOM data file that was downloaded from the instrument in Excel and trim the data rows to remove data before and after the actual test times. Note that the time shown for the Teom time stamp is the END of the 1-minute interval, not the start.

2. Paste the trimmed dichot tunnel TEOM data from Step 1 into the first template spreadsheet tab "Paste raw tunnel data here", including column headers. The TEOM must be configured to save data as specified in the SOP.

3. In the "1405" spreadsheet tab, if the TEOM flows are not 1.0 lpm, enter the flow setpoint flow value in cell C2, the yellow highlighted cell.

4. Verify there are no missing data records by comparing the reconstructed time with the last time reported by the TEOM in column B of the "1405 spreadsheet" tab. Missing data records can occur when the filters are changed, since no data are recorded during a filter change. If there are missing records, note the time, exit the template without saving, and insert a blank line in the original TEOM raw data file as a placeholder for the missing data record. Then copy and paste the TEOM data into the template and repeat the review of time records.

5. Review the three time-series plots in the "T, F, & Noise review" tab to verify that these parameters are within the SOP limits.

6. Open the lab-air TEOM data file, remove data rows before and after the actual test run times (time stamp is the END of the minute interval), and copy the data into the lab air TEOM template. Review the data for proper operation (flow and temperatures), removing any invalid PM concentration data such as large negative values. Lab air TEOM data are simpler to validate since there are no filter changes or other interruptions to the instrument operation during the test period, and thus all the data are usually valid.

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7. Paste the validated lab-air TEOM 1-minute PM data from column D into column D of the dichot TEOM template "1-min data and collo analysis" tab.

The final 1-minute data product is in column E (1-min avg PM) of the "1-min data and collo analysis" tab. This is the average of both dichot TEOM channels with lab air PM subtracted. Results are not shown in column E unless there are valid data for both dichot TEOM channels and for the lab air PM TEOM data.

The dichot TEOM performance for the entire test run is assessed with 10-minute block average data (without lab air PM subtracted). For the test run to be valid, the performance metrics in column V of the "1-min data and collo analysis" tab must meet the criteria specified in the TEOM SOP.

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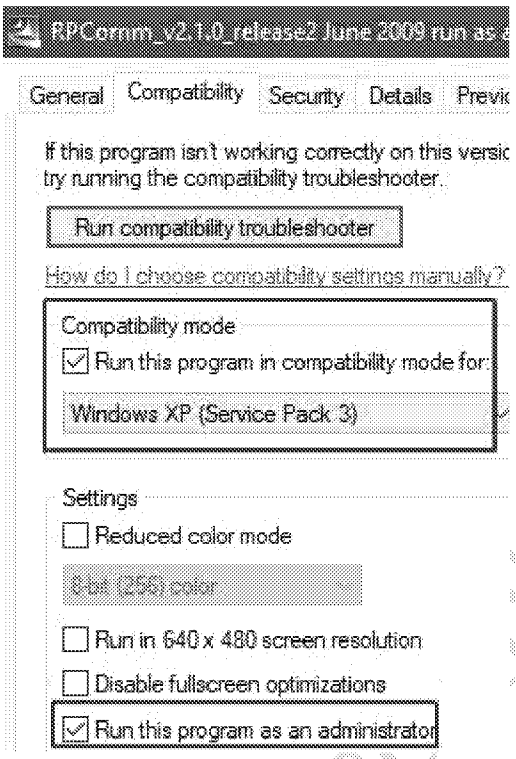
Installation of RPComm on Windows 10

1. The account you install it from must have administrator rights.

2. Right-click on the executable file for the RPComm install program, and on the compatibility tab enable settings for "Compatibility mode" and "Run as administrator". If these 2 compatibility settings are not available as shown in the screenshot below, you may not have administrator rights. RPComm may install and start, but it will crash when you try to use it.



It is recommended to create a Windows restore point or system backup before attempting to install RPComm. Things may go wrong that are not readily recovered from.

After installing but before running RPComm:
RPComm needs a parameter file that matches the firmware version installed on the TEOM. This file is included in the firmware update zip file on the 1405 web page – it is not included in the RPComm install package. Download the firmware file, open it, and copy the "RP14051.74.txt" file (or other RP14051.nn.txt file that matches the firmware version in use) to the location where RPComm is installed, usually "C:\Program Files (x86)\RPCO\RPComm\" (for 64-bit Windows). Then rename that file to remove the ".txt" filename extension to make the filename "RP14051.74".

Note: you must enable the Windows File Explorer to show file extensions. By default they are hidden for known extensions like ".txt".

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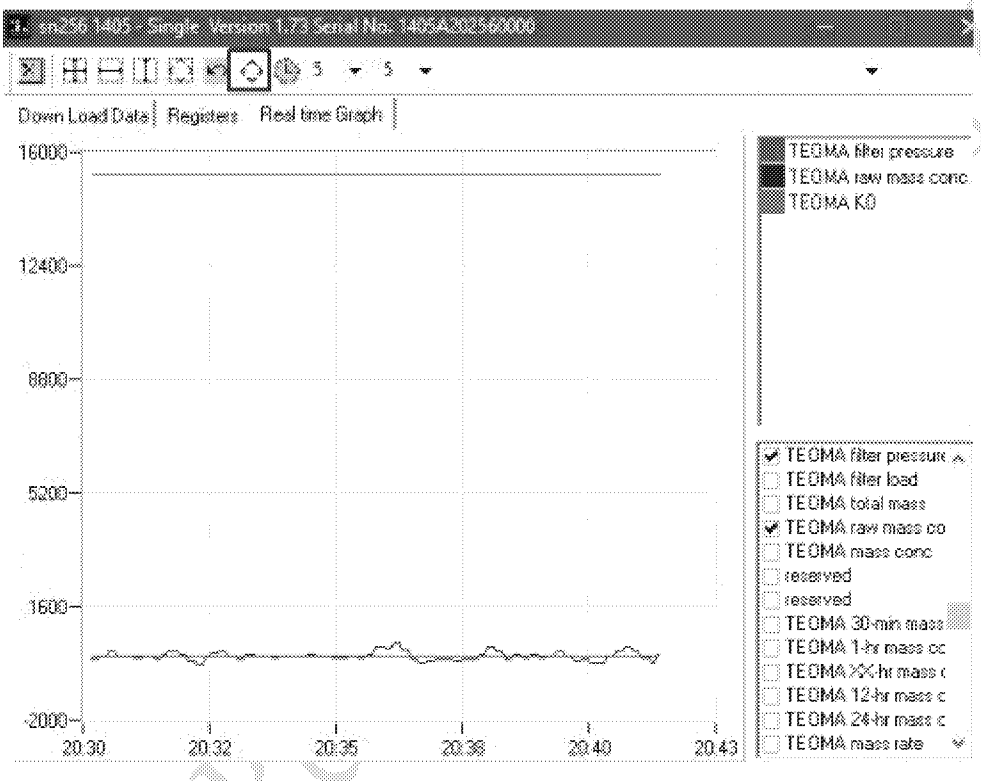
Using RPComm.

Multiple TEOMs can be accessed from a single instance of RPComm. To rename a connection in the main RPComm window, single-click it.

Below are screenshots showing how to use RPComm. These examples are from a single channel Teom.

For the plots, put a 0 [filter P] and a 15k value [K0] to anchor the scale, and the raw mass conc:



The icon circled in red auto-scales it as needed beyond these 2 values. You can also put TEOMB raw mass conc on the plot, but it's 16.7 times too low (at 1 lpm flow).

For the Register tab, set it to list key parameters - this is the only way to get a quick look at everything that matters for proper operation:

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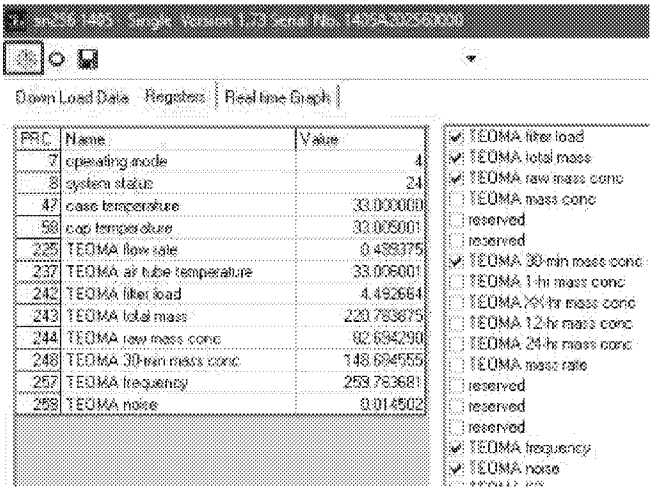

The icon circled in red refreshes the values. There is no auto-refresh in this screen. This is from a single channel TEOM.

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Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 6/25/2021 11:21:24 AM
To: Johnson, Steffan [johnson.steffan@epa.gov]
Subject: RE: draft IDC furnace protocol

Hi Stef, I was wondering if EPA had any comments on the draft IDC Furnace protocol we provided to EPA in March? We plan to update the protocol in the next month and would like to address any questions or issues EPA identified with the protocol.

Thanks!
Lisa

From: Lisa Rector
Sent: Friday, March 5, 2021 8:00 AM
To: Burkhard, Ellen G (NYSERDA) <Ellen.Burkhard@nyserda.ny.gov>; butcher@bnl.gov; Johnson, Steffan <johnson.steffan@epa.gov>
Cc: Kelli O'Brien (kelli@clearstak.com) <kelli@clearstak.com>; Brian Vinal <brian@clearstak.com>; George Allen <gallen@nescaum.org>; Mark Champion <mark@hearthlabsolutions.com>
Subject: draft IDC furnace protocol

Good morning, for our call at 10 am today I have attached the first draft of the furnace protocol. I look forward to talking to you soon.

Lisa

NESCAUM
Lisa Rector, Policy and Program Director at **NESCAUM**
89 South Street, Suite 602, Boston, Massachusetts, 02111 | 802.899.5306| 617.259.2095 | Fax: 617.742.9162 | lrector@nescaum.org

Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 11/16/2020 1:08:07 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
Subject: RE: paired dichot

Thanks Stef, sorry, but I am confused. I think Graham has reached out to set up a meeting, and I would concur with his request.

From: Johnson, Steffan <johnson.steffan@epa.gov>
Sent: Monday, November 16, 2020 8:02 AM
To: Lisa Rector <lrector@nescaum.org>
Subject: RE: paired dichot

Lisa,

To be clear, this should not be confused with paired tunnels /appliances. In such instances a dichot in each is the goal. But where there is a single appliance, a paired dichot is the expectation, to provide precision criteria for the dichot on that IDC.

I hope this is helpful and I also hope my earlier reply was not confusing.

STef

From: Lisa Rector <lrector@nescaum.org>
Sent: Friday, November 13, 2020 11:30 AM
To: Johnson, Steffan <johnson.steffan@epa.gov>
Subject: paired dichot

Hi Stef, quick question on the EPA data needs. When the file states paired dichot teoms, do anticipate two dichots on the same tunnel?

NESCAUM

Lisa Rector, Policy and Program Director at **NESCAUM**
89 South Street, Suite 602, Boston, Massachusetts, 02111 | 802.899.5306| 617.259.2095 | Fax: 617.742.9162
| lrector@nescaum.org

Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 11/16/2020 1:41:12 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
Subject: RE: paired dichot

I also have questions about ruggedness testing. The work plan only includes replicate testing, but I thought data on ruggedness testing was also required. I am wrong in that thinking?

From: Johnson, Steffan <johnson.steffan@epa.gov>
Sent: Monday, November 16, 2020 8:28 AM
To: Lisa Rector <lrector@nescaum.org>
Subject: RE: paired dichot

Lisa,

We will meet.

Just understand that at no time do we envision the need for 4 dichot TEOMs.

Stef

From: Lisa Rector <lrector@nescaum.org>
Sent: Monday, November 16, 2020 8:08 AM
To: Johnson, Steffan <johnson.steffan@epa.gov>
Subject: RE: paired dichot

Thanks Stef, sorry, but I am confused. I think Graham has reached out to set up a meeting, and I would concur with his request.

From: Johnson, Steffan <johnson.steffan@epa.gov>
Sent: Monday, November 16, 2020 8:02 AM
To: Lisa Rector <lrector@nescaum.org>
Subject: RE: paired dichot

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I hope this is helpful and I also hope my earlier reply was not confusing.

STef

From: Lisa Rector <lrector@nescaum.org>
Sent: Friday, November 13, 2020 11:30 AM
To: Johnson, Steffan <johnson.steffan@epa.gov>
Subject: paired dichot

Hi Stef, quick question on the EPA data needs. When the file states paired dichot teoms, do anticipate two dichots on the same tunnel?

NESCAUM

Lisa Rector, Policy and Program Director at **NESCAUM**
89 South Street, Suite 602, Boston, Massachusetts, 02111 | 802.899.5306| 617.259.2095 | Fax: 617.742.9162
| lrector@nescaum.org

Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 9/25/2020 9:51:20 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
CC: Garnett, Kim [Garnett.Kim@epa.gov]; Nash, Dave [Nash.Dave@epa.gov]; Brashear, Angelina [Brashear.Angelina@epa.gov]; Toney, Mike [Toney.Mike@epa.gov]; Lowe, Theresa [Lowe.Theresa@epa.gov]; gallen@nescaum.org
Subject: RE: Troubleshooting flow chart for TEOM operation?

Stef, I posed your question to George. His response was a little like mine, slight confusion. A step-by-step daily start-up list (things to do in the first hour or first 90 min before a test) is already in the SOP now. If you are referring to that element, can you tell us what is missing?

If it's an actual trouble-shooting flow chart, that could get complicated, and I am not sure we have the ability, both in terms of resources and experience, to develop such a guide. Our labs have been using the TEOMs for several years, and I am unsure of much trouble-shooting is actually happening, very little I think. I think we are concerned that labs will attempt to use the TEOM without understanding the basics. George and I were thinking of how we, or Thermo, might put a training program in place if/when broader use of the TEOM becomes a reality.

Perhaps we should consider two approaches:

1) During the EPA contract works, and assuming we get funds from NYSERDA to provide tech transfer and support to EPA and their contractors, we could keep a running list of items that come up during the testing. From that effort, we could build a trouble-shooting guide based on actual experiences. If/when they run into stuff they can't resolve, that can be an opportunity to learn. I'm not aware that we have to do much trouble-shooting with the labs that we are currently using, but George may be doing that work, and I am just unaware.
2) EPA could draft a flow chart of anticipated issues, and George could review and assist in development.

Thoughts on either of these options?

From: Johnson, Steffan <johnson.steffan@epa.gov>
Sent: Friday, September 25, 2020 3:05 PM
To: Lisa Rector <lrector@nescaum.org>
Cc: Garnett, Kim <Garnett.Kim@epa.gov>; Nash, Dave <Nash.Dave@epa.gov>; Brashear, Angelina <Brashear.Angelina@epa.gov>; Toney, Mike <Toney.Mike@epa.gov>; Lowe, Theresa <Lowe.Theresa@epa.gov>
Subject: Troubleshooting flow chart for TEOM operation?

Hi Lisa,

Mike and I were talking about the TEOM SOP on Wednesday and he brought up a good suggestion.

That said, it involves George's time and I know how many things you have waiting for George to do, so I thought I'd float this past you to see if it's a workable theory.

It makes sense that with technology transfer, meaning coaching other labs on how to run a TEOM, it would be good to have some sort of flow chart(s) for troubleshooting to accompany a sort of step-by-step daily start up list (things to do in the first hour or first 90 min before a test). We'd like to empower the labs to make a first attempt at a fix before calling for help.

Does this make sense to you and, if so, perhaps you might consider adding it to George's to-do list?

Thank you for your consideration,

Stef

Steffan M Johnson | Leader – Measurement Technology Group | US EPA Office of Air Quality Planning and Standards | Air Quality Assessment Division | 109 T.W. Alexander Drive, RTP, NC 27710 | Mail Drop: E-143-02 | Phone: (919) 541-4790 | Cell: (919) 698-5096

Message

From: Johnson, Steffan [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=EBA5C0DFC5FC4593AFA62CE7C3DD6F02-JOHNSON, STEFFAN]
Sent: 3/31/2021 4:10:25 PM
To: Lisa Rector [lrector@nescaum.org]
CC: Burkhard, Ellen G (NYSERDA) [Ellen.Burkhard@nyserda.ny.gov]
Subject: RE: revised protocol

Lisa,

This is very helpful, thank you. And thank you for the CC to Ellen.

Stef

From: Lisa Rector <lrector@nescaum.org>
Sent: Wednesday, March 31, 2021 11:19 AM
To: Johnson, Steffan <johnson.steffan@epa.gov>
Cc: Burkhard, Ellen G (NYSERDA) <Ellen.Burkhard@nyserda.ny.gov>
Subject: RE: revised protocol

Yes, but I can have her send you an email to confirm. Two notes:

1) For our research work - 100% of the fuel pieces had bark on one side. We modified it to 75% to address Ben Myren's concerns.
2) The protocol listed on the NESCAUM website has been updated.

From: Johnson, Steffan <johnson.steffan@epa.gov>
Sent: Wednesday, March 31, 2021 11:12 AM
To: Lisa Rector <lrector@nescaum.org>
Subject: RE: revised protocol

Lisa,

Did Ellen approve this? I feel like it's prudent to ask that question.

Thank you,

Stef

From: Lisa Rector <lrector@nescaum.org>
Sent: Tuesday, March 30, 2021 12:45 PM
To: cindy.heil@alaska.gov; Johnson, Steffan <johnson.steffan@epa.gov>; Toney, Mike <Toney.Mike@epa.gov>; Brashear, Angelina <Brashear.Angelina@epa.gov>
Subject: revised protocol

Hi everyone, my apologies, the ATM has been revised to reflect the IDCs as run for our research, which is 75% of the fuel pieces must have bark. The previous version had a typo that said 5%.

NESCAUM

Lisa Rector, Policy and Program Director at **NESCAUM**
89 South Street, Suite 602, Boston, Massachusetts, 02111 | 802.899.5306| 617.259.2095 | Fax: 617.742.9162
| lrector@nescaum.org

Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 12/28/2020 6:14:46 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
CC: Burkhard, Ellen G (NYSERDA) [Ellen.Burkhard@nyserda.ny.gov]
Subject: RE: Revised IDC protocol and calculator
Attachments: NYSERDA IDC Protocol for Wood Stoves draft version 12 28 20 V7 rev.docx

Flag: Follow up

Stef, my apologies, I found a few loose ends in the protocol I sent on Wednesday. This version removes all references to EPA M5G and instead refers to ASTM 2515. I also removed the User Guide section and standardized references to TEOM SOP. Please use this version for review.

Lisa

From: Lisa Rector
Sent: Wednesday, December 23, 2020 8:21 AM
To: Johnson, Steffan <johnson.steffan@epa.gov>
Cc: Burkhard, Ellen G (NYSERDA) <Ellen.Burkhard@nyserda.ny.gov>
Subject: Revised IDC protocol and calculator

Stef, attached to this email is the revised IDC stove protocol for your review and comment.

NESCAUM

Lisa Rector, Policy and Program Director at **NESCAUM**
89 South Street, Suite 602, Boston, Massachusetts, 02111 | 802.899.5306| 617.259.2095 | Fax: 617.742.9162
| lrector@nescaum.org

THIS INTEGRATED-DUTY-CYCLE (IDC) PROTOCOL FOR WOOD STOVES IS THE PROPERTY OF THE NEW YORK STATE ENERGY RESEARCH AND DEVELOPMENT AUTHORITY (NYSERDA) AND CAN BE USED TO TEST TECHNOLOGIES IN A LABORATORY SETTING. ANY DEVIATIONS OR CHANGES TO THIS IDC PROTOCOL FOR WOOD STOVES ARE NOT APPROVED OR SANCTIONED BY NYSERDA.

DO NOT CITE, COPY, or DISTRIBUTE THIS IDC PROTOCOL FOR WOOD STOVES WITHOUT THE WRITTEN PERMISSION OF NYSERDA

Integrated Duty Cycle Test Method for Certification of Wood-Fired Stoves Using Cordwood: Measurement of Particulate Matter (PM) and Carbon Monoxide (CO) Emissions and Heating Efficiency

Note: This method does not include all the specifications (e.g. equipment and supplies) and procedures (e.g., sample and analytical) essential to its performance. Some material is incorporated by reference from other methods. Therefore, to obtain reliable results, persons using this method shall have a thorough knowledge of at least the following EPA Tests

- Method 1- Sample and Velocity Traverses for Stationary Sources
- Method 2- Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube)
- Method 3 – Gas Analysis for the Determination of Dry Molecular Weight
- Method 4 – Determination of Moisture Content in Stack Gases
- Method 5G – Determination of Particulate Matter from Wood Heaters (Dilution Tunnel Sampling Location)
- Method 10 - Carbon Monoxide - Instrumental Analyzer
- Method 28 – Certification and Auditing if Wood Heaters

1. Scope and Application

1.1. This test method specifies operation and fueling for certification and auditing of manually operated wood-fired stoves and heaters.

1.2. This test method measures particulate matter (PM) emissions, carbon monoxide, and efficiency.

1.3. Particulate emissions are measured by the dilution tunnel method as specified in ASTM E2515 Standard Test Method for Determination of Particulate Matter Emissions Collected in a Dilution Tunnel using only Emfab Pallflex filters. Additional particulate matter emissions measurements may also use the Tapered Element Oscillating Microbalance (TEOM) continuous PM method, as detailed in this test method.

1.4. Analyte. Particulate matter (PM). No CAS number assigned. Carbon monoxide (CO). No CAS number assigned.

1.5. Applicability. This method is applicable for the certification and auditing of wood space heaters, which burn cordwood fuel. The test quantifies PM and CO emissions and provides overall efficiency ratings, maximum burn time, and heat output.

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1.6. Data Quality Objectives. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods

1.7. Distinguishing features of appliances covered by this standard include:

1.7.1. Cordwood fuel is hand-fed into firebox.

1.7.2. A chimney or vent that exhausts combustion products from the appliance.

1.8. The values stated are to be regarded as the standard, whether in I-P or SI units. The values given in parentheses are for information only.

1.9. Data Quality Objectives.

1.9.1. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods.

1.9.2. Measurement of emissions and heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

1.9.3. This is a laboratory method intended to capture operating periods that are representative of actual field use without excessive test burden.

2. Referenced Methods

2.1. NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel

2.2. ASTM 2515: Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel.

3. Definitions

3.1. Appliance – a wood heater capable of and intended for space heating defined in the applicable regulation. Appliance includes combustion chamber, combustion air settings, operating controls, and a thermostat, if specified, and any other accessory required for standard operation, such as a barometric damper,

3.2. Catch - any mass from the sample probe system on the filter.

3.3. Certification or audit test - a series of at least three test runs conducted for certification or audit purposes that meets the specifications detailed in this protocol.

3.4. Chop – using a poker or another piece of wood to strike a piece of the fuel charge to break it into smaller pieces.

3.5. Coal-bed Stirring – prior to adding a new fuel charge, using a poker or piece of wood to stir or level the coal bed of the appliance for the sole purpose of ensuring ease of loading of the fuel

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charge. No special formations can be made, such as creating coal bed formations or pushing coals to one side or creating slopes with the coals.

3.6. East-west stove – a stove where the firebox dimension parallel to the loading door is greater or equal to the stove depth measurement. Logs are loaded so that they are viewed on the long length of the stove.

3.7. Emission factor – the emission of a pollutant expressed in mass per unit of energy (typically) output from the appliance.

3.8. Firebox - the portion of the chamber in the wood heater in which the test fuel charge is placed and combusted.

3.9. Firebox depth - the horizontal length of the fire chamber dimension measured perpendicular to the loading door. If the manufacturer believes that a portion of the firebox depth is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.10. Firebox Height - the vertical distance extending above the top of the firebox to the floor of the firebox. Firebox height is not necessarily uniform. The measurement must account for variations caused by internal baffles, air channels, or other permanent obstructions. If the manufacturer believes that a portion of the firebox height is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.11. Firebox width - the horizontal fire chamber dimension that is parallel to the loading door. If the manufacturer believes that a portion of the firebox width is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.12. Fuel Adjustment –manipulations to the fuel charge to reflect typical owner practices that allow the cordwood fuel to burn appropriately during the test period. A fuel adjustment does not include chopping the wood or stirring the coal bed.

3.13. Fuel load calculator – The locked excel spreadsheet tool that determines the allowable test fuel load weights and required piece sizes for each individual load.

3.14. Fuel loading direction – Fuel shall be loaded parallel to the greater of the width and depth dimensions for loads 2, 3 and 4. Criss-cross is allowed for startup phase and cannot be used as a load configuration for loads 2, 3 or 4. If the firebox length and width are within 2" fuel shall be loaded in an east/west fashion, parallel to the loading door.

3.15. Kindling pieces – small pieces of wood less than 1" in diameter. No bark or moisture requirements for these pieces, however kindling pieces shall not be dried or stored anywhere but in laboratory ambient conditions. Kindling length shall be of the same as the fuel charge length. and shall represent weights that would enable 8 to 12 pieces equal one pound.

3.16. Large fuel pieces – pieces that are larger for the appliance as defined by the fuel load calculator.

3.17. L1 – Start-up – period of the test when the unit has kindling and startup fuel under the conditions described in Section 11.6.7.

3.18. L2 – High-fire Phase – period of the test when the unit has a small coal bed and the stoves air settings are fully open. Intended to replicate period when homeowners are trying to quickly heat an area, shortly after starting or restarting the appliance.

3.19. L3 - Maintenance-fire phase– period of the test when a fire is maintained with a medium-sized coal bed, and a smaller batch of wood. This is intended to simulate a period when the operator is trying to maintain consistent heat output.

3.20. L4 - Low-burn Rate Phase – period of the test when the stove has a large coal bed, stove is fully loaded, and the adjustable air settings are set to produce the lowest possible burn rate and have the lowest air settings. Intended to simulate a period the operator is trying to maintain heat over a long period of time, such as overnight or while away for significant periods of time.

3.21. North-south stove: a firebox which has its longest dimension measurement perpendicular to the loading door. In this stove type, logs are loaded so that the ends of the fuel are viewed when loaded.

3.22. Phase – A distinct period in the test run with its own operational procedures and conditions.

3.23. Primary air supply – air supply that introduces air to the wood heater in the combustion chamber and is adjusted to target a desired burn rate. The wood heater manufacturer or test facility can document this through design drawings.

3.24. Secondary air supply - air supply that introduces air to the wood heater such that the burn rate is not altered by more than 10 percent when the secondary air supply is adjusted during the test run. The wood heater manufacturer or test facility can document this through design drawings that show the secondary air is introduced only into a mixing chamber or secondary chamber outside the firebox.

3.25. Small fuel pieces - pieces that are small for the appliance as defined by the fuel load calculator.

3.26. Starter fuel – pieces of cordwood that can be smaller than small and large pieces but larger than kindling, as defined by the fuel load calculator.

3.27. Test data– means the data for all test runs conducted on the wood heater, including any data collected during failed and invalid runs and includes records of preparation of standards, identification of equipment used and personnel present, records of calibrations, raw data sheets for field sampling, raw data sheets for field and laboratory analyses, chain-of-custody documentation, and example calculations for reported results.

3.28. Test facility - the area in which the wood heater is installed, operated, and sampled for emissions.

3.29. Test fuel charge - the collection of test fuel pieces used in each of the four phases of the test run. L2, L3, and L4 require that at least 5% of the individual pieces with at least 80% bark on one side of the fuel piece. Bark shall not be removed for certification testing. Any fuel charge that suggests

bark was purposely removed or shaped shall deem the certification test invalid. Examples of fuel piece manipulation are provided in Section 11

3.30. Test fuel load – the group of test fuel pieces that are loaded, as specified by phase, throughout the test run. Test fuel loading means the arrangement of the test fuel charge.

3.31. Test fuel loading density - the calculation that determines the weight of the as-fired test fuel load. The calculation is based on the usable volume of the firebox.

3.32. Test run - an individual emission test that includes the four operational phases required by the fueling protocol.

3.33. Usable firebox volume - the calculated volume of the firebox determined using its height, width, and depth as defined in this section. This calculation represents the area where wood is likely to be loaded. If the manufacturer claims that portions of the firebox may not be used in the calculation a justification must be submitted with the test report. If the justification is not approved, the test results will be deemed unrepresentative for certification purposes. It is highly recommended that manufacturers obtain regulatory approval if making claims that portions of the firebox are not appropriate for inclusion in the calculation.

3.34. Wood heater - an enclosed, wood-burning appliance capable of and intended for space heating or domestic water heating, as defined in the applicable regulation.

4. *Interferences*

None.

5. *Summary of Method*

5.1. Particulate matter emissions are measured from a wood heater burning cordwood test fuel in a test facility maintained at a set of prescribed ambient conditions. Procedures for operating the appliance, measuring PM and CO emission rates, and methods for reducing data and calculating results are provided.

5.2. *Dilution Tunnel.* A dilution tunnel following the specifications detailed in ASTM E2515-11 shall be used for particulate measurements.

5.3. *Particulate Matter:* PM emissions are measured in a dilution tunnel with a Thermo model 1405-D 2-channel TEOM using NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel with a dilution tunnel as specified in ASTM 2515 with modifications discussed in Section 10.

5.4. *Carbon Monoxide*. The CO measured in the stack and is used to calculate efficiency determination.

5.5. *Operation*. Appliance operation is conducted on a cold-to-hot test cycle, meaning that the appliance starts the first test run at room temperature and ends with the appliance in fully heated

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state. The second and third test runs are started a slightly warmer temperature. The appliance is operated at a variety of operational phases representing start-up emissions, high heat demand, low heat demand, and refueling. The appliance is operated through four phases. To complete the certification test, a minimum of three full test runs are averaged to determine the test results.

5.6. *Repeatability.* A series of at least three test runs comprised of six different heat demands or phases conducted for certification or audit purposes

6. Significance and Use

6.1. The measurement of particulate matter emission rates is an important test method widely used in the practice of air pollution control.

6.1.1. These measurements, when approved by state or federal agencies, are often required for the purpose of determining compliance with regulations and statutes.

6.1.2. The measurements made before and after design modifications are necessary to demonstrate the effectiveness of design changes in reducing emissions and make this standard an important tool in manufacturers' research and development programs.

6.2. Measurement of heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

7. Safety

7.1. Disclaimer. This method may involve hazardous materials, operations, and equipment. This test method may not address all the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to performing this test method.

7.2. These tests involve combustion of wood, which releases substantial amounts of heat and combustion products. The heating system also produces large quantities of very hot water and the potential for steam production and system pressurization. Appropriate precautions must be taken to protect personnel from burn hazards and respiration of products of combustion. Exposure of personnel to unsafe levels of carbon monoxide must be avoided, and the use of continuous ambient carbon monoxide monitoring is strongly recommended.

8. Equipment and Supplies. The following items are required for sample collection:

8.1. Anemometer. A device capable of detecting air velocities less than 0.10 m/sec (20 ft/min), for measuring air velocities near the test appliance.

8.2. Appliance Flue.

8.2.1. Steel flue pipe extending to 8.5 ±0.5 ft. (2.6 ±0.15 m) above the top of the platform scale, and above this level, insulated solid pack type chimney extending to 15 ±1 ft (4.6 ±0.3 m) above the

platform scale, and of the size specified by the appliance manufacturer. This applies to both freestanding and inserts type appliances.

8.2.2. Other chimney types (e.g., solid pack insulated pipe) may be used in place of the steel flue pipe if the appliance manufacturer's written appliance specifications require such chimney for home installation (e.g., zero clearance appliance inserts). Such alternative chimney or flue pipe must remain and be sealed with the appliance following the certification test.

8.2.3. Solid pack insulated chimneys shall have a minimum of 2.5 cm (1 in.) solid-pack insulating material surrounding the entire flue and possess a label demonstrating conformance to U.L. 103 (incorporated by reference—see §60.17).

8.3. Appliance Platform Scale and Monitor. For monitoring of fuel load weight change. The scale shall be capable of measuring weight to within 0.01 kg (0.02 lb.) and calibrated to NIST traceable standards at least annually.

8.4. Barometer. Aneroid or another barometer capable of measuring atmospheric pressure to within 0.1 in. Hg (2.5 mm Hg) with an uncertainty of +/- 0.05 in Hg (+/- 1.27 mm Hg).

8.5. Dilution Tunnel must meet the requirements of ASTM E2515, clauses 6.1.6 and 9.2.

8.6. Dilution Tunnel temperature and relative humidity measurement. A probe capable of measuring tunnel temperature to within 0.9 °F (0.5 °C)) and tunnel RH to within 2%, such as the Omega HX85-A or equivalent.

8.7. Draft Gauge. Electromanometer or other devices for the determination of flue draft or static pressure readable to within 0.005 in. H2O (1.2 Pa)

8.8. Flue Gas Temperature Measurement. A type K- thermocouple or equivalent located in the centroid of the stack located 8.0 +/- 0.5 ft (2.44 m +/- 150 mm) above the platform scale. Capable of measuring with an accuracy of 4.0°F (2.2°C) or 0.75% of reading, whichever is greater.

8.9. Flue Gas Composition Measurement. A sample probe and continuous infrared analyzer or equivalent capable of measuring span of carbon monoxide (CO) and carbon dioxide (CO_2) in the flue gas produced by the appliance tested. Continuous analyzers (or equivalent) shall have maximum zero and span drift, over a 24 h period, of 1% of full scale

8.10. Fuel Scale. Balance capable of weighing the test fuel charge to within 0.02 kg (0.05 lb.) and calibrated to NIST traceable standards at least annually.

8.11. Humidity Gauge. Psychrometer or hygrometer for measuring room humidity to within +/- 4% from 25 to 95% RH.

8.12. Moisture Meter. Calibrated electrical resistance meter for measuring test fuel moisture to within 2 percent moisture content.

8.13. Surface Temperatures. Capable of measuring temperature to within 1.5 percent of expected absolute temperatures with an accuracy of 4.0°F (2.2°C) or 0.75% of reading, whichever is greater.

8.14. Test Facility Temperature Monitor. A thermistor, RTD, or other equivalent device, located centrally in a vertically oriented 150 mm (6 in.) long, 50 mm (2 in.) diameter pipe shield that is open at both ends, capable of measuring temperature to within 1°F of expected temperatures.

8.15. TEOM – Thermo Fisher Scientific TEOM model 1405-D (Thermo part # 1405D-ANF, excluding models 1405, 1405-DF, or 1405-F) to measure and report continuous particulate matter (PM) measurements in an ASTM 2515 dilution tunnel or equivalent dilution method, and operated according to the NESCAUM Dichot TEOM Standard Operating Procedures.

9. Calibration and Standardizations

9.1. Anemometer. Calibrate the anemometer as specified by the manufacturer's instructions before the first certification test and monthly thereafter.

9.2. Appliance Platform Scale. Perform a multi-point calibration (at least five points spanning the operational range) of the platform scale before its initial use. The scale manufacturer's calibration results are sufficient for this purpose. Before each certification test, audit the scale with the wood heater in place by weighing at least one calibration weight (Class F) that corresponds to between 20 percent and 80 percent of the expected test fuel charge weight. If the scale cannot reproduce the value of the calibration weight within 0.0045 kg (0.01 lb.) or 1 percent of the expected test fuel charge weight, whichever is greater, recalibrate the scale before use with at least five calibration weights spanning the operational range of the scale.

9.3. Barometer. Calibrate using a reference pressure monitor calibrator before the first certification test and semiannually after

9.4. Draft Gauge. Calibrate as per the manufacturer's instructions; a liquid manometer does not require calibration (but must be properly leveled, zeroed and the system leak checked).

9.5. Humidity Gauge. Calibrate as per the manufacturer's instructions before the first certification test and annually thereafter.

9.6. Fuel Scale. Calibrate as described in 9.2.

9.7. Moisture Meter. Calibrate as per the manufacturer's instructions before the first certification test and semiannually thereafter.

9.8. Temperature Sensors. Calibrate using at least five points within operating range within specification and in compliance with NIST Monograph 175. To be calibrated before the first certification test and semiannually thereafter.

10. Sampling, Test Specimens, and Test Appliances

10.1. Modifications to ASTM 2515 requirements.

10.1.1. Liquid water should not be present anywhere in the sampling system for a valid sample. The presence of condensed water anywhere in the sampling system invalidates the test run. All data from all invalid test runs shall be included in the report. The reviewing authority shall make a final determination on invalidated runs. Data from any invalidated test run shall not be used to calculate results. If the testing agency believes a run has been invalidated, the test run shall be repeated.

10.1.2. Dilution tunnel temperature and relative humidity shall be measured electronically and logged at one-minute intervals near the sample probe to calculate dewpoint. The temperature measurement method shall have an accuracy of 0.5 degrees C (type T-Special TC or a RTD).

10.1.3. The following section details test conditions that shall be maintained for a valid test run. A valid test shall have no more than two individual deviations from any of the conditions below to remain a valid run. An example of an individual deviations is a single, five-minute rolling average where the dilution tunnel exceeded temperature thresholds. Another five-minute period exceeding the tunnel temperature requirement shall be considered a second deviation.

10.1.3.1. Tunnel temperature shall not exceed 104 deg. F (40C) based on five-minute rolling averages derived from one-minute data.

10.1.3.2. Tunnel relative humidity shall not exceed 90% based on five-minute rolling averages derived from one-minute data.

10.1.3.3. Tunnel dew point temperature shall be at least 2 deg. C less than filter temperature based on five-minute rolling averages derived from one-minute data.

10.1.3.4. A minimum tunnel flow of 500 CFM is required. Higher tunnel flows may be required to meet the parameters of 8.6.3.

10.1.3.5. All exceedances must be reported in the test anomalies section, even if deviations are within the test method tolerances.

10.2. Sample Collection. The following are required for sample collection:

10.3. Teflon coated glass fiber filters as supplied by the TEOM manufacturer for use with the TEOM model 1405-D. These are Pallflex Emfab (TX40) with an exposed diameter of 13 mm, without organic binder, exhibiting at least 99.95 percent efficiency.

10.4. *Test Specimens.* Appliances shall be supplied as complete systems, including all controls and accessories necessary for installation at the test facility. A full set of specifications, designs, and assembly drawings shall be provided when the product is placed under certification of a third-party agency.

10.5. Preparation of Apparatus

10.5.1. Wood Heater Installation for Certification Testing. Assemble the wood heater appliance and parts in conformance with the manufacturer's provided User Guide. These instructions must match all instructions materials developed by the manufacturer and/or their distributors. Place the wood heater on the platform scale and connect the chimney to the appliance. Clean the flue with an appropriately sized, wire chimney brush before initiating Run 1 of the certification test. Test documentation should include the date and time of flue cleaning.

10.5.2. Wood Heater Temperature Monitors.

10.5.2.1. For catalyst-equipped wood heaters, locate a temperature monitor (optional) about 25 mm (1 in.) upstream of the catalyst at the centroid of the catalyst face area, and locate a temperature monitor (mandatory) that will indicate the catalyst exhaust temperature. This temperature monitor is centrally located within 25 mm (1 in.) downstream at the centroid of the catalyst face area. Record these locations.

10.5.2.2. Locate wood heater surface temperature monitors at five locations on the wood heater firebox exterior surface. Position the temperature monitors centrally on the top surface, centrally on two sidewall surfaces, and centrally on the bottom and back surfaces. Position the monitor sensing tip on the exterior of the firebox surface inside of any heat shield, room air circulation walls, or other wall or shield separated from the firebox exterior surface. Surface temperature locations for unusual design shapes (e.g., spherical, etc.) shall be positioned so that there are four surface temperature monitors in

10.6. Conditioning

10.6.1. Wood Heater Aging Prior to Certification Testing. A wood heater of any type shall be aged at least 50 hours before initiating a certification test. The aging procedure shall be conducted by the manufacturer prior to sending the appliance to the testing laboratory. The certification lab cannot be involved with wood heater aging in any manner. The appliance shall be operated at a variety of burn rates. Documentation for wood heating aging must be included in the test report. The testing laboratory shall not conduct any firing of the appliance prior to conducting the certification test.

10.6.1.1. The manufacturer shall supply wood heater aging information for the final test reports. Aging data that shall be reported include all fuel parameters (species, moisture content, load weights, piece amounts, and size), air settings used, time spent in each air setting phase, amount of fuel burned, and appliance burn rates.

10.6.1.2. If an appliance uses a catalytic combustor, it must be engaged according to the manufacturer's instructions and operate with the catalyst engaged for at least 50 hours during the break-in period. In addition to the reporting requirements listed in 8.1.1, catalytic appliances shall also report hourly catalyst exit temperature data to include the dates and hours of operation.

11. Procedure

11.1. Test Facility Conditions.

11.1.1. The test facility temperature shall be maintained between 55 and 90°F (13 and 32°C) during each test run.

11.1.2. The flue shall discharge into the same space or into a space freely communicating with the test facility. Any hood or similar device used to vent combustion products shall not induce a draft greater than 0.005 in. H_2O (1.25 Pa) on the wood heater measured when the wood heater is not operating.

11.1.3. For test facilities with artificially induced barometric pressures (e.g., pressurized chambers), the barometric pressure in the test facility shall not exceed 30.5 in. Hg (775 mm Hg) during any test run.

11.1.4. Locate the test facility temperature monitor on the horizontal plane that includes the primary air intake opening for the wood heater. Locate the temperature monitor 3 to 6 ft. (1 to 2 m) from the front of the wood heater in the 90° sector in front of the wood heater.

11.1.5. Use an anemometer, to measure the air velocity. Measure and record the room air velocity before the ignition period in L1 Startup and once immediately following the test run completion. Air velocities within 0.6 m (2 ft) of the test appliance and exhaust system shall be less than 0.25 m/sec (50 ft/min) without fire in the unit.

11.1.6. Measure and record the test facility's ambient relative humidity, barometric pressure, and temperature before and after each test run using equipment as specified in Section 6.

11.2. Wood Heater Firebox Volume.

11.2.1. Determine the firebox volume using the definitions for height, width, and length. Volume adjustments due to the presence of firebrick and other permanent fixtures may be necessary. All adjustments shall be detailed in the test report. Include areas adjacent to and above a baffle.

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11.2.2. If a manufacturer deems certain areas of the firebox as unusable for fuel load calculations, written documentation stating the basis for that claim and supporting photographic image(s) must be provided and approved by the regulatory authority prior to conducting the certification test. If approval is not granted prior to the test, then the test may be invalidated if the reviewing agency determines the firebox volume is inaccurate.

11.3. Test Fuel. The test fuel shall conform to the following requirements and meet specifications as required by the fuel loading calculator:

11.3.1. Fuel Species. Untreated, air-dried, cordwood fuel.

11.3.1.1. Allowable species: maple (big leaf, red, silver), oak (white), fir (Douglas), or white birch.

11.3.1.2. Kiln-dried fuel is not permitted.

11.3.1.3. Fuel shall be free of decay, fungus, or other contaminants.

11.3.2. Fuel Moisture.

11.3.2.1. Determine fuel moisture for each fuel piece by averaging four moisture meter readings, one from each of three sides, measured parallel to the wood grain.

11.3.2.2. The test fuel load shall have an average moisture content from 19% to 25%, wet basis.

11.3.2.3. Average individual piece moisture content shall have an average moisture content 18% to 27%.

11.3.2.4. The addition of moisture to previously dried wood is not allowed.

11.3.2.5. It is recommended that the test fuel be stored in a temperature and humidity-controlled room.

11.3.2.6. Fuel moisture shall be measured within 24 hours of using the fuel for the test and shall be stored in a humidity-controlled environment until 2 hours prior to testing.

11.3.3. Fuel Temperature. The test fuel shall be at the test facility temperature of 13 to 32°C (55 to 90°F).

11.3.4. Fuel Dimensions. The dimensions of each test fuel piece shall conform to definitions specified by the protocols using the fuel load calculator.

11.3.4.1. Fuel length:

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11.3.4.1.1.The length of the fuel pieces will be determined by the fuel load calculator.

11.3.4.1.2.Measurements shall be taken, and the length of the test fuel will be determined by entering the firebox dimensions, which calculates the length for all the fuel pieces into a generally available commercial size (14, 16, 18, 20 or 22 inches in length).

11.3.4.1.3.Piece length specified by the fuel calculator shall be communicated and specified for use in the owner's manual and website. Piece size shall be within 0.5" of the log length determined by the calculator, as measured on the shortest length measurement.

11.3.5.Fuel Loading Direction

11.3.5.1.Fuel loading direction shall be determined by the firebox measurement.

11.3.5.1.1.Stoves with a depth measurement greater than two inches from the width measurement shall be tested with the fuel in a north-south configuration and may not test with fuel in an east/west or crisscross configuration in any load other than Load 1 and Load 2.

11.3.5.1.2.Stoves with a width measurement greater than the depth measurement or a width measurement within two inches of the depth measurement shall be tested with the fuel loaded in an east-west configuration and may not test with fuel in a north/south configuration or crisscross configuration in any load other than Load 1 and Load 2.

11.3.6.Fuel piece weight for each phase of the protocol shall be determined by the fuel load calculator.

11.3.6.1.Kindling –shall be:

11.3.6.1.1.pieces of wood less than or equal to 1" in diameter.

11.3.6.1.2.No bark requirements for kindling fuel

11.3.6.1.3.Fuel species may be any species allowed in 7.2.1.1.

11.3.6.1.4.No moisture requirements.

11.3.6.1.5.Length of kindling shall be the fuel length specified by the fuel load calculator.

11.3.6.1.6.Kindling fuel shall conform to the rule that 7 to 12 pieces of kindling equal 1 pound of kindling fuel (+/- 10%).

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11.3.6.2. Starter fuel: pieces of cordwood shall be used during the startup phase. Individual piece weight for starter fuel shall be determined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall be not be used in testing (see Figure 1). Pieces that have squared cross sections shall be split to represent the typical triangle nature of wood (see Figure 2).

11.3.6.3.Small fuel pieces: smaller pieces of cordwood by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall not be used (see figure 1). Pieces that have square cross-sections shall be split to represent the typical triangle nature of wood (see Figure 2).

11.3.6.4.Large fuel pieces: larger pieces of cordwood, by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall be not be used (see figure 1). Pieces that have square cross sections shall be split to represent the typical triangle nature of wood (see Figure 2).

Figure 1. Schematic of unacceptable cross-sectional profiles

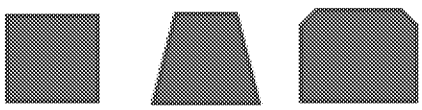
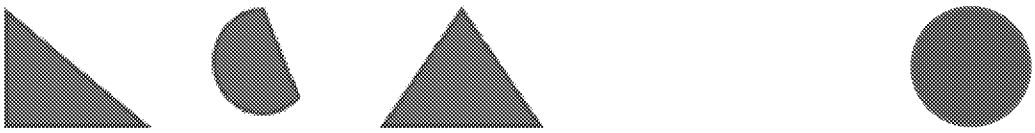


Figure 2. Schematics of acceptable cross-sectional profiles



11.4. Sampling Equipment.

11.4.1.Prepare the PM and ambient sampling equipment as defined by the TEOM Protocol.

11.4.2.Prepare all other equipment as defined by method EPA Method 1, 2, 3, 4 and 5G.

11.5. Manufacturer participation in certification testing

11.5.1. A representative of the manufacturer may observe testing but may not provide instructions to the certification lab, in any form, with testing staff or equipment once the certification tests begin. The names of testing witnesses cannot be withheld as confidential business information (CBI).

11.6. Test Run Procedure.

11.6.1. Before each test series, the firebox shall be vacuumed. Testing shall begin without any ash or other materials in the appliance.

11.6.2. Before initiating the compliance test, clean the flue and dilution tunnel with an appropriately sized wire chimney brush before each certification test. Test documentation should include the date and time of flue cleaning.

11.6.3. Record fuel weight data, temperature measurements, and gas concentrations at 1-minute intervals.

11.6.4. Wood Heater Operation and Adjustments. Record all adjustments made to the air supply controls, adjustments to and additions or subtractions of fuel, and any other changes to wood heater operations that occur during the test period.

11.6.5. The weight of fuel remaining at the end of the test run is determined as the difference between the weight of the wood heater with the remaining coals and fuel and the weight after loading the fuel charge. The starting weight is the tare weight of the cleaned, dry wood heater.

11.6.6. All runs shall be videotaped in their entirety. Video tape shall be of sufficient quality to determine fuel characteristics, fuel loading procedures, and firebox conditions during any testing or aging conducted by the test lab. The testing lab shall have the capacity to allow appropriate agencies the opportunity to remotely witness the test.

11.6.7.L1: Start-up Phase.

11.6.7.1.L1 Appliance requirements.

11.6.7.1.1. Stove temperature: internal and external stove temperature must not be greater than the ambient temperature +/- 2˚F (1.1˚C) for Run 1. There is no stove starting temperature requirement for Runs 2 and 3 except in the case of a failed first run. In this case, if Run 1 is invalid or incomplete and, the stove must meet Run 1 conditions for at least one valid run. Temperature measurements for the external and internal temperatures shall be taken within 15 minutes before starting the test and shall be reported in the test report.

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11.6.7.1.2.Tare the appliance scale before starting the test. Record appliance scale weights at the start and end of L1 phase

11.6.7.2.L1 Fuel requirements.

11.6.7.2.1.L1 Fuel type – during the startup phase newspaper (optional up to six full sheets traditional newspaper size), kindling, and starter fuel pieces are used. No other additions are allowed.

11.6.7.2.2.L1 loading density

11.6.7.2.2.1.Kindling loading density: 1 lb. per cubic foot for dry kindling, +/- 5%. The fuel load calculator determines the amount of kindling that can be used.

11.6.7.2.2.2.Starter Fuel loading density: 3 lb. per cubic foot, +/- 5%. The fuel load calculator will determine the minimum piece weight that can be used as starter fuel.

11.6.7.2.3.L1 fuel loading structure: The loading structure of the fire shall be a bottom-up configuration with newspaper on the bottom, kindling on top of the paper, and starter fuel on top of the kindling. Kindling and starter fuel shall be loaded in a crisscross configuration.

11.6.7.3.L1 Operational parameters.

11.6.7.3.1.All kindling, starter fuel, and newspaper must be in the firebox for light off.

11.6.7.3.2.Air settings are fully open.

11.6.7.3.3.Light the fire with a torch for a period of no more than 30 seconds.

11.6.7.3.4.Immediately after lighting the fire and completing the photo requirement, the appliance door shall be moved to a cracked open position. Cracked open position is defined as opening no more than one inch. The appliance door shall be closed 5 minutes after ignition.

11.6.7.4.L1 Fuel Adjustments: up to three fuel adjustments are allowed in the startup phase. The door may be open for 30 seconds during each fuel adjustment.

11.6.7.5.L1 End of Phase – the end of the startup phase is defined by the weight specified by the fuel load calculator.

11.6.7.6.L1 Photo documentation – Clear, close-up pictures shall be documented with individual pictures that must be included in the test report sufficient to determine fueling positioning and coal bed conditions.

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11.6.7.6.1.Picture(s) of the air setting before light-off

11.6.7.6.2.Picture(s) of the air setting at the end of L1 phase

11.6.7.6.3.Picture(s) fuel loaded in the stove prior to light-off

11.6.7.6.4.Picture(s) fuel just after light-off but prior to door cracked open period.

11.6.7.6.5.Picture(s) of the coal bed at the end L1 phase

11.6.8. *L2: High-fire Phase* – the high-fire phase commences immediately after the startup phase ends.

11.6.8.1.L2 Appliance requirements.

11.6.8.1.1.Record the weight of the stove prior to loading the L2 fuel charge, the weight of the fuel charge prior to loading, and the scale weight after loading the L2 fuel charge.

11.6.8.2. L2 Fuel requirements.

11.6.8.2.1. L2 piece size – during the high-fire phase, small cordwood pieces by weight, as defined by the fuel load calculator, are used.

11.6.8.2.2. L2 loading density: 7 lb. per cubic foot, +/- 5%. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.8.3.L2 Operational parameters: Open the door upon completion of the startup phase and load the L2 fuel load within 60 seconds. Once the fuel has been loaded, the appliance doors shall be closed immediately. Air settings shall be left fully open. When 50% of the L2 fuel load mass has been consumed, the air settings shall be moved to the lowest settings.

11.6.8.4.L2 Fuel Adjustments.

11.6.8.4.1.One fuel adjustment shall be made during the high-fire phase prior to moving the primary air control(s) to their lowest setting. The door shall remain open for 30 seconds for fuel adjustments.

11.6.8.4.2.Additional fuel adjustments shall be made if there is a five-minute period without a weight change at any point during the high-fire phase. The door may only be open for 30 seconds for fuel adjustments.

11.6.8.4.3.All fuel adjustments must be documented in the test report notes and summary.

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11.6.8.5.End of L2 Phase –The high-fire phase ends when the scale indicates that 90% of the high-fire fuel mass has been consumed.

11.6.8.6. L2 Photo documentation

11.6.8.6.1.Picture(s) of the L2 loaded into the stove with the door open and fuel loading pattern distinguishable.

11.6.8.6.2. Picture(s) of the air settings at the beginning of the L2 phase

11.6.8.6.3.Picture(s) of the air setting after 50% fuel consumption

11.6.8.6.4.Picture(s) of the air settings at the end of the L2 phase.

11.6.8.6.5.Picture(s) of the coal bed at the end of L2 phase.

11.6.8.6.6.Pictures before and after L2 fuel adjustments.

11.6.9. *L3: Maintenance-fire Phase* – the L3 maintenance-fire phase commences immediately after the L2 high-fire phase ends.

11.6.9.1.L3 Appliance Requirements.

11.6.9.1.1. Record the weight of the stove prior to loading the maintenance-fire fuel charge, the weight of the fuel charge prior to loading, and the scale weight after loading the maintenance-fire fuel charge.

11.6.9.2.L3 Fuel Requirements.

11.6.9.2.1.Fuel type – during the L3 phase, large cordwood pieces are used. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.9.2.2.L3 fuel loading structure: fuel shall be loaded in the direction specified by the fueling calculator.

11.6.9.2.3. L3 loading density: 5 lb. per cubic foot, +/- 5%. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.9.3. L3 Operational Parameters:

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11.6.9.3.1.Open door upon completion of the L2 phase and load the maintenance-fire fuel charge.

11.6.9.3.2.L3 Load - L3 fuel loaded within 30 seconds of the door opening. Close the loading door immediately.

11.6.9.4. L3 Fuel Adjustments: If there is a fifteen-minute period without weight change at any point during the L3-fire phase, a fuel adjustment shall be made to increase the burn rate. The door may be open for up to 30 seconds for fuel adjustments.

11.6.9.5.L3 End of Phase – The L3-fire phase ends when the scale indicates that 90% of the maintenance-fire fuel mass has been consumed.

11.6.9.6.L3 Photo documentation

11.6.9.6.1.Picture(s) of the L3 loaded into the stove with the door open and fuel loading pattern distinguishable.

11.6.9.6.2. Picture(s) of the air settings at the beginning of the L3 phase

11.6.9.6.3.Picture(s) of the air settings at the end of the L3 phase.

11.6.9.6.4.Picture(s) of the coal bed at the end of L3 phase.

11.6.9.6.5.Pictures before and after fuel adjustments in L3.

11.6.10.*L4: Low burn rate phase* – L4 phase commences immediately after the L3- ends.

11.6.10.1.L4 Appliance Requirements.

11.6.10.1.1.Record the weight of the stove prior to loading the L4-fire fuel charge, the load of the fuel charge prior to loading, and the scale weight after loading the overnight-fire fuel charge. Alternatively, if the scale was zeroed prior to starting the test, record the scale weight before and after loading the overnight-fire fuel charge.

11.6.10.2.L4 Fuel requirements

11.6.10.2.1. L4 fuel type –a mix of small and large cordwood pieces are used. At least 50% of the fuel charge load, by the number of pieces, must be large pieces.

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11.6.10.2.2.L4 Loading structure: fuel will be loaded in one direction.

11.6.10.2.3.L4 loading density: The fuel load calculator specifies a load volume of 12 lb/ft^3 .+/-5%. Fuel shall be loaded in a manner to maximize the number of pieces that will fit in the stove without using force.

11.6.10.3. L4 Operational Parameters:

11.6.10.3.1. Open the loading door upon completion of the L3 maintenance-fire phase.

11.6.10.3.2.Load the L4 fuel charge within two minutes (120 seconds).

11.6.10.3.3.Keep the door in the 1" cracked position for five minutes from the beginning of the L4 phase.

11.6.10.3.4.Air controls shall be placed in the fully open position for the first ten minutes of the phase.

11.6.10.4.L4 Fuel Adjustments.

11.6.10.4.1.Unlimited fuel adjustments are allowed within the first five minutes of the phase. After ten minutes, air control(s) shall be moved to their lowest position. A picture of the air setting used must be included in the test report. The door may be open for up to 30 seconds for fuel adjustments.

11.6.10.5.L4 End of Phase – The L4 phase shall end when the scale indicates that 90% of the total L4 fuel mass has been consumed.

11.6.10.6.L3 Photo documentation

11.6.10.6.1.Picture(s) of the L4 loaded into the stove with the door open and fuel loading pattern distinguishable.

11.6.10.6.2. Picture(s) of the air settings at the beginning of the L4 phase

11.6.10.6.3.Picture(s) of the air settings at the end of the L4 phase.

11.6.10.6.4.Picture(s) of the coal bed at the end of L4 phase.

11.6.10.6.5.Pictures before and after fuel adjustments in L4.

11.6.10.7.L4 Photo documentation

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11.7. Test Run. A complete test run requires completion of all four burn phases and loads. For any appliance that will not accommodate the loading arrangement specified in this test method, the test facility personnel shall contact the Agency Administrator to obtain written approval for an alternative loading arrangement:

11.8. Test Run Requirements. The following describes the required parameters for each test run. Each emission test run shall include all phases of the operational and fueling protocol run in order as described.

11.8.1. Consecutive Test Runs. Consecutive test runs may be conducted, provided that the following requirements are met:

11.8.1.1. Run 1 – The appliance shall have an internal and external starting temperature within +/- 2 °F (1.1°C) of laboratory ambient temperature at the beginning of Run 1

11.8.1.2. Run 2 – The second test run may commence 24 hours after the start of Run 1. Stove coals and ash can remain in the stove until 1 hour before conducting Run 2. All coals and ash shall be removed at least one hour prior to commencing Run 2.

11.8.1.3. Run 3 – The third test run may commence 24 hours after the start of Run 2. Stove coals and ash may remain in the stove until 1 hour before conducting Run 3. All coals and ash shall be removed at least one hour prior to commencing Run 2.

11.9. *Failure to Operate at All Test Conditions*

11.9.1. If the appliance fails two runs due to incomplete test runs, it shall be determined that the appliance has failed the certification test and requires a modification to appliance design. All data for incomplete runs shall be reported. Incomplete failed test runs are defined as the following:

11.9.1.1. If a wood heater fails to complete all four phases of the test run, the run shall be considered a failed test run.

11.9.1.2. If there is no weight change for a consecutive period of 30 minutes at any point during the test, the unit has failed the test run.

11.9.1.3. If the wood heater fails to comply with test protocol parameters

11.9.2. If a test run violates the parameters of the test method, the run is invalid.

11.9.3. If during certification testing a critical component of the stove is damaged or breaks, the certification test will be stopped and considered invalid.

11.9.3.1. If damage is noted during a test, repairs shall be made by the manufacturer (or by laboratory personnel with written direction from the manufacturer). If the repair involves components that would need aging, the appliance shall then undergo another round of wood heater aging as specified in section 10.6. These components may include but are not limited to catalyst elements, gaskets, and refractory components. The aging process is intended not only to 'cure' the stove but also to cycle parts that may fail with extended use. Alternate aging techniques may be approved by the administrator, depending on the nature of the failure, material, and critical nature.

11.10. Test Run Completion. Once three valid runs have been completed, the testing is complete. No additional runs may be completed.

11.10.1. *Additional Test Runs*. If there is an invalid run, may attempt two additional runs to complete the test series. If more than three test runs are conducted, the results from all valid test runs shall be used in calculating the average emission rate. The measurement data and results of all test runs shall be reported regardless of which values are used in calculating the emission rate. No test run data can be eliminated from the reporting requirements of this method.

11.11. Auxiliary Wood Heater Equipment Operation. If optional heat exchange blowers are sold for use with the wood heater, three runs without the fan and an additional run with the fan shall be completed. If emissions are more than 1 gram per higher with the fan on, an additional two runs must be completed with the fan on. Heat exchange blowers shall operate in the highest airflow setting. (Automatically operated blowers shall be operated as designed) during the entire test.

11.12. PM Data Recording.

11.13. All data shall be collected and recorded at intervals of no more than 1 minute. TEOM data shall be averaged up to 1-minute intervals for reporting. TEOM operation shall follow the procedures listed in NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

11.13.1. Data shall be reported in an Excel or compatible spreadsheet following the minimum data reporting requirements. All electronic files shall be submitted as part of the test report. Spreadsheet files shall be supplied as part of the publicly available test report.

11.13.2. Room PM measurement – TEOM. A TEOM shall be used to measure ambient lab air PM during the test, as configured in NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel. The sample flow shall be 2 LPM

12. Quality Control Measures

12.1. Dilution tunnel - Conduct sampling equipment leak check and calibration pre- and post-test.

12.2. TEOM – Flow and Leak checks are done before and after every test run per NESCAUM

Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

12.3. Volume Metering System Checks.

13. Data Analysis and Calculations. –

13.1. Emission Calculations. Particulate matter, carbon dioxide, and carbon monoxide shall be calculated using the following methodology and reported in grams per hour, grams per kilogram and pounds per million British Thermal Unit (BTU) heat output. All calculations shall be conducted using all decimal values provided by the instrumentation or recorded by the operator. No truncation of data is acceptable. Only the final calculation of the PM emissions rate shall be rounded, to three significant figures.

13.2. TEOM data shall be reported as follows.

13.2.1. Emissions from each of the 4 phases of the test shall be reported as individual results in grams per hour, grams per kilogram, and lb/MMBtu (heat output).

Emissions from the entire test run in grams per hour, grams per kilogram, and lb/MMBtu (heat output).

Nomenclature

AER = Ei/∑N
BR – average dry fuel burn rate, lb./min
$BR_{(x)}$ – Burn rate for specific phase, BR_{L1}, BR_{L2}, BR_{L3}, BR_{L4}
CO – Carbon Monoxide
CO_2 – Carbon Dioxide
H_2- Hydrogen
O_2 – Oxygen
BT = time of 90% of overnight load consumed – time of overnight loading
C_{steel} – Specific heat of steel (0.1 Btu/ lb., ˚F)
E_T – Total particulate emissions for the full test run in grams
$E_{g/MJ}$ – PM Emissions rate in grams per megajoule of heat output
$E_{g/kg}$ – PM Emissions factor in grams per kilogram of dry fuel burned
$E_{g/hr}$ – PM Emissions factor in grams per hour
E_{Rco} – CO emission rate, g/hr.
EIi – Average CO emission index for interval i
E_{ICO} – CO emission index, g/kg dry fuel
EIco,avg – Average CO emission index for the run
HHV – Higher heating value of fuel = Use accredited test results
LHV – Lower heating value of fuel = Use accredited test results
$\%M_d$ = Fuel moisture content, dry basis, percent.

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$\%M_w$ = Average moisture in test fuel charge, wet basis, percent
N = Total number of test runs.
PCTCO2– average CO_2 in the dry flue gas (%)
PPMco -average CO in the dry flue gas (ppm)
Q_{out} – Total heat output in BTU's (megajoules)
SC_i – Scale weight at specific time interval, lb.
$t_{(i)}$ – Data sampling interval in minutes
T1 – Surface Temperature 1 °F (°C)
T2 – Surface Temperature 2 °F (°C)
T3 – Surface Temperature 3 °F (°C)
T4 – Surface Temperature 4 °F (°C)
T5 – Surface Temperature 5 °F (°C)
T6 – Pre Catalyst Temperature 1 °F (°C)
T7 – Post Catalyst Temperature 2 °F (°C)
T8 – Tunnel Temperature °F (°C)
T9 - Flue Gas Temperature °F (°C)
T10 – Room Temperature °F (°C)
$TS_{avg(i)}$ – Initial Average Surface Temperature °F (°C)
$TS_{avg(f)}$ – Final Average Surface Temperature °F (°C)
W_{fuel} – Fuel charge weight in pounds (kg)
W_i – Weight of fuel in pounds (kg)
W_{app} – Weight of empty appliance in pounds (kg)
Θ – Total length of test run, hours
$\Theta_{(x)}$ – Total length of test run in hours per phase, X
$\%M_w = 100(\%M_d)/100+\%M_d$

13.3. Average Wood Heater Surface Temperatures. Calculate the average of the wood heater surface temperatures at the start of the phase (L4) and end at the end of the test (L4) of the test run.
L4 $TS_{avg(i)} = (T1 + T2 + T3 + T4 + T5) / 5$
L4 $TS_{avg(f)} = (T1 + T2 + T3 + T4 + T5) / 5$
Average surface temperatures at the start and end of any phase can be determined by averaging all five sensors at the beginning and end of each phase.
L_x $TS_{avg(i)} = (T1 + T2 + T3 + T4 + T5) / 5$
L_x $TS_{avg(f)} = (T1 + T2 + T3 + T4 + T5) / 5$

13.4. Burn Time Rating– A standardized burn time rating shall be determined by rounding the duration of the overnight-fire phase of the test up to the nearest 1 hour. Burn time shall be calculated as the time L4 is loaded into the stove until 90% of the fuel has been consumed. This provides an important rating for consumers and is not intended for any calculation purposes and shall be reported on the all manufacturers materials that provides specifications on appliance performance. Language such as "this stove has demonstrated a low setting burn time of x hours in official

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testing"

13.5. Determine Burn Rates

BR_{L1} = not applicable
BR_{L2} = (L2 Initial SC_i – L2 Final SC_i) / $\Theta_{(L2)}$, lbs./hr
BR_{L3} = (L3 Initial SC_i – L3 Final SC_i) / $\Theta_{(L3)}$, lbs./hr
BR_{L4} = (L4 Initial SC_i – L4 Final SC_i) / $\Theta_{(L4)}$, lbs./hr

13.6. Emissions

13.6.1. Determine emission rates and emission factors as:

$E_{g/MJ} = E_T/(Q_{out} \times 0.001055)$, g/MJ
$E_{g/kg} = E_T/(W_{fuel}/(1+M\%M_d/100))$, g/dry kg
$E_{g/hr} = E_T/\Theta$, g/hr

13.7. Efficiency calculation.

Ultimate Analysis of dry fuel (% by weight)

Carbon – CA
Hydrogen – HY
Oxygen – OX
Moisture Content – mass of water per mass of dry fuel – Mcdb
Ambient Humidity Ratio – mass of water per unit mass of dry air – ω
Flue gas temperature (F) – Ts
Room temperature (F)-Tr
CO in the dry flue gas (ppm) – PPMco
CO2 in the dry flue gas (%) – PCTCO2
Higher heating value of the dry fuel (lb/MMBtu) – HHV

<u>Combustion Balance Equation:</u>

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

Where:

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

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[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4] excess air parameter, e.g. if [EMBED Equation.DSMT4] 0.5 there is 50 % excess air

From this:

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

With flue gas CO and CO_2 measured, these two equations can be solved simultaneously for [EMBED Equation.DSMT4] and [EMBED Equation.DSMT4].

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

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Calculation of the Molar Coefficient for Each of the Products

For the assumption of 100 kg of dry fuel, this is the number of moles of each product for the input conditions

[EMBED Equation.DSMT4] Molar Coefficient for CO

[EMBED Equation.DSMT4] Molar Coefficient for CO_2

[EMBED Equation.DSMT4] Molar Coefficient for H_2O

[EMBED Equation.DSMT4] Molar Coefficient for O_2

[EMBED Equation.DSMT4] Molar Coefficient for N_2

Heat Capacity of Exhaust Products

The general equation for representing how the heat capacity of the exhaust products varies with temperature is:

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[EMBED Equation.DSMT4]

Where:

C = heat capacity J/mol K or kJ/kgmol K

A and B are constants

Tk = Temperature in °K

The values for A and B for the exhaust components are provided in the table below

Component	A	B
CO	.0056	27.162
CO2	.029	29.54
H2O	.0057	32.859
O2	.009	26.782
N2	.0062	26.626

For each component, heat capacity is calculated at the stack temperature and at room temperature. The average of these is used to calculate sensible heat loss.

<u>Calculation of Heat Losses for Efficiency Determination</u>

[EMBED Equation.DSMT4] Higher heating value in kJ/kg (conversion from Btu/lb)

[EMBED Equation.DSMT4] Latent heat of water vapor in kJ/kgmol

[EMBED Equation.DSMT4] Heat loss in latent heat of water vapor, % of input energy

[EMBED Equation.DSMT4] Heat loss in chemical energy in CO, % of input energy

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4] Heat loss in sensible heat in flue gas, % of input energy

[EMBED Equation.DSMT4] Stack loss efficiency, %

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14. Reporting Requirements. The report shall include the following:

14.1.1. Introduction

14.1.2. Purpose of test: certification, audit, efficiency,

14.1.3. Name and location of the laboratory conducting the test.

14.1.4. Wood appliance identification – manufacturer, model number/name, design type, description of the appliance tested, stove condition, and date of receipt.

14.1.5. Test information – location of testing, date of tests, sampling methods used, number of test runs, a statement detailing any previous certification testing completed on the wood appliance.

14.1.6. A list of people who conducted research on the appliance, participated in testing preparation, or witnessed the certification testing. This list shall clearly specify their roles in the testing program for the appliance. The list shall include the participant's name, title, company, contact information and the purpose of their participation.

14.1.7. A statement that the test results apply only to the specific appliance tested.

14.2. Summary and Discussion of Results

14.2.1. Table of results to include test run number, average burn rate for entire run and each phase, carbon monoxide and particulate emission rate for full run, particulate and carbon monoxide emission rate for each load phase (L1, L2, L3, L4), efficiency for the full run and each phase, burn time for total run and each phase.

14.2.2. For each test run use the TEOM data and use real-time gas analyzer data for other emissions to report: Θ_1,Θ_2, Θ_3, CO, CO_2, PM, and efficiency for (1) L1 - the startup phase and (2) L2 - high-, (3) L3-maintenance-, and (4) L5 low burn rate fire phases. Calculated results for the emissions shall be reported as total emissions in grams, pounds per million Btu output, grams per MJ, grams per kilogram of dry fuel and grams per hour, and pounds per hour.

14.2.3. A narrative discussion detailing any issues or anomalies that arose during each test run and how those were handled, including comments about the fuel, and loading of the appliance.

14.2.4. A plot of CO emission rate in ppm vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.5. A plot of CO_2 emission rate in ppm vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.6. A plot of PM emission rate in grams/hour vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.7. A plot of PM emission rate in g/kg vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.8. Summary of other data – test facility conditions, surface temperature averages, catalyst temperature averages, pretest fuel weights, test fuel charge weights – total and by phase.

14.3. Discussion. Test run result, specific test run problems and solutions. Comments on fuel, loading, analysis, and anything that may impact the reported result(s).

14.3.1. Details of deviations from, additions to or exclusions from the test method, and their data quality implications on the test results (if any), as well as information on specific test conditions, such as environmental conditions. An explanation of the deviations, additions, or exclusions shall be provided along with an analysis as to why these elements had no impact.

14.4. Process description:

14.4.1. Data and drawings indicating the firebox size and location of the fuel charge.

14.4.2. Drawings and calculations used to determine firebox volume to include volume, height, width, and lengths, weight, and volume adjustments.

14.4.3. Firebox configuration – At a minimum to include air supply locations and operation, air supply introduction location, refractory location and dimensions, catalyst location, baffle and by-pass location and operation (include line drawings or photographs)

14.4.4. Appliance operation during the test – shall supply details on air supply settings and adjustments.

14.5. Test fuel properties – the report shall provide information on the species, density, fuel moisture, fuel temperature, and load details from the fuel load calculator to include all measurements including the number of pieces, individual piece weights, piece length, moisture content and weight.

14.6. Sampling

14.6.1. A description of the test procedures and test equipment, including a schematic or other drawing showing the location of all required test equipment. Also, a description of test fuel sourcing, handling and storage practices shall be included.

14.6.2. Describe the sampling location relative to the wood heater, include drawing or photographs.

14.6.3. Provide data on sampling blanks.

14.7. Quality Control and Assurance Procedures

14.7.1. Calibration procedures and results certification procedures, sample and analysis procedures.

14.7.2. Test method quality control procedures to include TEOM leak and flow checks, stratification (velocity) checks, tunnel flow range results, filter temperature range verification and dilution tunnel RH verification.

14.8. Appendices

14.8.1. Results and Example Calculations. Raw data and complete calculations for data included in summary tables.

14.8.2. Raw data. Copies of all files or sheets for sampling measurement, temperature records, and other materials used by lab related to testing.

14.8.3. Calibration Results. Summary of all calibrations, check, and audits pertinent to the certification.

14.8.4.Sampling and Operation Records. Copies of all uncorrected records of activities not included in raw data sheets (e.g., wood heater door open, times and durations) as well as photographs of fuel loading and air flow settings.

14.8.5.Correspondence. Any correspondence to include written, electronic or verbal communications regarding appliance testing. Items shall include:

14.8.5.1.Request to conduct testing

14.8.5.2.Scheduling of testing

14.8.5.3. Notice to EPA to conduct test, and any modifications to that request.

14.8.5.4. Notice and submission of data to EPA after testing completed.

14.8.6.Test Facility Information. Report test facility temperature, air velocity, and humidity information.

14.8.7.Test Equipment Calibration and Audit Information. Report calibration and audit results for the platform scale, test fuel balance, test fuel moisture meter, and sampling equipment including volume metering systems and gaseous analyzers.

14.8.8.Pretest procedures. Report all pretest procedures conducted at the lab on the appliance to burns, rates, and amounts.

14.8.9.All required data for each test run shall be provided in spreadsheet format both in the printed report and in a computer file such that the data can be easily analyzed and calculations easily verified. Formulas used for all calculations shall be accessible for review.

14.8.10.For each test run: report TEOM flow and temperature and verification of all TEOM data validation parameters as required in NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

14.8.11.Raw data, calibration records, and other relevant documentation shall be retained by the laboratory for a minimum of 7 years.

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Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 6/15/2021 8:03:31 PM
To: Alice.Edwards@alaska.gov; Johnson, Steffan [johnson.steffan@epa.gov]
CC: cindy.heil@alaska.gov; Burkhard, Ellen G (NYSERDA) [Ellen.Burkhard@nyserda.ny.gov]; Brashear, Angelina [Brashear.Angelina@epa.gov]
Subject: RE: revised IDC stove for filters

Stef, please note that this protocol relies on other documents currently in the EPA docket, such as the NYSERDA TEOM SOP, processing sheets, and the fuel calculator.

From: Edwards, Alice L S (DEC) <alice.edwards@alaska.gov>
Sent: Tuesday, June 15, 2021 4:00 PM
To: Johnson, Steffan <johnson.steffan@epa.gov>
Cc: Heil, Cynthia L (DEC) <cindy.heil@alaska.gov>; Burkhard, Ellen G (NYSERDA) <Ellen.Burkhard@nyserda.ny.gov>; Brashear, Angelina <Brashear.Angelina@epa.gov>; Lisa Rector <lrector@nescaum.org>; Edwards, Alice L S (DEC) <alice.edwards@alaska.gov>
Subject: RE: revised IDC stove for filters

Stef,

Attached is the IDC method dated 6/10/2021 and a letter of approval from NYSERDA for ADEC and US EPA's use of the IDC-Cordwood Stove test method and Fuel Loading Protocol – filter method, the Tapered Element Oscillating Microbalance standard operating procedures, and excel processing sheet for TEOM data dated June 1, 2021 for use in certification testing under US EPA's Residential Wood Heater New Source Performance Standards. Please let me know if there is anything further you may require.

Thanks!

Alice

Alice Edwards
Director, Division of Air Quality
Alaska Department of Environmental Conservation

Phone: (907) 465-5109
Email: alice.edwards@alaska.gov

From: Johnson, Steffan [mailto:johnson.steffan@epa.gov]
Sent: Thursday, June 10, 2021 4:13 AM
To: lisa rector <lrector@nescaum.org>; Edwards, Alice L S (DEC) <alice.edwards@alaska.gov>
Cc: Heil, Cynthia L (DEC) <cindy.heil@alaska.gov>; Burkhard, Ellen G (NYSERDA) <Ellen.Burkhard@nyserda.ny.gov>; Brashear, Angelina <Brashear.Angelina@epa.gov>
Subject: RE: revised IDC stove for filters

Lisa,

Thank you for that clarification, this is very helpfuil.

I would still ask that Alaska obtain permission from NYSERDA for the use of the TEOM SOP and TEOM data spreadsheet before we post this to our public web site.

I just want to be sure that we're not overstepping anything here.

Thank you very much,

Stef

From: Lisa Rector <lrector@nescaum.org>
Sent: Wednesday, June 9, 2021 5:06 PM
To: Johnson, Steffan <johnson.steffan@epa.gov>; Alice.Edwards@alaska.gov
Cc: cindy.heil@alaska.gov; Burkhard, Ellen G (NYSERDA) <Ellen.Burkhard@nyserda.ny.gov>; Brashear, Angelina <Brashear.Angelina@epa.gov>
Subject: RE: revised IDC stove for filters

Just to clarify, the TEOM is only used for the first-hour value and to apportion emissions by phase. The full run value still must be reported using the filter measurement to show compliance with the NSPS standards. So the PM testing includes ASTM filter data per ASTM 2515 and full run data using the TEOM. I apologize for any confusion my previous email caused.

Lisa

From: Johnson, Steffan <johnson.steffan@epa.gov>
Sent: Wednesday, June 9, 2021 3:10 PM
To: Alice.Edwards@alaska.gov
Cc: cindy.heil@alaska.gov; Burkhard, Ellen G (NYSERDA) <Ellen.Burkhard@nyserda.ny.gov>; Lisa Rector <lrector@nescaum.org>; Brashear, Angelina <Brashear.Angelina@epa.gov>
Subject: FW: revised IDC stove for filters

Dear Alice,

The attached revision to the IDC protocol to support your request to use the IDC for wood heating compliance and now includes provisions for mandatory TEOM use.

In order to accept this, we will need a revised request letter from Alaska stating your intent that this version, including TEOM PM measurements, be used. Furthermore, the current data set we have in support of our approval for ATM-140 supports the filter measurements for compliance with the IDC. We would need additional data provided to us if we were to use the TEOM for compliance purposes.

Additionally, we will need a letter from NYSERDA to Alaska, granting the use of their proprietary protocols and spreadsheets for these purposes.

Thank you for your assistance and attention in this matter.

Sincerely,

Stef

Steffan M Johnson | Leader – Measurement Technology Group | US EPA Office of Air Quality Planning and Standards | Air Quality Assessment Division | 109 T.W. Alexander Drive, RTP, NC 27710 | Mail Drop: E-143-02 | Phone: (919) 541-4790 | Cell: (919) 698-5096

From: Lisa Rector <lrector@nescaum.org>
Sent: Wednesday, June 9, 2021 1:00 PM
To: Burkhard, Ellen G (NYSERDA) <Ellen.Burkhard@nyserda.ny.gov>; Alice.Edwards@alaska.gov
Cc: Johnson, Steffan <johnson.steffan@epa.gov>
Subject: revised IDC stove for filters

Ellen, Alice, and Stef; attached to this email is a revised IDC Stove method for filters. This method has incorporated revisions based on input from Ben Myren and PFS. The most significant change is the testing must use both a filter and a TEOM for PM measurement purposes. The options to use the method without a TEOM has been eliminated. I have also addressed language and formula typos. Note that the processing spreadsheets and fueling calculator in the docket for EPA's research should also be used for testing under the ATM.

Please feel free to contact me with any questions. Thanks!

Lisa

NESCAUM

Lisa Rector, Policy and Program Director at **NESCAUM**
89 South Street, Suite 602, Boston, Massachusetts, 02111 | 802.899.5306| 617.259.2095 | Fax: 617.742.9162 | lrector@nescaum.org

Message

From: Johnson, Steffan [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=EBA5C0DFC5FC4593AFA62CE7C3DD6F02-JOHNSON, STEFFAN]
Sent: 5/25/2021 1:51:09 PM
To: Lisa Rector [lrector@nescaum.org]; gallen@nescaum.org
CC: Burkhard, Ellen G (NYSERDA) [Ellen.Burkhard@nyserda.ny.gov]
Subject: FW: IDC Comments
Attachments: IDC Stove protocol EPA Research 4 14 21 with comments.docx; Model B - Maple.xlsm; Fuel Load Calculator Comments.docx

Lisa,

As we spoke, here are the comments we received from our contractor.

If we can get a final copy in hand, that would be great!

Thank you!

Stef

From: Jill Mozier <jmozier@scainc.com>
Sent: Monday, May 24, 2021 5:38 PM
To: Nash, Dave <Nash.Dave@epa.gov>; Garnett, Kim <Garnett.Kim@epa.gov>
Cc: Johnson, Steffan <johnson.steffan@epa.gov>; Sebastian Button <sebastian.button@pfsteco.com>; John Steinert <john.steinert@pfsteco.com>; aaron.kravitz@pfsteco.com; Graham Fitzsimons <gfitzsimons@scainc.com>
Subject: FW: IDC Comments

I'm just forwarding the below and attached to Dave Nash and Kim Garnett from EPA, so they are on this thread too. (Thanks for copying me, Sebastian.)

Jill Mozier
(984) 234-3968
jmozier@scainc.com

From: Sebastian Button <sebastian.button@pfsteco.com>
Sent: Monday, May 24, 2021 5:30 PM
To: 'Johnson, Steffan' <johnson.steffan@epa.gov>; Graham Fitzsimons <gfitzsimons@scainc.com>; Jill Mozier <jmozier@scainc.com>
Cc: John Steinert <john.steinert@pfsteco.com>; Aaron Kravitz <aaron.kravitz@pfsteco.com>
Subject: IDC Comments

Hi Stef,

We wanted to follow-up with after our last call to give you an idea of where we are at with getting started. At this point, based on the preliminary tests we have performed, I feel we are at a place where we are ready to kick off official testing. We have familiarized ourselves enough with both the equipment and the methodology and are eager to get started. However, there are still a number of road blocks that need to be cleared before we take that next step. First and foremost, as discussed, we need an updated copy of the IDC covering the changes to the method we discussed in our call 4/27. Some of those changes are critical regarding clarifications of procedural issues, such as bypass operation and air settings at the beginning of load cycles. Additionally, I am sure you have seen, but George has issued several

"updated" TEOM SOPs and data templates, and is currently working on yet another one as we speak. All that to say, I would like to hear, directly from you, which versions of these documents we should be using (once you have them) and that is it for revisions until further notice.

Having said all of that, I have some additional comments and points for clarifications for both the method and the fuel load calculator. The good news is, with the exception of a couple issues in the calculator, I don't think any of these are show stoppers, but are certainly areas that need to be addressed. The main thrust of this is that now that we have generated some raw data, we were able to take a closer look at the calculations section so that we could put our own calculation sheets together. We feel there are some shortcomings with the calculation section and report requirements. A good test method will lead you in a straight line from your raw data to the final results with all calculations needed to be performed. With this method, there are a lot of gaps that primarily rely on a user who is experienced enough to know what needs to be done, and even then, a small handful of assumptions and best guesses had to be made in order to calculate all the required data points. Please take a look at the attached IDC protocol, our comments are in the margin, primarily focused in section 13 and 14.

As for the fuel calculator, I have also attached a semi-filled out version of the calculator for you to take a look at (see run#1 tab) as well as a separate word document with comments. I feel like I've mentioned this a handful of times at this point, but it bears repeating, this sheet is a black box that spits out numbers without telling you how it got them. This makes it very difficult to know if any given number is right or wrong, and based on the fact that I have found at least a couple verifiable errors, that doesn't instill a ton of confidence. Anyway, take a look, at a minimum we need points #1 and 2 clarified before getting started with testing, everything else is mostly me griping about how redundant/not user friendly this required use sheet is.

The other issue is with the HPBA's request to piggyback off this project to and collect some additional data using traditional PM sampling means. We should discuss the implications of this make sure we are all in agreement with this add-on prior to starting.

Sebastian Button
Laboratory Supervisor - Portland Laboratory

PFS TECO
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www.pfsteco.com

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NYSERDA Integrated Duty Cycle Test Method for Certification of Wood-Fired Stoves Using Cordwood: Measurement of Particulate Matter (PM) and Carbon Monoxide (CO) Emissions and Heating Efficiency

Note: This method does not include all the specifications (e.g. equipment and supplies) and procedures (e.g., sample and analytical) essential to its performance. Some material is incorporated by reference from other methods. Therefore, to obtain reliable results, persons using this method shall have a thorough knowledge of at least the following EPA Tests

- Method 1- Sample and Velocity Traverses for Stationary Sources
- Method 2- Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot

Tube)

- Method 3 – Gas Analysis for the Determination of Dry Molecular Weight
- Method 4 – Determination of Moisture Content in Stack Gases
- Method 5G – Determination of Particulate Matter from Wood Heaters (Dilution Tunnel Sampling Location)
- Method 10 - Carbon Monoxide - Instrumental Analyzer
- Method 28 – Certification and Auditing if Wood Heaters

1. Scope and Application

1.1. This test method specifies operation and fueling for certification and auditing of manually operated wood-fired stoves and heaters.

1.2. This test method measures particulate matter (PM) emissions, carbon monoxide, and efficiency.

1.3. Particulate emissions are measured in the dilution tunnel method as specified in ASTM E2515 Standard Test Method for Determination of Particulate Matter Emissions Collected in a Dilution Tunnel using the Tapered Element Oscillating Microbalance (TEOM) continuous PM method, as detailed in this test method.

1.4. Analyte. Particulate matter (PM). No CAS number assigned. Carbon monoxide (CO). No CAS number assigned.

1.5. Applicability. This method is applicable for the certification and auditing of wood space heaters, which burn cordwood fuel. The test quantifies PM and CO emissions and provides overall efficiency ratings, maximum burn time, and heat output.

1.6. Data Quality Objectives. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods

1.7. Distinguishing features of appliances covered by this standard include:

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1.7.1. Cordwood fuel is hand-fed into firebox.

1.7.2. A chimney or vent that exhausts combustion products from the appliance.

1.8. The values stated are to be regarded as the standard, whether in I-P or SI units. The values given in parentheses are for information only.

1.9. Data Quality Objectives.

1.9.1. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods.

1.9.2. Measurement of emissions and heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

1.9.3. This is a laboratory method intended to capture operating periods that are representative of actual field use without excessive test burden.

2. Referenced Methods

2.1. NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel

2.2. ASTM 2515: Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel.

3. Definitions

3.1. Appliance – a wood heater capable of and intended for space heating defined in the applicable regulation. The appliance includes a combustion chamber, combustion air settings, operating controls, and a thermostat if specified, and any other accessory required for standard operation, such as a barometric damper,

3.2. Catch - any mass from the sample probe system on the filter.

3.3. Certification or audit test - a series of at least three test runs conducted for certification or audit purposes that meets the specifications detailed in this protocol.

3.4. Chop – using a poker or another piece of wood to strike a piece of the fuel charge to break it into smaller pieces.

3.5. Coal-bed Stirring – prior to adding a new fuel charge, using a poker or piece of wood to stir or level the coal bed of the appliance for the sole purpose of ensuring ease of loading of the fuel charge. No special formations can be made, such as creating coal bed formations or pushing coals to one side or creating slopes with the coals.

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3.6. East-west stove – a stove where the firebox dimension parallel to the loading door is greater or equal to the stove depth measurement. Logs are loaded so that they are viewed on the long length of the stove.

3.7. Emission factor – the emission of a pollutant expressed in mass per unit of energy (typically) output from the appliance.

3.8. Firebox - the portion of the chamber in the wood heater in which the test fuel charge is placed and combusted.

3.9. Firebox depth - the horizontal length of the fire chamber dimension measured perpendicular to the loading door. If the manufacturer believes that a portion of the firebox depth is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.10. Firebox Height - the vertical distance extending above the top of the firebox to the floor of the firebox. Firebox height is not necessarily uniform. The measurement must account for variations caused by internal baffles, air channels, or other permanent obstructions. If the manufacturer believes that a portion of the firebox height is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.11. Firebox width - the horizontal fire chamber dimension that is parallel to the loading door. If the manufacturer believes that a portion of the firebox width is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.12. Fuel Adjustment – manipulations to the fuel charge to reflect typical owner practices that allow the cordwood fuel to burn appropriately during the test period. A fuel adjustment includes minor changes in fuel placement. It does not include chopping the wood, stirring the coal bed, or reorganizing fuel placement.

3.13. Fuel load calculator – The locked excel spreadsheet tool that determines the allowable test fuel load weights and required piece sizes for each individual load.

3.14. Fuel loading direction – For loads 2, 3, and 4 fuel shall be loaded based parallel to the dimension with the largest value. If the firebox length and width are within 2", fuel shall be loaded in an east/west fashion, parallel to the loading door. A crisscross configuration is allowed for L1 but cannot be used as a load configuration for loads 2, 3, or 4.

3.15. Kindling pieces – small pieces of wood less than 1" in diameter. No bark or moisture requirements for these pieces, however kindling pieces shall not be dried or stored anywhere but in laboratory ambient conditions. Kindling length shall be of the same wood species as the fuel charge length. Individually kindling pieces may weigh no less than 1.5 ounces.

3.16. Large fuel pieces – pieces that are larger for the appliance as defined by the fuel load calculator.

3.17. L1 – Start-up – period of the test when the unit has kindling and startup fuel under the conditions described in Section 11.6.7.

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3.18. L2 – High-fire Phase – period of the test when the unit has a small coal bed and the stoves air settings are fully open. It is intended to replicate periods when homeowners are trying to quickly heat an area, shortly after starting or restarting the appliance.

3.19. L3 - Maintenance-fire phase– period of the test when a fire is maintained with a medium-sized coal bed, and a smaller batch of wood made up of two large pieces. This is intended to simulate a period when the operator is trying to maintain consistent heat output.

3.20. L4 - Low-burn Rate Phase – period of the test when the stove has a large coal bed, the stove is fully loaded, and the adjustable air settings are set to produce the lowest possible burn rate and have the lowest air settings. It is intended to simulate when the operator is trying to maintain heat over a long time, such as overnight or while away for significant periods of time.

3.21. North-south stove: a firebox that has its longest dimension measurement perpendicular to the loading door. In this stove type, logs are loaded so that the ends of the fuel are viewed when loaded.

3.22. Phase – A distinct period in the test run with its own operational procedures and conditions.

3.23. Primary air supply – air supply that introduces air to the wood heater in the combustion chamber and is adjusted to target a desired burn rate. The wood heater manufacturer or test facility can document this through design drawings.

3.24. Secondary air supply - air supply that introduces air to the wood heater such that the burn rate is not altered by more than 10 percent when the secondary air supply is adjusted during the test run. The wood heater manufacturer or test facility can document this through design drawings that show the secondary air is introduced only into a mixing chamber or secondary chamber outside the firebox.

3.25. Small fuel pieces - pieces that are small for the appliance as defined by the fuel load calculator.

3.26. Starter fuel – pieces of cordwood that can be smaller than small and large pieces but larger than kindling, as defined by the fuel load calculator.

3.27. Test data– means the data for all test runs conducted on the wood heater, including any data collected during failed and invalid runs and includes records of preparation of standards, identification of equipment used and personnel present, records of calibrations, raw data sheets for field sampling, raw data sheets for field and laboratory analyses, chain-of-custody documentation, and example calculations for reported results.

3.28. Test facility - the area in which the wood heater is installed, operated, and sampled for emissions.

3.29. Test fuel charge - the collection of test fuel pieces used in each of the four phases of the test run. L2, L3, and L4 require that at least 75% of the individual pieces with at least 80% bark on one side of the fuel piece. Bark shall not be removed for certification testing. Any fuel charge that suggests bark was purposely removed or shaped shall deem the certification test invalid. Examples of fuel piece manipulation are provided in Section 11.

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3.30. Test fuel load – the group of test fuel pieces that are loaded, as specified by phase, throughout the test run. Test fuel loading means the arrangement of the test fuel charge.

3.31. Test fuel loading density - the calculation that determines the weight of the as-fired test fuel load. The calculation is based on the usable volume of the firebox.

3.32. Test run - an individual emission test that includes the four operational phases required by the fueling protocol.

3.33. Usable firebox volume - the calculated volume of the firebox determined using its height, width, and depth as defined in this section. This calculation represents the area where wood is likely to be loaded. If the manufacturer claims that portions of the firebox may not be used in the calculation, a justification must be submitted with the test report. If the justification is not approved, the test results will be deemed unrepresentative for certification purposes. It is highly recommended that manufacturers obtain regulatory approval if making claims that portions of the firebox are not appropriate for inclusion in the calculation.

3.34. Wood heater - an enclosed, wood-burning appliance capable of and intended for space heating or domestic water heating, as defined in the applicable regulation.

4. Interferences

None.

5. Summary of Method

5.1. Particulate matter emissions are measured from a wood heater burning cordwood test fuel in a test facility maintained at a set of prescribed ambient conditions. Procedures for operating the appliance, measuring PM and CO emission rates, and methods for reducing data and calculating results are provided.

5.2. *Dilution Tunnel*. A dilution tunnel following the specifications detailed in ASTM E2515-11 shall be used for particulate measurements.

5.3. *Particulate Matter*: PM emissions are measured in a dilution tunnel with a Thermo model 1405-D 2-channel TEOM using NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel with a dilution tunnel as specified in ASTM 2515 with modifications discussed in Section 10.

5.4. *Carbon Monoxide*. The CO is measured in the stack and is used to calculate efficiency determination.

5.5. *Operation*. Appliance operation is conducted on a cold-to-hot test cycle, meaning that the appliance starts the first test run at room temperature and ends with the appliance in fully heated state. The second and third test runs may start at a slightly warmer temperature if the appliance is designed to retain the heat from the first run. The appliance is operated at operational phases representing start-up emissions, high heat demand, low heat demand, and refueling. To complete

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the certification test, the appliance shall complete three valid test runs that are averaged to determine the test results.

5.6. *Repeatability.* A series of at least three test runs comprised of five different heat demands or phases conducted for certification or audit purposes.

6. Significance and Use

6.1. The measurement of particulate matter emission rates is an important test method widely used in the practice of air pollution control.

6.1.1. These measurements, when approved by state or federal agencies, are often required for the purpose of determining compliance with regulations and statutes.

6.1.2. The measurements made before and after design modifications are necessary to demonstrate the effectiveness of design changes in reducing emissions and make this standard an important tool in manufacturers' research and development programs.

6.2. Measurement of heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

7. Safety

7.1. Disclaimer. This method may involve hazardous materials, operations, and equipment. This test method may not address all the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to performing this test method.

7.2. These tests involve combustion of wood, which releases substantial amounts of heat and combustion products. The heating system also produces large quantities of very hot water and the potential for steam production and system pressurization. Appropriate precautions must be taken to protect personnel from burn hazards and respiration of products of combustion. Exposure of personnel to unsafe levels of carbon monoxide must be avoided, and the use of continuous ambient carbon monoxide monitoring is strongly recommended.

8. ***Equipment and Supplies.*** The following items are required for sample collection:

8.1. Anemometer. A device capable of detecting air velocities less than 0.10 m/sec (20 ft/min), for measuring air velocities near the test appliance.

8.2. Appliance Flue.

8.2.1. Steel flue pipe extending to 8.5 ±0.5 ft. (2.6 ±0.15 m) above the top of the platform scale, and above this level, insulated solid pack type chimney extending to 15 ±1 ft (4.6 ±0.3 m) above the platform scale, and of the size specified by the appliance manufacturer. This applies to both freestanding and inserts type appliances.

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8.2.2. Other chimney types (e.g., solid pack insulated pipe) may be used in place of the steel flue pipe if the appliance manufacturer's written appliance specifications require such chimney for home installation (e.g., zero clearance appliance inserts). Such alternative chimney or flue pipe must remain and be sealed with the appliance following the certification test.

8.2.3. Solid pack insulated chimneys shall have a minimum of 2.5 cm (1 in.) solid-pack insulating material surrounding the entire flue and possess a label demonstrating conformance to U.L. 103 (incorporated by reference—see §60.17).

8.3. Appliance Platform Scale and Monitor. For monitoring of fuel load weight change. The scale shall be capable of measuring weight to within 0.01 kg (0.02 lb.) and calibrated to NIST traceable standards at least annually.

8.4. Barometer. Aneroid or another barometer capable of measuring atmospheric pressure to within 0.1 in. Hg (2.5 mm Hg) with an uncertainty of +/- 0.05 in Hg (+/- 1.27 mm Hg).

8.5. Dilution Tunnel must meet the requirements of ASTM E2515, clauses 6.1.6 and 9.2.

8.6. Dilution Tunnel temperature and relative humidity measurement. A probe capable of measuring tunnel temperature to within 0.9 °F (0.5 °C)) and tunnel RH to within 2%, such as the Omega HX85-A or equivalent.

8.7. Draft Gauge. Electromanometer or other devices for the determination of flue draft or static pressure readable to within 0.005 in. H2O (1.2 Pa)

8.8. Flue Gas Temperature Measurement. A type K- thermocouple or equivalent located in the centroid of the stack located 8.0 +/- 0.5 ft (2.44 m +/- 150 mm) above the platform scale. Capable of measuring with an accuracy of 4.0°F (2.2°C) or 0.75% of reading, whichever is greater.

8.9. Flue Gas Composition Measurement. A sample probe and continuous infrared analyzer or equivalent capable of measuring span of carbon monoxide (CO) and carbon dioxide (CO_2) in the flue gas produced by the appliance tested. Continuous analyzers (or equivalent) shall have maximum zero and span drift, over a 24 h period, of 1% of full scale

8.10. Fuel Scale. Balance capable of weighing the test fuel charge to within 0.02 kg (0.05 lb.) and calibrated to NIST traceable standards at least annually.

8.11. Humidity Gauge. Psychrometer or hygrometer for measuring room humidity to within +/- 4% from 25 to 95% RH.

8.12. Moisture Meter. Calibrated electrical resistance meter for measuring test fuel moisture to within 2 percent moisture content.

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8.13. Surface Temperatures. Capable of measuring temperature to within 1.5 percent of expected absolute temperatures with an accuracy of 4.0˚F (2.2˚C) or 0.75% of reading, whichever is greater.

8.14. Test Facility Temperature Monitor. A thermistor, RTD, Type T-Special thermocouple, or other equivalent device, located centrally in a vertically oriented 150 mm (6 in.) long, 50 mm (2 in.) diameter pipe shield that is open at both ends, capable of measuring temperature to within 1˚F of expected temperatures.

8.15. TEOM – Thermo Fisher Scientific TEOM model 1405-D (Thermo part # 1405D-ANF, excluding models 1405, 1405-DF, or 1405-F) to measure and report continuous particulate matter (PM) measurements in an ASTM 2515 dilution tunnel or equivalent dilution method, and operated according to the NESCAUM Dichot TEOM Standard Operating Procedures.

9. Calibration and Standardizations

9.1. Anemometer. Calibrate the anemometer as specified by the manufacturer's instructions before the first certification test and monthly thereafter.

9.2. Appliance Platform Scale. Perform a multipoint calibration (at least five points spanning the operational range) of the platform scale before its initial use. The scale manufacturer's calibration results are sufficient for this purpose. Before each certification test, audit the scale with the wood heater in place by weighing at least one calibration weight (Class F) that corresponds to between 20 percent and 80 percent of the expected test fuel charge weight. If the scale cannot reproduce the value of the calibration weight within 0.0045 kg (0.01 lb.) or 1 percent of the expected test fuel charge weight, whichever is greater, recalibrate the scale before use with at least five calibration weights spanning the operational range of the scale.

9.3. Barometer. Calibrate using a reference pressure monitor calibrator before the first certification test and semiannually after

9.4. Draft Gauge. Calibrate as per the manufacturer's instructions; a liquid manometer does not require calibration (but must be properly leveled, zeroed, and the system leak checked).

9.5. Humidity Gauge. Calibrate as per the manufacturer's instructions before the first certification test and annually thereafter.

9.6. Fuel Scale. Calibrate as described in 9.2.

9.7. Moisture Meter. Calibrate as per the manufacturer's instructions before the first certification test and semiannually thereafter.

9.8. Temperature Sensors. Calibrate using at least five points within operating range within specification and in compliance with NIST Monograph 175. To be calibrated before the first certification test and semiannually thereafter.

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10. Sampling, Test Specimens, and Test Appliances

10.1. Modifications to ASTM 2515 requirements.

10.1.1. Liquid water should not be present anywhere in the sampling system for a valid sample. The presence of condensed water anywhere in the sampling system invalidates the test run. All data from all invalid test runs shall be included in the report. The reviewing authority shall make a final determination on invalidated runs. Data from any invalidated test run shall not be used to calculate results. If the testing agency believes a run has been invalidated, the test run shall be repeated.

10.1.2. Dilution tunnel temperature and relative humidity shall be measured electronically and logged at one-minute intervals near the sample probe to calculate dewpoint. The temperature measurement method shall have an accuracy of 0.9˚F (0.5˚C) (type T-Special TC or an RTD).

10.1.3. The following section details test conditions that shall be maintained for a valid test run. A valid test shall have no more than two individual deviations from any of the conditions below to remain a valid run. An example of an individual deviation is a single, ten-minute rolling average where the dilution tunnel exceeded temperature thresholds. Another ten-minute period exceeding the tunnel temperature requirement shall be considered a second deviation.

10.1.3.1. Tunnel temperature shall not exceed 104 deg. F (40C) based on ten-minute rolling averages derived from one-minute data, excluding periods when the appliance door is open.

10.1.3.2. Tunnel relative humidity shall not exceed 90% based on ten-minute rolling averages derived from one-minute data excluding periods when the appliance door is open.

10.1.3.3. Tunnel dew point temperature shall not exceed 87.8˚F (31.0˚C).

10.1.3.4. A minimum tunnel flow of 600 CFM is required. Higher tunnel flows may be required to meet the parameters of Section 10.1.3, 10.13.2, and 10.1.3.3.

10.1.3.5. All exceedances must be reported in the test anomalies section, even if deviations are within the test method tolerances.

10.2. Sample Collection. The following are required for sample collection:

10.3. Teflon coated glass fiber filters as supplied by the TEOM manufacturer for use with the TEOM model 1405-D. These are Pallflex Emfab (TX40) with an exposed diameter of 13 mm, without organic binder, exhibiting at least 99.95 percent efficiency.

10.4. *Test Specimens*. Appliances shall be supplied as complete systems, including all controls and accessories necessary for installation at the test facility. A full set of specifications, designs, and

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assembly drawings shall be provided when the product is placed under certification of a third-party agency.

10.5. Preparation of Apparatus

10.5.1. Wood Heater Installation for Certification Testing. Assemble the wood heater appliance and parts in conformance with the manufacturer's provided User Guide. These instructions must match all instructions materials developed by the manufacturer and/or their distributors. Place the wood heater on the platform scale and connect the chimney to the appliance. Clean the flue with an appropriately sized, wire chimney brush before initiating Run 1 of the certification test. Test documentation should include the date and time of flue cleaning.

10.5.2. Wood Heater Temperature Monitors.

10.5.2.1. For catalyst-equipped wood heaters, locate a temperature monitor (optional) about 25 mm (1 in.) upstream of the catalyst at the centroid of the catalyst face area, and locate a temperature monitor (mandatory) that will indicate the catalyst exhaust temperature. This temperature monitor is centrally located within 25 mm (1 in.) downstream at the centroid of the catalyst face area. Record these locations.

10.5.2.2. Locate wood heater surface temperature monitors at five locations on the wood heater firebox exterior surface. Position the temperature monitors centrally on the top surface, centrally on two sidewall surfaces, and centrally on the bottom and back surfaces. Position the monitor sensing tip on the exterior of the firebox surface inside of any heat shield, room air circulation walls, or other wall or shield separated from the firebox exterior surface. Surface temperature locations for unusual design shapes (e.g., spherical, etc.) shall be positioned so that there are four surface temperature monitors in

10.6. Conditioning

10.6.1. Wood Heater Aging Prior to Certification Testing. A wood heater of any type shall be aged at least 50 hours before initiating a certification test. The aging procedure shall be conducted by the manufacturer or a manufacturer's agent prior to sending the appliance to the testing laboratory. The certification lab cannot be involved with wood heater aging in any manner.

During aging, the appliance shall be operated at a variety of burn rates. Documentation for wood heating aging must be included in the test report to include data on individual hourly burn rates. The testing laboratory shall not conduct any firing of the appliance prior to conducting the certification test.

10.6.1.1. The manufacturer shall supply wood heater aging information for the final test reports. Aging data that shall be reported include all fuel parameters (species, moisture content, load weights, piece amounts, and size), air settings used, time spent in each air setting phase, amount of fuel burned, and appliance burn rates.

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10.6.1.2. If an appliance uses a catalytic combustor, it must be engaged according to the manufacturer's instructions and operate with the catalyst engaged for at least 50 hours during the break-in period. In addition to the reporting requirements listed in 8.1.1, catalytic appliances shall also report hourly catalyst exit temperature data to include the dates and hours of operation.

11. Procedure

11.1. Test Facility Conditions. The test facility shall meet the following requirements during testing.

11.1.1. The test facility temperature shall be maintained between 55 and 88°F (13 and 31.1°C) during each test run.

11.1.2. The flue shall discharge into the same space or into a space freely communicating with the test facility. Any hood or similar device used to vent combustion products shall not induce a draft greater than 0.005 in. H_2O (1.25 Pa) on the wood heater measured when the wood heater is not operating.

11.1.3. For test facilities with artificially induced barometric pressures (e.g., pressurized chambers), the barometric pressure in the test facility shall not exceed 30.5 in. Hg (775 mm Hg) during any test run.

11.1.4. Locate the test facility temperature monitor on the horizontal plane that includes the primary air intake opening for the wood heater. Locate the temperature monitor 3 to 6 ft. (1 to 2 m) from the front of the wood heater in the 90° sector in front of the wood heater.

11.1.5. Use an anemometer, to measure the air velocity. Measure and record the room air velocity before the ignition period in L1 Startup and once immediately following the test run completion. Air velocities within 0.6 m (2 ft) of the test appliance and exhaust system shall be less than 0.25 m/sec (50 ft/min) without fire in the unit.

11.1.6. Measure and record the test facility's ambient relative humidity, barometric pressure, and temperature before and after each test run using equipment as specified in Section 6.

11.2. Wood Heater Firebox Volume.

11.2.1. Determine the firebox volume using the definitions for height, width, and length. Volume adjustments due to the presence of firebrick and other permanent fixtures may be necessary. All adjustments shall be detailed in the test report and shall conform to the definition of usable firebox volume contained in this test method. Measurements shall include areas adjacent to and above a baffle.

11.2.2. If a manufacturer deems certain areas of the firebox as unusable for fuel load calculations, written documentation stating the basis for that claim and supporting photographic image(s) must be provided and approved by the regulatory authority prior to conducting the certification test. If approval is not granted prior to the test, then the test may be invalidated if the reviewing agency determines the firebox volume is inaccurate.

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11.3. Test Fuel. The test fuel shall conform to the following requirements and meet specifications as required by the fuel loading calculator:

11.3.1. Fuel Species. Untreated, air-dried, cordwood fuel.

11.3.1.1.For EPA research purposes allowable species: maple (big leaf, red, silver), oak (white), or birch (black, white, yellow, paper).

11.3.1.2.Kiln-dried fuel is not permitted.

11.3.1.3.Fuel shall be free of decay, fungus, or other contaminants.

11.3.2. Fuel Moisture.

11.3.2.1.Determine fuel moisture for each fuel piece by averaging four moisture meter readings, one from each of three sides, measured parallel to the wood grain.

11.3.2.2.The test fuel load shall have an average moisture content from 19% to 25%, dry basis.

11.3.2.3.Average individual piece moisture content shall have an average moisture content 18% to 27% dry basis.

11.3.2.4.The addition of moisture to previously dried wood is not allowed.

11.3.2.5.It is recommended that the test fuel be stored in a temperature and humidity-controlled room.

11.3.2.6.Fuel moisture shall be measured within 24 hours of using the fuel for the test and shall be stored in a humidity-controlled environment until 2 hours prior to testing.

11.3.3. Fuel Temperature. The test fuel shall be at the test facility temperature of 13 to 32°C (55 to 90°F) +/-2F.

11.3.4. Fuel Dimensions. The dimensions of each test fuel piece shall conform to definitions specified by the protocols using the fuel load calculator.

11.3.4.1.Fuel length:

11.3.4.1.1.The length of the fuel pieces will be determined by the fuel load calculator.

11.3.4.1.2.Measurements shall be taken, and the length of the test fuel will be determined by entering the firebox dimensions, which calculates the length for all the fuel pieces into a generally available commercial size (14, 16, 18, 20, or 22 inches in length).

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11.3.4.1.3.Piece length specified by the fuel calculator shall be communicated and specified for use in the owner's manual and website. Piece size shall be within 0.5" of the log length determined by the calculator, as measured on the shortest length measurement.

11.3.5.Fuel Loading Direction

11.3.5.1.Fuel loading direction shall be determined by the firebox measurement.

11.3.5.1.1.Stoves with a depth measurement greater than two inches from the width measurement shall be tested with the fuel in a north-south configuration and may not test with fuel in an east/west or crisscross configuration in any load other than Load 1 and Load 2.

11.3.5.1.2.Stoves with a width measurement greater than the depth measurement or a width measurement within two inches of the depth measurement shall be tested with the fuel loaded in an east-west configuration and may not test with fuel in a north/south configuration or crisscross configuration in any load other than Load 1 and Load 2.

11.3.6.Fuel piece weight for each phase of the protocol shall be determined by the fuel load calculator.

11.3.6.1.Kindling –shall be:

11.3.6.1.1.pieces of wood less than or equal to 1" in diameter.

11.3.6.1.2.No bark requirements for kindling fuel

11.3.6.1.3.Fuel species may be any species allowed in 7.2.1.1.

11.3.6.1.4.No moisture requirements.

11.3.6.1.5.Length of kindling shall be the fuel length specified by the fuel load calculator.

11.3.6.1.6.Kindling fuel shall conform to the rule that 7 to 10 pieces of kindling equal 1 pound of kindling fuel (+/- 5%).

11.3.6.2. Starter fuel: pieces of cordwood shall be used during the startup phase. Individual piece weight for starter fuel shall be determined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall be not be used in testing (see Figure 1). Pieces that have squared cross sections shall be split to represent the typical triangle nature of wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible and fuel load pieces shall be composed to include different shapes of wood if using any trapezoidal pieces. .

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11.3.6.3. Small fuel pieces: smaller pieces of cordwood by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall not be used (see figure 1). Pieces that have square cross-sections shall be split to represent the typical triangle nature of wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible. No more than two (2) small fuel pieces can be trapezoidal in shape (Figure 2) per fuel load.

11.3.6.4. Large fuel pieces: larger pieces of cordwood, by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall be not be used (see figure 1). Pieces that have square cross-sections shall be split to represent the typical triangle nature of wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible. No more than one (1) large fuel piece can be trapezoidal in shape (Figure 2) per fuel load.

Figure 1. Schematic of unacceptable cross-sectional profiles

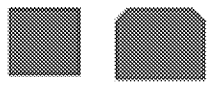

Figure 2. Schematic of undesirable and limited use shapes

Figure 3. Schematics of acceptable cross-sectional profiles

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11.4. Sampling Equipment.

11.4.1. Prepare the PM and ambient sampling equipment as defined by the TEOM Protocol.

11.4.2. Prepare all other equipment as defined by method EPA Method 1, 2, 3, 4, and ASTM 2515 (dilution tunnel specifications only)

11.5. Manufacturer participation in certification testing

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11.5.1. A representative of the manufacturer may observe testing but may not provide instructions to the certification lab, in any form, with testing staff or equipment once the certification tests begin. The names of testing witnesses cannot be withheld as confidential business information (CBI).

11.6. Test Run Procedure.

11.6.1. Before each test series, the firebox shall be vacuumed. Testing shall begin without any ash or other materials in the appliance.

11.6.2. Before initiating the compliance test, clean the flue and dilution tunnel with an appropriately sized wire chimney brush before each certification test. Test documentation should include the date and time of flue cleaning.

11.6.3. Record fuel weight data, temperature measurements, and gas concentrations at 1-minute intervals.

11.6.4. Wood Heater Operation and Adjustments. Record all adjustments made to the air supply controls, adjustments to and additions or subtractions of fuel, and any other changes to wood heater operations that occur during the test period.

11.6.5. The weight of fuel remaining at the end of the test run is determined as the difference between the weight of the wood heater with the remaining coals and fuel and the weight after loading the fuel charge. The starting weight is the tare weight of the cleaned, dry wood heater.

11.6.6. All runs shall be videotaped in their entirety. Video tape shall be of sufficient quality to determine fuel characteristics, fuel loading procedures, and firebox conditions during any testing or aging conducted by the test lab. The testing lab shall have the capacity to allow appropriate agencies the opportunity to remotely witness the test.

11.6.7.L1: Start-up Phase.

11.6.7.1.L1 Appliance requirements.

11.6.7.1.1. Stove temperature: internal and external stove temperature must not be greater than the ambient temperature +/- 2˚F (1.1˚C) for Run 1. There is no stove starting temperature requirement for Runs 2 and 3 except in the case of a failed first run. In this case, if Run 1 is invalid or incomplete and, the stove must meet Run 1 conditions for at least one valid run. Temperature measurements for the external and internal temperatures shall be taken within 15 minutes before starting the test and shall be reported in the test report.

11.6.7.1.2. Tare the appliance scale before starting the test. Record appliance scale weights at the start and end of L1 phase

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11.6.7.2.L1 Fuel requirements.

11.6.7.2.1.L1 Fuel type – during the startup phase newspaper (optional up to six full sheets traditional newspaper size), kindling, and starter fuel pieces are used. No other additions are allowed.

11.6.7.2.2.L1 loading density

11.6.7.2.2.1.Kindling loading density: 1 lb. per cubic foot for dry kindling, +/- 5%. The fuel load calculator determines the amount of kindling that can be used.

11.6.7.2.2.2.Starter Fuel loading density: 3 lb. per cubic foot, +/- 5%. The fuel load calculator will determine the minimum piece weight that can be used as starter fuel.

11.6.7.2.3.L1 fuel loading structure: The loading structure of the fire shall be a bottom-up configuration with newspaper on the bottom, kindling on top of the paper, and starter fuel on top of the kindling. Kindling and starter fuel shall be loaded in a crisscross configuration.

11.6.7.3.L1 Operational parameters.

11.6.7.3.1.All kindling, starter fuel, and newspaper must be in the firebox for light off.

11.6.7.3.2.Air settings are fully open.

11.6.7.3.3.Light the fire with a torch for a period of no more than 30 seconds.

11.6.7.3.4.Immediately after lighting the fire and completing the photo requirement, the appliance door shall be moved to a cracked open position. Cracked open position is defined as opening no more than one inch. The appliance door shall be closed 5 minutes after ignition.

11.6.7.4.L1 Fuel Adjustments: up to three fuel adjustments are allowed in the startup phase. The door may be open for 30 seconds during each fuel adjustment.

11.6.7.5.L1 End of Phase – the end of the startup phase is defined by the weight specified by the fuel load calculator.

11.6.7.6. L1 Documentation – Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed, and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge.

11.6.8. *L2: High-fire Phase* – the high-fire phase commences immediately after the startup phase ends.

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11.6.8.1.L2 Appliance requirements.

11.6.8.1.1.Record the weight of the stove prior to loading the L2 fuel charge, the weight of the fuel charge prior to loading, and the scale weight after loading the L2 fuel charge.

11.6.8.2. L2 Fuel requirements.

11.6.8.2.1. L2 piece size – during the high-fire phase, small cordwood pieces by weight, as defined by the fuel load calculator, are used.

11.6.8.2.2. L2 loading density: 7 lb. per cubic foot, +/- 5%. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.8.3.L2 Operational parameters: Open the door upon completion of the startup phase and load the L2 fuel load within 60 seconds. Once the fuel has been loaded, the appliance doors shall be closed immediately. Air settings shall be left fully open. When 50% of the L2 fuel load mass has been consumed, the air settings shall be moved to the lowest settings.

11.6.8.4.L2 Fuel Adjustments.

11.6.8.4.1.One fuel adjustment shall be made during the high-fire phase prior to moving the primary air control(s) to their lowest setting. The door shall remain open for 30 seconds for fuel adjustments.

11.6.8.4.2.Additional fuel adjustments shall be made if there is a five-minute period without a weight change of 0.1 pounds at any point during the high-fire phase.

11.6.8.4.3.if there is a five-minute period without a weight change at any point during the high-fire phase. The door may only be open for 30 seconds for fuel adjustments.

11.6.8.4.4.All fuel adjustments must be documented in the test report notes and summary.

11.6.8.5.End of L2 Phase –The high-fire phase ends when the scale indicates that 90% of the high-fire fuel mass has been consumed.

11.6.8.6. L2 Documentation - – Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed, and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge prior to loading.

11.6.9. *L3: Maintenance-fire Phase* – the L3 maintenance-fire phase commences immediately after the L2 high-fire phase ends.

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11.6.9.1.L3 Appliance Requirements.

11.6.9.1.1. Record the weight of the stove prior to loading the maintenance-fire fuel charge, the weight of the fuel charge prior to loading, and the scale weight after loading the maintenance-fire fuel charge.

11.6.9.2.L3 Fuel Requirements.

11.6.9.2.1.Fuel type – during the L3 phase, large cordwood pieces are used. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.9.2.2.L3 fuel loading structure: fuel shall be loaded in the direction specified by the fueling calculator.

11.6.9.2.3. L3 loading density: 5 lb. per cubic foot, +/- 5%. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.9.3. L3 Operational Parameters:

11.6.9.3.1.Open door upon completion of the L2 phase and load the maintenance-fire fuel charge.

11.6.9.3.2.L3 Load - L3 fuel loaded within 30 seconds of the door opening. Close the loading door immediately.

11.6.9.4. L3 Fuel Adjustments: Fuel Adjustments: If there is a ten-minute period without weight change (0.1 lb.) at any point during the L3-fire phase, a fuel adjustment shall be made to increase the burn rate. The door may be open for up to 30 seconds for fuel adjustments. Only two fuel adjustments may be made during this phase. If after the second fuel adjustment, another period of no weight change (0.1 lb.) occurs, the run ends, and it is a failed test run.

11.6.9.5.L3 End of Phase – The L3-fire phase ends when the scale indicates that 90% of the maintenance-fire fuel mass has been consumed.

11.6.9.6.L3 Documentation – Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed, and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge prior to loading.

11.6.10.*L4: Low burn rate phase* – L4 phase commences immediately after the L3- ends.

11.6.10.1.L4 Appliance Requirements.

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11.6.10.1.1.Record the weight of the stove prior to loading the L4-fire fuel charge, the load of the fuel charge prior to loading, and the scale weight after loading the overnight-fire fuel charge. Alternatively, if the scale was zeroed prior to starting the test, record the scale weight before and after loading the overnight-fire fuel charge.

11.6.10.2.L4 Fuel requirements

11.6.10.2.1. L4 fuel type –a mix of small and large cordwood pieces are used. At least 50% of the fuel charge load, by the number of pieces, must be large pieces.

11.6.10.2.2.L4 Loading structure: fuel will be loaded in one direction.

11.6.10.2.3.L4 loading density: The fuel load calculator specifies a load volume of 12 lb/ft^3 .+/-5%. Fuel shall be loaded in a manner to maximize the number of pieces that will fit in the stove without using force.

11.6.10.3. L4 Operational Parameters:

11.6.10.3.1. Open the loading door upon completion of the L3 maintenance-fire phase.

11.6.10.3.2.Load the L4 fuel charge within two minutes (120 seconds).

11.6.10.3.3.Keep the door in the 1" cracked position for five minutes from the beginning of the L4 phase.

11.6.10.3.4.Air controls shall be placed in the fully open position for the first ten minutes of the phase.

11.6.10.4.L4 Fuel Adjustments.

11.6.10.4.1.Unlimited fuel adjustments are allowed within the first five minutes of the phase. After ten minutes, air control(s) shall be moved to their lowest position. A picture of the air setting used must be included in the test report. The door may be open for up to 30 seconds for fuel adjustments.

11.6.10.4.2.If there is a ten-minute period without weight change (0.1 lb.) during the first hour of the L4- phase, a fuel adjustment shall be made. The door may be open for up to 30 seconds for fuel adjustments.

11.6.10.4.3.Only two fuel adjustments may be made during the first hour. If after the second fuel adjustment, another period of no weight change (0.1 lb.) is observed, the run ends, and it is a failed test run.

11.6.10.4.4.No fuel adjustments are allowed after the first hour of the phase.

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11.6.10.4.5.If there is no weight change for a consecutive period of 20 minutes at any point after the first hour of the phase, the unit has failed the test run.

11.6.10.5.L4 End of Phase – The L4 phase shall end when the scale indicates that 90% of the total L4 fuel mass has been consumed. If the fuel load does not burn to 90%, it is a failed test run.

11.6.10.6. L4 Documentation - Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed, and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge prior to loading.

11.7. Test Run. A complete test run requires the completion of all four burn phases and loads. For any appliance that will not accommodate the loading arrangement specified in this test method, the test facility personnel shall contact the Agency Administrator to obtain written approval for an alternative loading arrangement:

11.8. Test Run Requirements. The following describes the required parameters for each test run. Each emission test run shall include all phases of the operational and fueling protocol run in order as described.

11.8.1.Consecutive Test Runs. Consecutive test runs may be conducted, provided that the following requirements are met:

11.8.1.1.Run 1 – The appliance shall have an internal and external starting temperature within +/- 2 ˚F (1.1˚C) of ambient laboratory temperature at the beginning of Run 1

11.8.1.2.Run 2 – The second test run may commence 24 hours after the start of Run 1. Stove coals and ash can remain in the stove until 1 hour before conducting Run 2. All coals and ash shall be removed at least one hour prior to commencing Run 2.

11.8.1.3.Run 3 – The third test run may commence 24 hours after the start of Run 2. Stove coals and ash may remain in the stove until 1 hour before conducting Run 3. All coals and ash shall be removed at least one hour prior to commencing Run 2.

11.9. *Failure to Operate at All Test Conditions*

11.9.1.If the appliance fails two runs due to incomplete or invalid test runs, it shall be determined that the appliance has failed the certification test and requires a modification to appliance design. All data for incomplete runs shall be reported. Incomplete failed test runs are defined as the following:

11.9.1.1.If a wood heater fails to complete all four phases of the test run, the run shall be considered a failed test run.

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11.9.1.2. If there is no weight change for a consecutive period of 20 minutes at any point during the test, the unit has failed the test run.

11.9.1.3. If the wood heater fails to comply with test protocol parameters

11.9.2. If a test run violates the parameters of the test method, the run is invalid.

11.9.3. If during certification testing a critical component of the stove is damaged or breaks, the certification test will be stopped and considered invalid.

11.9.3.1. If damage is noted during a test, repairs shall be made by the manufacturer (or by laboratory personnel with written direction from the manufacturer). If the repair involves components that would need aging, the appliance shall then undergo another round of wood heater aging as specified in section 10.6. These components may include but are not limited to catalyst elements, gaskets, and refractory components. The aging process is intended not only to 'cure' the stove but also to cycle parts that may fail with extended use. Alternate aging techniques may be approved by the administrator, depending on the nature of the failure, material, and critical nature.

11.10. Test Run Completion. Once three valid runs have been completed, the testing is complete. No additional runs may be completed.

11.10.1. *Additional Test Runs*. If there is an invalid run, may attempt two additional runs to complete the test series. If more than three test runs are conducted, the results from all valid test runs shall be used in calculating the average emission rate. The measurement data and results of all test runs shall be reported regardless of which values are used in calculating the emission rate. No test run data can be eliminated from the reporting requirements of this method.

11.10.2. *Invalid Runs*. When a test run fails to meet one of the QA/QC criteria stipulated in the test method, the data are invalid, and the run must be repeated. Data for the invalidated test run must be included in the test report, but the data must not be used in the calculation of average emission values.

11.10.3. *Incomplete Runs:* When an appliance cannot successfully complete all operational elements of the protocol specified in Section 11.6.7 through 11.6.10, it is an incomplete run

11.11. Auxiliary Wood Heater Equipment Operation. If optional heat exchange blowers are sold for use with the wood heater, three runs with the fan and an additional run without the fan shall be completed. If emissions are more than 1 gram per higher with the fan on, an additional two runs must be completed with the fan on. Heat exchange blowers shall operate in the highest airflow setting. (Automatically operated blowers shall be operated as designed) during the entire test.

11.12. PM Data Recording.

11.12.1. All data shall be collected and recorded at intervals of no more than 1 minute. TEOM data shall be averaged up to 1-minute intervals for reporting. TEOM operation shall follow the procedures

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listed in NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

11.12.2. Data shall be reported in an Excel or compatible spreadsheet following the minimum data reporting requirements. All electronic files, including raw instrument data, shall be submitted as part of the test report. Spreadsheet files shall be supplied as part of the publicly available test report.

11.12.3. Room PM measurement – TEOM. A single channel TEOM shall be used to measure ambient lab air PM during the test, as configured in NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel. The sample flow shall be 3 LPM.

12. Quality Control Measures

12.1. Dilution tunnel - Conduct sampling equipment leak check and calibration pre- and post-test.

12.2. TEOM – Flow and Leak checks are done before and after every test run per NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel. Additional quality control measures are included in the TEOM Operating Procedure.

12.3. Volume Metering System Checks.

13. Data Analysis and Calculations.

Proportioning of emission factors and rates per phase according to Appendix A, variables shall have subscript added to determine the relevancy of phase i.e. $E_{T(P1)}$ indicates Total particulate emissions for Phase 1 and $E_{g/hr(P2)}$ indicates emissions factor in grams per hour for Phase 2.

13.1. Emission Calculations. Particulate matter, carbon dioxide, and carbon monoxide shall be calculated using the following methodology and reported in grams per hour, grams per kilogram and pounds per million British Thermal Unit (BTU) heat output. All calculations shall be conducted using all decimal values provided by the instrumentation or recorded by the operator. No truncation of data is acceptable. Only the final calculation of the PM emissions rate shall be rounded, to three significant figures.

13.2. TEOM data shall be reported as follows.

13.2.1. Emissions from each of the 4 phases of the test shall be reported as individual results in grams per hour, grams per kilogram, and lb/MMBtu (heat output).

Emissions from the entire test run in grams per hour, grams per kilogram, and lb/MMBtu (heat output).

Nomenclature

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AER = Ei/∑N

BR – average dry fuel burn rate, lb./min

$BR_{(x)}$ – Burn rate for specific phase, BR_{L1}, BR_{L2}, BR_{L3}, BR_{L4}

CO – Carbon Monoxide

CO_2 – Carbon Dioxide

H_2- Hydrogen

O_2 – Oxygen

BT = time of 90% of overnight load consumed – time of overnight loading

C_{steel} – Specific heat of steel (0.1 Btu/ lb., ˚F)

E_i – Total particulate emissions for the full test run in grams

$E_{g/MJ}$ – PM Emissions rate in grams per megajoule of heat output

$E_{g/kg}$ – PM Emissions factor in grams per kilogram of dry fuel burned

$E_{g/hr}$ – PM Emissions factor in grams per hour

E_{Rco} – CO emission rate, g/hr.

EIi – Average CO emission index for interval i

E_{ICO} – CO emission index, g/kg dry fuel

EIco,avg – Average CO emission index for the run

HHV – Higher heating value of fuel = Use accredited test results

LHV – Lower heating value of fuel = Use accredited test results

$\%M_d$ = Fuel moisture content, dry basis, percent.

$\%M_w$ = Average moisture in test fuel charge, wet basis, percent

N = Total number of test runs.

PCTCO2– average CO_2 in the dry flue gas (%)

PPMco -average CO in the dry flue gas (ppm)

Q_{out} – Total heat output in BTU's (megajoules)

SC_i – Scale weight at specific time interval, lb.

$t_{(i)}$ – Data sampling interval in minutes

T1 – Surface Temperature 1 ˚F (˚C)

T2 – Surface Temperature 2 ˚F (˚C)

T3 – Surface Temperature 3 ˚F (˚C)

T4 – Surface Temperature 4 ˚F (˚C)

T5 – Surface Temperature 5 ˚F (˚C)

T6 – Pre Catalyst Temperature 1 ˚F (˚C)

T7 – Post Catalyst Temperature 2 ˚F (˚C)

T8 – Tunnel Temperature ˚F (˚C)

T9 - Flue Gas Temperature ˚F (˚C)

T10 – Room Temperature ˚F (˚C)

$TS_{avg(i)}$ – Initial Average Surface Temperature ˚F (˚C)

$TS_{avg(f)}$ – Final Average Surface Temperature ˚F (˚C)

W_{fuel} – Fuel charge weight in pounds (kg)

W_i – Weight of fuel in pounds (kg)

Commented [SB1]: This term is not referenced anywhere else in the document

Commented [SB2]: Section 13.5 refernces burn rate units as lb/hr, which is it?

Commented [SB3]: This term is not referenced anywhere else in the document

Commented [SB4]: This term is not referenced anywhere else in the document

Commented [SB5]: Between this method and the IDC, there is limited information on how to actually calculate this number. At a minimum, a reference to another method should be in here somewhere for calculationg tunnel velocity, as well as a formula for flow since it is "non-standard" (i.e. use of "wet flow")

Commented [SB6]: These terms are not referenced anywhere else in the document

Commented [SB7]: This is implying the fuel samples should be sent out for lab analysis, is that correct or are use of published values acceptable? There is no mention of this anywhere else in the document

Commented [SB8]: This term is not referenced anywhere else in the document

Commented [SB9]: This term is not referenced anywhere else in the document

Commented [SB10]: These terms are not references anywhere else in this document in this form. There are references to both flue and room temperature, but not at T9, T10, etc.

Commented [SB11]: This term is not referenced anywhere else in the document

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W_{app} – Weight of empty appliance in pounds (kg)

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Θ – Total length of test run, hours

$\Theta_{(x)}$ – Total length of test run in hours per phase, X

$\%M_w = 100(\%M_d)/100 + \%M_d$

13.3. Average Wood Heater Surface Temperatures. Calculate the average of the wood heater surface temperatures at the start of the phase (L4) and end at the end of the test (L4) of the test run.

L4 $TS_{avg(i)}$ – (T1 + T2 + T3 + T4 + T5) / 5

L4 $TS_{avg(f)}$ – (T1 + T2 + T3 + T4 + T5) / 5

Average surface temperatures at the start and end of any phase can be determined by averaging all five sensors at the beginning and end of each phase.

L_X $TS_{avg(i)}$ – (T1 + T2 + T3 + T4 + T5) / 5

L_X $TS_{avg(f)}$ – (T1 + T2 + T3 + T4 + T5) / 5

13.4. Burn Time Rating– A standardized burn time rating shall be determined by rounding the duration of the overnight-fire phase of the test up to the nearest 1 hour. Burn time shall be calculated as the time L4 is loaded into the stove until 90% of the fuel has been consumed. This provides an important rating for consumers and is not intended for any calculation purposes and shall be reported on the all manufacturers materials that provides specifications on appliance performance. Language such as "this stove has demonstrated a low setting burn time of x hours in official testing"

13.5. Determine Burn Rates

BR_{L1} = not applicable

BR_{L2} = (L2 Initial SC_i – L2 Final SC_i) / $\Theta_{(L2)}$, lbs./hr

BR_{L3} = (L3 Initial SC_i – L3 Final SC_i) / $\Theta_{(L3)}$, lbs./hr

BR_{L4} = (L4 Initial SC_i – L4 Final SC_i) / $\Theta_{(L4)}$, lbs./hr

13.6. Emissions

13.6.1. Determine emission rates and emission factors as:

$E_{g/MJ} = E_T/(Q_{out} \times 0.001055)$, g/MJ

$E_{g/kg} = E_T/(W_{fuel}/(1+M\%M_d/100))$, g/dry kg

$E_{g/hr} = E_T/\Theta$, g/hr

Commented [SB13]: This calculation should be using %Mw, not %Md.

Furthermore, it isn't made clear here, but section 14.2.2 requires this calculation for each phase as well as the overall burn. There is no guidance on how to handle the moisture of content of the remaining fuel load (assume it to be zero?) Nor does this take into account that not all of the fuel is burned, the term should be Wfuel * 90% or something to that effect.

Finally, there is not a requirement to take moisture measuments for kindling, but that needs to be accounted for somehow for the L1 phase calculation, assume 0%? 10%?

13.7. Efficiency calculation.

Commented [SB14]: This section does not make clear if these calculations are to be based on the overall average values for a given phase or minutes by minute basis, or some other value.

Ultimate Analysis of dry fuel (% by weight)

Carbon – CA

Hydrogen – HY

Oxygen – OX

Moisture Content – mass of water per mass of dry fuel – Mcdb

Commented [SB15]: Again, there is no guidance on what moisture content to use for the kindling, which goes into this calculation, nor does it specify how to average moisture for the entire test run, is it an artimetic average across all fuel loads, a weighted average by piece, by fuel load, etc.

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Ambient Humidity Ratio – mass of water per unit mass of dry air – ω

Flue gas temperature (F) – Ts

Room temperature (F)-Tr

CO in the dry flue gas (ppm) – PPMco

CO2 in the dry flue gas (%) – PCTCO2

Higher heating value of the dry fuel (lb/MMBtu) – HHV

Commented [SB16]: Again, no guidance on how to calculated this term.

Commented [SB17]: These units don't match those used in the equation below (Kelvin)

Commented [SB18]: These units don't match those used in the equation below (btu/lb)

Combustion Balance Equation:

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

Where:

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4] excess air parameter, e.g. if [EMBED Equation.DSMT4] 0.5 there is 50 % excess air

From this:

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

Commented [SB19]: Throughout this section the symbiol used to indicate multiplication shows up only as invalid character square block thing, which makes for difficult reading

With flue gas CO and CO_2 measured, these two equations can be solved simultaneously for [EMBED Equation.DSMT4] and [EMBED Equation.DSMT4].

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

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Calculation of the Molar Coefficient for Each of the Products

For the assumption of 100 kg of dry fuel, this is the number of moles of each product for the input conditions

[EMBED Equation.DSMT4] Molar Coefficient for CO

[EMBED Equation.DSMT4] Molar Coefficient for CO_2

[EMBED Equation.DSMT4] Molar Coefficient for H_2O

[EMBED Equation.DSMT4] Molar Coefficient for O_2

[EMBED Equation.DSMT4] Molar Coefficient for N_2

Heat Capacity of Exhaust Products

The general equation for representing how the heat capacity of the exhaust products varies with temperature is:

[EMBED Equation.DSMT4]

Where:

C = heat capacity J/mol K or kJ/kgmol K

A and B are constants

Tk = Temperature in °K

The values for A and B for the exhaust components are provided in the table below

Component	A	B
CO	.0056	27.162
CO2	.029	29.54
H2O	.0057	32.859
O2	.009	26.782
N2	.0062	26.626

For each component, heat capacity is calculated at the stack temperature and at room temperature. The average of these is used to calculate sensible heat loss.

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Calculation of Heat Losses for Efficiency Determination

[EMBED Equation.DSMT4] Higher heating value in kJ/kg (conversion from Btu/lb)

[EMBED Equation.DSMT4] Latent heat of water vapor in kJ/kgmol

[EMBED Equation.DSMT4] Heat loss in latent heat of water vapor, % of input energy

[EMBED Equation.DSMT4] Heat loss in chemical energy in CO, % of input energy

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4] Heat loss in sensible heat in flue gas, % of input energy

Commented [SB20]: I could be wrong, but it appears that this equation is missing a term, the term shown here should be, I believe, multiplied by the temperature differential of the room air and stack temp (in Kelvin)

[EMBED Equation.DSMT4] Stack loss efficiency, %

14. ***Reporting Requirements.*** The report shall include the following:

14.1.1. Introduction

14.1.2. Purpose of test: certification, audit, efficiency,

14.1.3. Name and location of the laboratory conducting the test.

14.1.4. Wood appliance identification – manufacturer, model number/name, design type, description of the appliance tested, stove condition, and date of receipt.

14.1.5. Test information – location of testing, date of tests, sampling methods used, number of test runs, a statement detailing any previous certification testing completed on the wood appliance.

14.1.6. A list of people who conducted research on the appliance, participated in testing preparation, or witnessed the certification testing. This list shall clearly specify their roles in the testing program for the appliance. The list shall include the participant's name, title, company, contact information and the purpose of their participation.

14.1.7. A statement that the test results apply only to the specific appliance tested.

14.2. Summary and Discussion of Results

14.2.1. Table of results to include test run number, average burn rate for entire run and each phase, carbon monoxide and particulate emission rate for full run, particulate and carbon monoxide emission rate for each load phase (L1, L2, L3, L4), efficiency for the full run and each phase, burn time for total run and each phase.

14.2.2. For each test run and pollutant with real-time data to include: Θ_1, Θ_2, Θ_3, CO, CO_2, PM, and efficiency for (1) L1 - the startup phase and (2) L2 - high-, (3) L3-maintenance-, and (4) L5 low burn rate fire phases. Calculated results for the emissions shall be reported as total emissions in grams, pounds per million Btu output, grams per MJ, grams per kilogram of dry fuel and grams per hour, and pounds per hour.

14.2.3. A narrative discussion detailing any issues or anomalies that arose during each test run and how

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those were handled, including comments about the fuel, and loading of the appliance.

14.2.4. A plot of CO emission rate in ppm vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.5. A plot of CO_2 emission rate in ppm vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

Commented [SB21]: I am not sure how to calculate CO or CO2 emissions rates (g/hr) without a known stack flow rate. There are a certainly ways to estimate stack flow rate based on a series of assumptions, but it would be best to spell out how you would like emissions rates to be calculated

14.2.6. PM Plots

14.2.6.1. a plot of PM emission rate in grams/hour vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.6.2. A plot of PM emission rate in g/kg vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

Commented [SB22]: How is minutute by minute PM g/kg meant to be calculated, using the minute by minute scale changes? Is there any accounting for fuel moisture?

14.2.7. Summary of other data – test facility conditions, surface temperature averages, catalyst temperature averages, pretest fuel weights, test fuel charge weights – total and by phase.

14.3. Discussion. Test run result, specific test run problems, and solutions. Comments on fuel, loading, analysis, and anything that may impact the reported result(s).

14.3.1. Details of deviations from, additions to or exclusions from the test method, and their data quality implications on the test results (if any), as well as information on specific test conditions, such as environmental conditions. An explanation of the deviations, additions, or exclusions shall be provided along with an analysis as to why these elements had no impact.

14.4. Process description:

14.4.1. Data and drawings indicating the firebox size and location of the fuel charge.

14.4.2. Drawings and calculations used to determine firebox volume to include volume, height, width, and lengths, weight, and volume adjustments.

14.4.3. Firebox configuration – At a minimum to include air supply locations and operation, air supply introduction location, refractory location and dimensions, catalyst location, baffle and by-pass location and operation (include line drawings or photographs)

14.4.4. Appliance operation during the test – shall supply details on air supply settings and adjustments.

14.5. Test fuel properties – the report shall provide information on the species, density, fuel moisture, fuel temperature, and load details from the fuel load calculator to include all measurements including the number of pieces, individual piece weights, piece length, moisture content and weight.

14.6. Sampling

14.6.1. A description of the test procedures and test equipment, including a schematic or other drawing showing the location of all required test equipment. Also, a description of test fuel sourcing,

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handling and storage practices shall be included.

14.6.2. Describe the sampling location relative to the wood heater, include drawing or photographs.

14.6.3. Provide data on sampling blanks.

14.7. Quality Control and Assurance Procedures

14.7.1. Calibration procedures and results certification procedures, sample and analysis procedures.

14.7.2. Test method quality control procedures to include TEOM leak and flow checks, stratification (velocity) checks, tunnel flow range results, filter temperature range verification and dilution tunnel RH verification.

14.8. Appendices

14.8.1. Results and Example Calculations. Raw data and complete calculations for data included in summary tables.

14.8.2. Raw data. Copies of all files or sheets for sampling measurement, temperature records, and other materials used by lab related to testing.

14.8.3. Calibration Results. Summary of all calibrations, check, and audits pertinent to the certification.

14.8.4. Sampling and Operation Records. Copies of all uncorrected records of activities not included in raw data sheets (e.g., wood heater door open, times and durations) as well as photographs of fuel loading and air flow settings.

14.8.5. Correspondence. Any correspondence to include written, electronic or verbal communications regarding appliance testing. Items shall include:

14.8.5.1. Request to conduct testing

14.8.5.2. Scheduling of testing

14.8.5.3. Notice to EPA to conduct test, and any modifications to that request.

14.8.5.4. Notice and submission of data to EPA after testing completed.

Commented [SB23]: How does one include information on notice and submission of a report to EPA in the report before the report has been submitted?

14.8.6. Test Facility Information. Report test facility temperature, air velocity, and humidity information.

14.8.7. Test Equipment Calibration and Audit Information. Report calibration and audit results for the platform scale, test fuel balance, test fuel moisture meter, and sampling equipment including volume metering systems and gaseous analyzers.

14.8.8. Pretest procedures. Report all pretest procedures conducted at the lab on the appliance to burns, rates, and amounts.

14.8.9. All required data for each test run shall be provided in spreadsheet format both in the printed report and in a computer file such that the data can be easily analyzed and calculations easily verified. Formulas used for all calculations shall be accessible for review.

14.8.10. For each test run: report TEOM flow and temperature and verification of all TEOM data validation parameters as required in NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

14.8.11. Raw data, calibration records, and other relevant documentation shall be retained by the laboratory for a minimum of 7 years.

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Integrated Duty Cycle Fuel Calculator

Last updated of the tool: 3/8/2021

Link to download the latest version:

Start a New Calculation for a Stove

Go to the Last Saved Calculation

Start a New Calculation for a Stove

Unlock The Spreadsheet

Instruction:

1- Color Codes and Cells Lock

In this tool, the user can only select and change the content of pre-determined cells. If a cell cannot be selected it means it is not designated to be changed by the user.

There are four main levels of color coding to help the user navigate through the tool easier:

(A) White cells with black font: these cells are either a parameter name, a parameter unit, a fixed formula, or some sort of information about the table. The user cannot change the content of these cells directly. For example, non of these three cells can be edited directly by the user:

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Firebox volume:	3.361	ft^3

(B) Green background cells with blue font: these cells are designed to accept necessary input data by the user. If the content of these cells are empty they will turn into yellow, meaning that data is required to be entered by the user. However, if the cell background is green but the font is black it means the data is NOT required and the cell can be left empty. For example, firebox width, depth and height are necessary data fields but the Volume adjustment is not necessary. Therefore, the firebox dimension cells are yellow and the volume adjustment cell is green when they are empty. After entering valid data into all cells, the font color in the three first cells turn blue:

1.2 Firebox Information		
Firebox width:		in.
Firebox depth:		in.
Firebox height:		in.
Volume adjustment:		ft^3
Firebox volume:		ft^3

1.2 Firebox Information		
Firebox width:	14.0	in.
Firebox depth:	16.5	in.
Firebox height:	18.0	in.
Volume adjustment:	0.200	ft^3
Firebox volume:	2.206	ft^3

(C) Yellow background cells: these cells are missing data that is required. Yellow background cells are two types: the first type are locked and cannot be directly edited, and the second type can be edited directly by the user. In the previous example the cell in front of the "Firebox volume" cell is the one that cannot be directly selected and edited. Rather, it gets updated automatically because there is a formula in it. To change the value in it, the user should enter data in other yellow cells. In this example when the user set the width, height, and depth of the firebox, the volume cell gets updated and it turns white.

(D) Red background cells with yellow font: The red color of these cells is a warning that the number is out of the allowable range and it should be modified either directly or indirectly (by changing the cells that participate in the formula). For example, in the following table for Load 3 the "Load total" weight is red because it is higher than the allowable limit. But user cannot directly change the total load value. Rather, she should change the value of each piece weight to make the "Load total" fall in the correct range:

set the # of logs	Weight (lb)
Piece 1:	5.00
Piece 2:	5.00
Piece 3:	6.00
Load total:	16.00

set the # of logs	Weight (lb)
Piece 1:	5.00
Piece 2:	5.00
Piece 3:	5.10
Load total:	15.10

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In addition to the above color coding, there are white background cells with gray front that show helpful information to user:

Load total:	14.20
	↑↑ Remove some fuel pieces or use lighter logs to reach the target weight :11.00~12.15 lb Allowed weight of each piece: 1.00~2.26 lb

2- Starting a new calculation

2.1 To start a fresh and new fuel calculation for a stove testing click on "Start a new Calculation for a Stove" in this tab. NOTE: by starting a new calculation all previous calculations and data will be DELETED WITHOUT UNDO. Therefore, before starting a new calculation make sure you have made a copy of the spreadsheet to save your previous data. Preparing the tool for a new calculation may take several minutes.

2.2 After the tool is re-started, it will proceed to the '1-Stove' tab. In this tab the user is required to fill in stove information, firebox dimensions, and test lb information. The firebox dimensions should be between 0-40 inches and the volume adjustment value cannot be more than 1 cubic feet. After entering data, click on "Next >>" button at the bottom-right corner of the tab to proceed to the "2- Fuel Load" tab.

2.3 In the Fuel Load tab there is only one parameter to enter: Wood Species. The user can select one of the four wood species from the drop-down list. With each selection the wood density and all load piece details will be updated automatically. After selecting the wood species, click on "Next >>" to show 4 new tabs for run details.

2.4 There are four identical and independent run details tab in this tool. Each tab contains 12 tables to enter details of the run. The first set of tables (Table 3.1 through 3.6) are designed to enter details of wood pieces in each load. To start entering information the first step is to enter the number of pieces for each load in the last column (Actual # of pieces) in Table 3.1:

Enter the number of fuel pieces first, then enter the weight and MC details in Tables 3.2 through 3.6 ↓↓

3.1 Fuel Load Data

	Target load (lb)	Actual weight (lb)	Allowed # of pieces	Actual # of pieces	
L1 - Kindling weight	2.75 ~ 3.04		20	20	Go to table
L1 - Starter	8.25 ~ 9.12		6	5	Go to table
L2 - Small pieces	19.24 ~ 21.27		6	6	Go to table
L3 - Large pieces	13.75 ~ 15.19		2	2	Go to table
L4 - Small pieces	11.00 ~ 12.15		4	3	Go to table
L4 - Large pieces	21.99 ~ 24.31		4	4	Go to table

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For each load a separate table is designed in the tab that can be reached either by scrolling down or by clicking on "Go to table" link.

Notice: In the load tables (Tables 3.2 through 3.6) the number of pieces cannot be changed. To add or remove pieces you should use the "Actual # of pieces" column in Table 3.1

By entering the actual number of pieces in Table 3.1, the tool will automatically make the correct number of rows available in the corresponding t

3.3 Load 2 - Small pieces						
set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)	pin 3 (%)	pin 4 (%)	Avg moisture
Piece 1:						
Piece 2:						
Piece 3:						
Piece 4:						
Piece 5:						
Piece 6:						
Piece 7:						
Piece 8:						
Piece 9:						
Piece 10:						
Load total						

↑↑ Add more fuel pieces or use heavier logs to reach the target weight: 19.24–21.27 lb
Allowed weight of each piece: 2.29–4.83 lb

In each row of the load detail table, the user should enter weight and four MC pin readings in the corresponding cells. The total weight, average moisture of each piece, and final weighted average moisture will update automatically (cannot be edited directly):

3.3 Load 2 - Small pieces						
set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)	pin 3 (%)	pin 4 (%)	Avg moisture
Piece 1:	2.30	22.0	21.0	22.0	21.0	21.5
Piece 2:	4.10	21.0	21.0	22.0	21.0	21.3
Piece 3:	4.00	23.0	24.0	22.0	20.0	22.3
Piece 4:	3.50	19.0	18.0	19.0	19.0	18.8
Piece 5:	3.00	21.0	21.0	22.0	22.0	21.5
Piece 6:	3.00	21.0	21.0	21.0	23.0	21.5
Piece 7:						
Piece 8:						
Piece 9:						
Piece 10:						
Load total:	19.90					21.12

✓ Load weight is in the range

If you click on "set the # of logs" link on the top-left corner of each load table, it will take you to Table 3.1, where you can set the number of pieces. Below each of the load table, there is an information cell with gray font that shows useful hints about data in the table

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the table.

After finishing data entry in Tables 3.1 through 3.6, the user should provide information about run information and test lab condition in Tables 3.7 and 3.8.

Tables 3.9 through 3.11 are designed to be filled out as the test goes on. User should enter data about the weights and timing of the loads at the beginning and end of each load.

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Integrated Duty Cycle Fuel Calculator

1- Stove and Lab Information

1.1 Stove Information	
Appliance manufacturer:	Model B
Appliance model:	B1

1.2 Firebox Information		
Firebox Shape:	◉ Cubic	○ Cylindrica
Firebox width:	18.8	in.
Firebox depth:	16.5	in.
Firebox height:	12.3	in.
Volume adjustment:	0.300	ft^3
Firebox Net Volume:	1.908	ft^3

Dead areas on side and back where air channels are located, height listed is tallest point, but baffle slopes down to back of stove.

Explain the reason for volume adjustment ↑↑

1.3 Test Lab Information	
Lab name:	PFS TECO
Test lab location:	Clackamas, OR
Primary testing staff name:	Sebastian Button
Test lab phone:	503-650-0088
Test lab contact email:	ian.button@pfste
Third party certifier:	PFS TECO
Third party phone:	503-650-0088
Third party email:	.steinert@pfsteco
Other people present or participating either in person or remotely in the test:	

These timestamps cannot be edited

Calculation Started at:	4/12/2021 19:52
Saved and Finished at:	Still in progress

Next >>

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Integrated Duty Cycle Fuel Calculator

2- Fuel Load Information

2.1 Fuel Load General Information			
Wood species:	Maple		
Wood density:	0.61	10^3 kg/m^3	= 38.1 lb/ft3
Firebox Volume:	1.91	ft^3	
Loadind direction:	East-West		
Target log length:	14	in.	

2.2 Load Piece Details				
Load	Total load weight (lb)	Min. piece weight (lb)	Max. piece weight (lb)	Target piece number per load
L1 - Kindling	1.91	0.10	0.20	13
L1 - Starter	5.72	1.00	1.84	5
L2 - Small pieces	13.36	1.86	3.74	5
L3 - Large pieces	9.54	3.82	5.72	2
L4 - Small pieces	7.63	1.86	3.74	3
L4 - Large pieces	15.26	3.78	6.61	3

<< Back

Next >>

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Poly
"Small" Volume
"Medium" Volume
"Large" Volume
Poly Small Low
Poly Small Hi
Poly Large Low
Poly Large Hi

Min. Small Log Diamter Ta
Max. Small Log Diamter Ta
Min. Large Log Diamter Ta
Max. Large Log Diamter Ta

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y curve fitting paramaters for calculating log characteristics

Firebox Volume, ft^3	Sm Pc. Low (in)	Sm pc Hi (in)	Lg Pc Low (in)	Lg Pc Hi (in)
0.80	2.2	3.1	3.1	4.5
2.00	2.8	4	4	5.3
3.00	3	4.4	4.4	6.3
	x2	x	c	
	-0.136363636	0.881818182	1.581818182	
	-0.159090909	1.195454545	2.245454545	
	-0.159090909	1.195454545	2.245454545	
	0.151515152	0.242424242	4.209090909	

Range of the Log Diameters:

rget (in):	2.767908303			
ırget (in):	3.947230014			
rget:	3.947230014			
ırget:	5.223239842			

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Int

3.1 I

	Target load (lb)	Actual weight (lb)	Target # of pieces
L1 - Kindling weight	1.81 – 2.00	1.84	13
L1 - Starter	5.44 – 6.01	5.82	5
L2 - Small pieces	12.69 – 14.02	13.00	5
L3 - Large pieces	9.06 – 10.02	9.82	2
L4 - Small pieces	7.25 – 8.01	7.48	3
L4 - Large pieces	14.50 – 16.03	15.64	3

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Kindling total:	1.84		
Piece 1:	1.12	20.0	20.0
Piece 2:	1.18	20.0	20.0
Piece 3:	1.10	20.0	20.0
Piece 4:	1.28	20.0	20.0
Piece 5:	1.14	20.0	20.0
Piece 6:			
Piece 7:			
Piece 8:			
Piece 9:			
Piece 10:			
Load total:	7.66		

✓ Load weight is in the range

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)

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egrated Duty Cycle Fuel Calculator

3.1 Run #1 Details

Detailed Fuel Information

Enter the number of fuel pieces first, then enter the weight and MC details in Tables 3.2 through 3.6 ↓↓

Fuel Load Data	
Actual # of pieces	
13	Go to table
5	Go to table
5	Go to table
2	Go to table
3	Go to table
3	Go to table

3.2 Load 1 - Kindling and starter fuel

pin 3 (%)	pin 4 (%)	Avg moisture
Not applicable		
20.0	20.0	20.0
20.0	20.0	20.0
20.0	20.0	20.0
20.0	20.0	20.0
20.0	20.0	20.0
		15.20

3.3 Load 2 - Small pieces

pin 3 (%)	pin 4 (%)	Avg moisture

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Piece 1:	2.10		
Piece 2:	3.22		
Piece 3:	2.30		
Piece 4:	2.28		
Piece 5:	3.10		
Piece 6:			
Piece 7:			
Piece 8:			
Piece 9:			
Piece 10:			
Load total:	13.00		

✓ Load weight is in the range

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:	4.94		
Piece 2:	4.88		
Piece 3:			
Load total:	9.82		

✓ Load weight is in the range

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:	2.22		
Piece 2:	2.82		
Piece 3:	2.44		
Piece 4:			
Piece 5:			
Piece 6:			
Load total:	7.48		

✓ Load weight is in the range

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:	5.46		
Piece 2:	5.22		
Piece 3:	4.96		
Piece 4:			
Piece 5:			
Piece 6:			
Load total:	15.64		

✓ Load weight is in the range

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3.4 Load 3 - Large pieces

pin 3 (%)	pin 4 (%)	Avg moisture

3.5 Load 4 - Small pieces

pin 3 (%)	pin 4 (%)	Avg moisture

3.6 Load 4 - Large pieces

pin 3 (%)	pin 4 (%)	Avg moisture

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3.7 Run Information	
Run date:	
Run number:	
Testing staff:	
Witnesses or others present for test:	
Start time:	
End time:	

Temperature:	
Barometric pressure:	
Relative humidity:	

3.9 Ru

Load	Actual weight at start of phase before loading (lb)	Actual weight at start of phase after loading (lb)	Target weight at end of phase (lb)
L1 (Fully Open)	0.00	7.66	2.28
L2(A) (Fully Open)	2.24	15.06	6.57
L2(B) (Fully Closed)	6.51	Not applicable	3.54
L3 (Fully Closed)	3.52	13.34	4.50
L4 (Fully Closed)	4.50	27.62	6.81

3.10 Ru

Load	Start time	End time	Door open time
L1 (Fully Open)			
L2(A) (Fully Open)			
L2(B) (Fully Closed)			
L3 (Fully Closed)			
L4 (Fully Closed)			

Load	
L1 (Fully Open)	
L2(A) (Fully Open)	
L2(B) (Fully Closed)	
L3 (Fully Closed)	
L4 (Fully Closed)	

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Other Testing Information

3.8 Test Lab Condition		
pre-test	post-test	
		F
		in. Hg
		%

n Operation Data	
Actual Weight at end of phase (lb)	
2.24	Allowable range: 2.16–2.39
8.65	Allowable range: 6.24–6.90
3.52	Allowable range: 3.36–3.72
4.50	Allowable range: 4.28–4.73
6.81	Allowable range: 6.47–7.15

ın Operation Data
Door closed time

3.11 Run Operation Data
Notes on fuel adjustments/time

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	3.12 Po
1) Any data points with filter temperatures outside the 80-90F?	
If yes, how many and for how long	
2) Did tunnel temperature exceed 40C during the test?	
If yes, how many and for how long	
3) Did tunnel humidity exceed 90%?	
If yes, how many and for how long	
4) Any tunnel dew point measurements within 2C of filter temp	
If yes, how many and for how long	
5) Tunnel flow for test? (dscf/min)	

<< Back

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st Run Data Check

Next >>

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Integra

3.1 I

	Target load (lb)	Actual weight (lb)	Target # of pieces
L1 - Kindling weight	1.81 – 2.00		13
L1 - Starter	5.44 – 6.01		5
L2 - Small pieces	12.69 – 14.02		5
L3 - Large pieces	9.06 – 10.02		2
L4 - Small pieces	7.25 – 8.01		3
L4 - Large pieces	14.50 – 16.03		3

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Kindling total:			
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Piece 7:			
Piece 8:			
Piece 9:			
Piece 10:			
Load total:			

↑↑ Add more fuel pieces or use heavier logs to reach the target weight: 7.25–8

Allowed weight of each piece: 1.00–1.84 lb

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)

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ted Duty Cycle Fuel Calculator

3.2 Run #2 Details

Detailed Fuel Information

Enter the number of fuel pieces first, then enter the weight and MC details in Tables 3.2 through 3.6 ↓↓

Fuel Load Data	
Actual # of pieces	
	Go to table
	Go to table
	Go to table
	Go to table
	Go to table
	Go to table

3.2 Load 1 - Kindling and starter fuel		
pin 3 (%)	pin 4 (%)	Avg moisture
Not applicable		

3.01 lb

3.3 Load 2 - Small pieces		
pin 3 (%)	pin 4 (%)	Avg moisture

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Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Piece 7:			
Piece 8:			
Piece 9:			
Piece 10:			
Load total:			

↑↑ Add more fuel pieces or use heavier logs to reach the target weight: 12.69-

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Load total:			

↑↑ Add more fuel pieces or use heavier logs to reach the target weight: 9.06--

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Load total:			

↑↑ Add more fuel pieces or use heavier logs to reach the target weight: 7.25--8

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Load total:			

↑↑ Add more fuel pieces or use heavier logs to reach the target weight: 14.50-

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-14.02 lb

3.4 Load 3 - Large pieces

pin 3 (%)	pin 4 (%)	Avg moisture

10.02 lb

3.5 Load 4 - Small pieces

pin 3 (%)	pin 4 (%)	Avg moisture

3.01 lb

3.6 Load 4 - Large pieces

pin 3 (%)	pin 4 (%)	Avg moisture

-16.03 lb

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3.7 Run Information	
Run date:	
Run number:	
Testing staff:	
Witnesses or others present for test:	
Start time:	
End time:	

Temperature:	
Barometric pressure:	
Relative humidity:	

3.9 Ru

Load	Actual weight at start of phase before loading (lb)	Actual weight at start of phase after loading (lb)	Target weight at end of phase (lb)
L1 (Fully Open)			
L2(A) (Fully Open)			
L2(B) (Fully Closed)		Not applicable	
L3 (Fully Closed)			
L4 (Fully Closed)			

3.10 Ru

Load	Start time	End time	Door open time
L1 (Fully Open)			
L2(A) (Fully Open)			
L2(B) (Fully Closed)			
L3 (Fully Closed)			
L4 (Fully Closed)			

Load	
L1 (Fully Open)	
L2(A) (Fully Open)	
L2(B) (Fully Closed)	
L3 (Fully Closed)	
L4 (Fully Closed)	

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Other Testing Information

3.8 Test Lab Condition		
pre-test	post-test	
		F
		in. Hg
		%

n Operation Data
Actual Weight at end of phase (lb)

ın Operation Data
Door closed time

3.11 Run Operation Data
Notes on fuel adjustments/time

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	3.12 Po
1) Any data points with filter temperatures outside the 80-90F?	
If yes, how many and for how long	
2) Did tunnel temperature exceed 40C during the test?	
If yes, how many and for how long	
3) Did tunnel humidity exceed 90%?	
If yes, how many and for how long	
4) Any tunnel dew point measurements within 2C of filter temp	
If yes, how many and for how long	
5) Tunnel flow for test? (dscf/min)	

<< Back

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st Run Data Check

Next >>

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Integra

3.1

	Target load (lb)	Actual weight (lb)	Target # of pieces
L1 - Kindling weight	1.81 – 2.00		13
L1 - Starter	5.44 – 6.01		5
L2 - Small pieces	12.69 – 14.02		5
L3 - Large pieces	9.06 – 10.02		2
L4 - Small pieces	7.25 – 8.01		3
L4 - Large pieces	14.50 – 16.03		3

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Kindling total:			
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Piece 7:			
Piece 8:			
Piece 9:			
Piece 10:			
Load total:			

↑↑ Add more fuel pieces or use heavier logs to reach the target weight: 7.25–8

Allowed weight of each piece: 1.00–1.84 lb

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)

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ted Duty Cycle Fuel Calculator

3.3 Run #3 Details

Detailed Fuel Information

Enter the number of fuel pieces first, then enter the weight and MC details in Tables 3.2 through 3.6 ↓↓

Fuel Load Data	
Actual # of pieces	
	Go to table
	Go to table
	Go to table
	Go to table
	Go to table
	Go to table

3.2 Load 1 - Kindling and starter fuel		
pin 3 (%)	pin 4 (%)	Avg moisture
Not applicable		

3.01 lb

3.3 Load 2 - Small pieces		
pin 3 (%)	pin 4 (%)	Avg moisture

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Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Piece 7:			
Piece 8:			
Piece 9:			
Piece 10:			
Load total:			

↑↑ Add more fuel pieces or use heavier logs to reach the target weight: 12.69-

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Load total:			

↑↑ Add more fuel pieces or use heavier logs to reach the target weight: 9.06--

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Load total:			

↑↑ Add more fuel pieces or use heavier logs to reach the target weight: 7.25--8

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Load total:			

↑↑ Add more fuel pieces or use heavier logs to reach the target weight: 14.50-

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-14.02 lb

3.4 Load 3 - Large pieces

pin 3 (%)	pin 4 (%)	Avg moisture

10.02 lb

3.5 Load 4 - Small pieces

pin 3 (%)	pin 4 (%)	Avg moisture

3.01 lb

3.6 Load 4 - Large pieces

pin 3 (%)	pin 4 (%)	Avg moisture

-16.03 lb

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3.7 Run Information	
Run date:	
Run number:	
Testing staff:	
Witnesses or others present for test:	
Start time:	
End time:	

Temperature:	
Barometric pressure:	
Relative humidity:	

3.9 Ru

Load	Actual weight at start of phase before loading (lb)	Actual weight at start of phase after loading (lb)	Target weight at end of phase (lb)
L1 (Fully Open)			
L2(A) (Fully Open)			
L2(B) (Fully Closed)		Not applicable	
L3 (Fully Closed)			
L4 (Fully Closed)			

3.10 Ru

Load	Start time	End time	Door open time
L1 (Fully Open)			
L2(A) (Fully Open)			
L2(B) (Fully Closed)			
L3 (Fully Closed)			
L4 (Fully Closed)			

Load	
L1 (Fully Open)	
L2(A) (Fully Open)	
L2(B) (Fully Closed)	
L3 (Fully Closed)	
L4 (Fully Closed)	

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Other Testing Information

3.8 Test Lab Condition		
pre-test	post-test	
		F
		in. Hg
		%

n Operation Data
Actual Weight at end of phase (lb)

ın Operation Data
Door closed time

3.11 Run Operation Data
Notes on fuel adjustments/time

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	3.12 Po
1) Any data points with filter temperatures outside the 80-90F?	
If yes, how many and for how long	
2) Did tunnel temperature exceed 40C during the test?	
If yes, how many and for how long	
3) Did tunnel humidity exceed 90%?	
If yes, how many and for how long	
4) Any tunnel dew point measurements within 2C of filter temp	
If yes, how many and for how long	
5) Tunnel flow for test? (dscf/min)	

<< Back

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st Run Data Check

Next >>

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Integra

3.1

	Target load (lb)	Actual weight (lb)	Target # of pieces
L1 - Kindling weight	1.81 – 2.00		13
L1 - Starter	5.44 – 6.01		5
L2 - Small pieces	12.69 – 14.02		5
L3 - Large pieces	9.06 – 10.02		2
L4 - Small pieces	7.25 – 8.01		3
L4 - Large pieces	14.50 – 16.03		3

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Kindling total:			
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Piece 7:			
Piece 8:			
Piece 9:			
Piece 10:			
Load total:			

↑↑ Add more fuel pieces or use heavier logs to reach the target weight: 7.25–8

Allowed weight of each piece: 1.00–1.84 lb

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)

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ted Duty Cycle Fuel Calculator

3.4 Run #4 Details

Detailed Fuel Information

Enter the number of fuel pieces first, then enter the weight and MC details in Tables 3.2 through 3.6 ↓↓

Fuel Load Data	
Actual # of pieces	
	Go to table
	Go to table
	Go to table
	Go to table
	Go to table
	Go to table

3.2 Load 1 - Kindling and starter fuel		
pin 3 (%)	pin 4 (%)	Avg moisture
Not applicable		

3.01 lb

3.3 Load 2 - Small pieces		
pin 3 (%)	pin 4 (%)	Avg moisture

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Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Piece 7:			
Piece 8:			
Piece 9:			
Piece 10:			
Load total:			

↑↑ Add more fuel pieces or use heavier logs to reach the target weight: 12.69-

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Load total:			

↑↑ Add more fuel pieces or use heavier logs to reach the target weight: 9.06--

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Load total:			

↑↑ Add more fuel pieces or use heavier logs to reach the target weight: 7.25--8

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Load total:			

↑↑ Add more fuel pieces or use heavier logs to reach the target weight: 14.50-

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-14.02 lb

3.4 Load 3 - Large pieces

pin 3 (%)	pin 4 (%)	Avg moisture

10.02 lb

3.5 Load 4 - Small pieces

pin 3 (%)	pin 4 (%)	Avg moisture

3.01 lb

3.6 Load 4 - Large pieces

pin 3 (%)	pin 4 (%)	Avg moisture

-16.03 lb

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3.7 Run Information	
Run date:	
Run number:	
Testing staff:	
Witnesses or others present for test:	
Start time:	
End time:	

Temperature:	
Barometric pressure:	
Relative humidity:	

3.9 Ru

Load	Actual weight at start of phase before loading (lb)	Actual weight at start of phase after loading (lb)	Target weight at end of phase (lb)
L1 (Fully Open)			
L2(A) (Fully Open)			
L2(B) (Fully Closed)		Not applicable	
L3 (Fully Closed)			
L4 (Fully Closed)			

3.10 Ru

Load	Start time	End time	Door open time
L1 (Fully Open)			
L2(A) (Fully Open)			
L2(B) (Fully Closed)			
L3 (Fully Closed)			
L4 (Fully Closed)			

Load	
L1 (Fully Open)	
L2(A) (Fully Open)	
L2(B) (Fully Closed)	
L3 (Fully Closed)	
L4 (Fully Closed)	

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Other Testing Information

3.8 Test Lab Condition		
pre-test	post-test	
		F
		in. Hg
		%

n Operation Data
Actual Weight at end of phase (lb)

ın Operation Data
Door closed time

3.11 Run Operation Data
Notes on fuel adjustments/time

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	3.12 Po
1) Any data points with filter temperatures outside the 80-90F?	
If yes, how many and for how long	
2) Did tunnel temperature exceed 40C during the test?	
If yes, how many and for how long	
3) Did tunnel humidity exceed 90%?	
If yes, how many and for how long	
4) Any tunnel dew point measurements within 2C of filter temp	
If yes, how many and for how long	
5) Tunnel flow for test? (dscf/min)	

<< Back

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st Run Data Check

Next >>

1. The calculated average moisture content for the L1 load isn't correct, in the example below it should be 20%

Detailed Fuel Information

Enter the number of fuel pieces first, then enter the weight and MC details in Tables 3.2 through 3.6 ↓↓

3.1 Fuel Load Data					
	Target load (lb)	Actual weight (lb)	Target # of pieces	Actual # of pieces	
L1 - Kindling weight	1.81 – 2.00	1.84	13	13	Go to table
L1 - Starter	5.44 – 6.01	5.82	5	5	Go to table
L2 - Small pieces	12.69 – 14.02	12.82	5	5	Go to table
L3 - Large pieces	9.06 – 10.02	9.82	2	2	Go to table
L4 - Small pieces	7.25 – 8.01	7.48	3	3	Go to table
L4 - Large pieces	14.50 – 16.03	15.64	3	3	Go to table

3.2 Load 1 - Kindling and starter fuel						
set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)	pin 3 (%)	pin 4 (%)	Avg moisture
Kindling total:	1.84	Not applicable				
Piece 1:	1.12	20.0	20.0	20.0	20.0	20.0
Piece 2:	1.18	20.0	20.0	20.0	20.0	20.0
Piece 3:	1.19	20.0	20.0	20.0	20.0	20.0
Piece 4:	1.23	20.0	20.0	20.0	20.0	20.0
Piece 5:	1.14	20.0	20.0	20.0	20.0	20.0
Piece 6:						
Piece 7:						
Piece 8:						
Piece 9:						
Piece 10:						
Load total:	7.66					15.20

✓ Load weight is in the range

2. The table below is confusing for a couple reasons, and the lack of transparency in this calculator makes it impossible to know what is "right." For starters, the target weight at end of phase L1, we *think* this value is 17.5% of the L2 load weight, but that fact is that it is not plainly stated anywhere in either the fuel load calculator or the IDC method.

   Furthermore, the rest of the weights in that same column are all based on the weights listed in the far-right column, the target weights are based on the coal bed you have built, but the target weight for the end of the L2(A) phase is incorrect. With a 12.82 lb L2 fuel load, the target weight should be 6.41 lbs + 2.24 lbs = 8.65 lbs, yet the table lists a weight of 6.51 lbs, which isn't the correct number under any circumstance, unless we are grossly misunderstanding the method. But if we were to not enter that value in the far-right column, it will generate a red flag.

   Ideally, this table would base target weights on the far-left column, Actual weight at start of phase before loading. This would allow us to perform testing with our preferred SOP, which is taring the scale prior to each fuel load, but it also allows for doing it the way the calculator is currently structured (no scale tares between loads).

3.9 Run Operation Data					
Load	Actual weight at start of phase before loading (lb)	Actual weight at start of phase after loading (lb)	Target weight at end of phase (lb)	Actual Weight at end of phase (lb)	
L1 (Fully Open)	0.00	7.66	2.24	2.24	Allowable range: 2.13–2.36
L2(A) (Fully Open)	2.24	15.06	6.51	6.51	Allowable range: 6.19–6.84
L2(B) (Fully Closed)	6.51	Not applicable	3.52	3.52	Allowable range: 3.35–3.70
L3 (Fully Closed)	3.52	13.34	4.50	4.50	Allowable range: 4.28–4.73
L4 (Fully Closed)	4.50	27.62	6.81	6.81	Allowable range: 6.47–7.15

3. This calculator is so locked down that it is difficult to use for other practical reasons. For example, the average fuel moistures and fuel load weights are needed for other calculations outside of this spreadsheet, but they are contained in cells that do not let you copy the data to paste it into those other spreadsheets. That is very frustrating!

4. With the possible exception of table 3.11, the entire "other testing information" section of the fuel load calculator is, frankly, outside the scope of this calculator. All these additional data points are already captured elsewhere. By necessity, a separate spreadsheet is required to perform all the other calculations required by the method. That other spreadsheet requires and actually uses these values for performing various calculations. Whereas in this document, they are not used for any calculations, it is just requiring redundant documentation.

5. In the table below, item 1) is a reference to an obsolete requirement that should be deleted. Points 2), 3), and 4) are similar in language to the requirements of the IDC (section 10.1.3) but are different enough to be asking for something that is not in line with the actual requirements.

3.12 Post Run Data Check	
1) Any data points with filter temperatures outside the 80-90F?	
If yes, how many and for how long	
2) Did tunnel temperature exceed 40C during the test?	
If yes, how many and for how long	
3) Did tunnel humidity exceed 90%?	
If yes, how many and for how long	
4) Any tunnel dew point measurements within 2C of filter temp	
If yes, how many and for how long	
5) Tunnel flow for test? (dscf/min)	

Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 5/27/2021 1:09:02 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]; Jill Mozier [jmozier@scainc.com]; Nash, Dave [Nash.Dave@epa.gov]; Sebastian Button [sebastian.button@pfsteco.com]; John Steinert [john.steinert@pfsteco.com]
Subject: FW: Teom SOP for posting
Attachments: NYSERDA DRAFT TEOM 1405-Dichot SOP 21-05-25 secured.pdf; NYSERDA DRAFT TEOM 1405-Dichot SOP data template ver 0.9 21-05-25.xlsx

Hi everyone! Attached is the TEOM SOP for EPA's project.

-----Original Message-----
From: George Allen <gallen@nescaum.org>
Sent: Tuesday, May 25, 2021 12:08 PM
To: Lisa Rector <lrector@nescaum.org>
Subject: Teom SOP for docket posting

Attached, secured. If EPA comes back with any requested changes in response to my comment Qs, we can change it. But the big issues discussed today are addressed - minimal QC on between-channel agreement.

Revised Excel data analysis sheet attached also, to reflect minimal QC criteria as discussed on today's call. This is part of the SOP.

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NYSERDA Standard Operation Procedures for Thermo Scientific™ 1405-D TEOM™ for use in a dilution tunnel

DRAFT May 25, 2021

Section 1. Introduction

This document covers operation concepts and procedures for use of the Thermo Scientific model 1405-D TEOM to measure and report continuous particulate matter (PM) concentration measurements in an EPA Method 5G dilution tunnel or equivalent dilution method. The TEOM is designed for ambient real-time PM measurements, and is an inertial microbalance - a true continuous mass measurement method with resolution of 0.01 µg (0.00001 mg). The TEOM is highly configurable, allowing the instrument to be configured to best meet the needs of a specific application.

The version of the TEOM used here for measurement of PM in the dilution tunnel is the "Dichotomous" (Dichot) 2-channel configuration (custom configuration, 1405D Base unit without Accessories), without any inlet hardware, virtual impactor, flow splitter, pump, T/RH sensor, or sample conditioning options such as "FDMS". For this application, the TEOM flows, temperatures, and timing settings are changed from the normal ambient settings to allow for fast filter changes with minimal data loss (typically four to five minutes). The second ("PM-coarse") TEOM channel is used as a co-located PM measurement for quality control purposes, similar to the paired filter train in ASTM-2515. Configuration settings are the same for each channel. There are no hardware modifications needed. Instrument manuals, Microsoft Windows instrument software, and related support information are available from the Thermo web site.[1] Technical support is available during eastern time business hours by calling the main Thermo Scientific number: 866 282 0430.

Note: This procedure requires that dilution tunnel flows be at least 600 cfm to avoid condensation of water vapor in the sampling system.

Instrument Software

Thermo provides two Microsoft Windows programs for the TEOM that can be obtained from the 1405 web page. "RPComm" (the serial port interface program) can be used to display the last 15 minutes of data on a graph, download data, and quickly read all key operating parameters during a test run. It is also used to document the instrument settings. "ePort" (the ethernet interface program) is used to control the instrument remotely and to download data. Both programs can

[1]The TEOM manual, revision of 15Feb2008, is referenced in this SOP, and is available here: https://www.thermofisher.com/order/catalog/product/TEOM1405D

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be used at the same time. Instrument control and data can be accessed remotely using any program that provides remote PC access.

Instrument Installation.
The TEOM must be positioned close to the dilution tunnel sample port location. The length of the sample lines from the tunnel wall to the TEOM inlets must be no more than 18 inches. Consistent with ASTM-2515, samples are taken no more than 1 inch from the tunnel center line, and there must be at least 1 inch distance between the two sample line ends. Sample tubing must be conductive (either metal or conductive flexible tubing) with ¼" ID. A short piece of ¼" OD x 3/16" ID metal tubing must be used for insertion into the tunnel. All of the inlet tubing must be replaced or solvent-cleaned after every series of tests.

The laboratory temperature at the location of the TEOM must be kept sufficiently cool enough to keep the instrument's Case temperature reading from exceeding 0.1° C of the setpoint. This requires that the laboratory temperature at the TEOM be at least 1° and ideally 1.5 to 2° C lower than the Case temperature setpoint.

The TEOM does NOT have any clear visual warning that the filter needs changing due to loading. The TEOM digital outputs (relay contact closures, page 3-31 of the TEOM manual) must be used to trigger an external audible alarm at 115% filter loading, as shown in the alarm configuration instructions at the end of this SOP.

<u>Supplies and Parts needed for this test method:</u>
1405D Dual TEOM Base unit without Accessories, Thermo p/n tbdxxx
1405 Single TEOM Base unit without Accessories, Thermo p/n tbdxxx
Teom filters, 6 to 8 per test, ordered from Thermo, p/n 57-007225-0020 (box of 20 filters)
Black sample filter change tool, Thermo, p/n 55-002013-0001
Mass transducer calibration kit, Thermo p/n 59-008298 and 1 refill, p/n 59-008299
TEOM sample tube brush, Thermo p/n 30-002227
Particle filter for zero-air tests and transducer calibration
Vacuum pump for 5 lpm at 20" vacuum (connects to TEOMs with 3/8" plastic tubing)
3/8" or 1/4" conductive inlet tubing (metal or conductive plastic[2])
(2) 1/2" to 3/8" swage SS reducing union for inlet tubing
NIST-traceable flowmeter for 0.9 to 3.3 lpm at 20 C and 1 Atm, accuracy of 2% or better.
Windows PC for RPComm (needs a USB to serial port adaptor) and EPort (ethernet connection)
Filter change alarm parts: a DB25 male breakout connector, alarm, and alarm power supply

Lab air PM is also measured with a TEOM without any particle size cut, with the inlet of the probe located within 10 feet of the bottom of the tunnel's hood and an inlet line using conductive tubing of at least ¼" ID and no longer than 5 feet. This TEOM can be a single channel TEOM (1405). It can use the same pump as the dilution tunnel TEOM, and is configured the same way except for the following settings to increase sensitivity:

Inlet flow = 3 lpm

[2]Available from Freelin-Wade, Static Dissipative 90A Plastic Tubing - 90A-452, p/n 1J-452-90-01

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MRMC and MassAVG times set to 120 seconds

The filter for the lab air TEOM must be changed before the start of a series of test runs or when filter loading exceeds 80% before the start of a test day. All other operating parameters and procedures are the same as for the dilution tunnel dichot TEOM. Lab air PM concentrations are subtracted from tunnel PM concentrations before any other calculations are performed.

Section 2. Routine Operation Procedures for Thermo 1405-D TEOM

This section is a summary of routine operating procedures.

A. Quality Assurance checks to be completed before and after each set of test runs:

1. Modify system settings as detailed in Section 8 (initial installation only).
2. Perform K0 mass transducer verification checks on both channels as detailed in Section 4 of this procedure.
3. Document the system settings listed below using the Thermo RPComm program to display and save the values to a text file. Instrument time (PRC90) is in Unix Epoch format (seconds since 1/1/70, valid through 2037). This example is at May 14, 2021 1:59:05 PM (instrument clock time, not UTC). TEOMA (left sensor) is PM2.5 and TEOMB (right sensor) is PM-coarse. K0 values are calibration constants specific to each of the two TEOM mass transducers.

PRC	Name	Value
1	serial number	1405A247642010
2	instrument firmware version	1.74
3	instrument model	TEOM 1405-D
4	Instrument model variant	Dichot
28	system wait time	0
35	mass average time	30
74	average temperature set point	20.000000
75	standard temperature set point	25.000000
76	average pressure set point	1.000000
77	standard pressure set point	1.000000
78	volumetric flow control	1
79	mass conc reporting	1
91	bypass flow mass set point	0.000000
259	TEOMA K0	15317.000000
343	TEOMB K0	17551.000000
390	instrument time	1621000745
392	MRMC average time	30
407	TEOMA mass constant A	0.000000
408	TEOMA mass constant B	1.000000
409	TEOMB mass constant A	0.000000
410	TEOMB mass constant B	1.000000

Other key instrument operating parameters are always recorded in the data file and thus are not listed here.

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B. Routine procedures before every test run to be conducted 1-2 hours prior to testing.

1. Check the TEOM time and set as needed to be within 5 seconds of laboratory time. Changing the time causes an instrument reboot and loss of up to an hour of data. See notes section below. Verify that the 1-minute data records are being recorded with time-stamps within 5 seconds of the top of the minute. If they are not, reboot the instrument and re-check after the top of the next hour.

2. Before installing new filters, perform a leak test and flow check on both TEOM channels using the procedures in section 3 of the SOP. The leak test net results shall be no greater than 0.05 lpm. The flow checks must be performed with a traceable calibration standard. If either measured flow is greater than 2% different than the reported flow, a flow calibration shall be performed using the procedures in section 3.

3. Initial filter change.
Install a clean filter for each channel before each run and put 2 clean filters on the storage pins inside the sensor. See section 5 for the filter change procedure, including confirmation of proper operation after the filter change.

4. Lab-air TEOM
Verify that the lab-air 1405 TEOM is operating properly and that the filter loading is less than 80%. Change the filter if needed to ensure it does not overload during the test run.

C. Operation During Testing

1. Before initiating the test, run the TEOM while sampling dilution tunnel air (with tunnel flow) for at least 10 minutes. The change of pressure in the tunnel can cause a large transient TEOM response which would invalidate the data for several minutes.

2. TEOM filter changes during a test run must be done when any of the following conditions are met, using the "Advanced" filter change mode and the procedure in Section 5. Filters for both channels must always be changed at the same time.

   a. Near the end of burn phases 2 and 3, when 80% of the fuel charge has been burned. This is sufficiently in advance of loading the next fuel charge to allow the TEOM to stabilize after completion of the filter change procedure, and ensures that valid data are available when the next fuel charge is loaded.
   b. Percent loading reaches 115% for <u>either</u> TEOM channel
   c. When the sample flow drops more than 5% of the flow setpoint for either channel.

   (b) will not normally trigger a filter change on a low-emitting device, and (c) should never occur without (b) unless there is a problem with the pump. Note that filter "plugging" does not end the test run – it triggers a filter change and the run continues.

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Proper operation of the TEOM must always be confirmed after a filter change as detailed in the section 5 filter change procedure.

Note that if the flow starts to drop from the setpoint before 115% is reached, that is an indication of a vacuum pump problem. Vacuum is usually between 0.25 and 0.35 atm as read on the "System Status" TEOM display screen. If it exceeds 0.40 atm, the pump must be serviced.

Detailed information on performing filter changes during testing is provided in Section 5 of this document.

3. At the end of the test, perform external leak and flow checks on both channels as detailed in Section 3 and record the results. For valid results, leak checks shall be no more than 0.05 lpm, and flow checks shall be within 2.0 % of the TEOM flow reading.

4. Download the test data using either the Thermo ePort software (preferred), RPComm, or to a USB thumb drive. Note: the data format may be different depending on how the data are downloaded; the TEOM data template is based on downloading data using the ePort software.

Notes:

- The instrument "Status" code is not normally used for data validation. If the ambient T/RH sensors are not used, a status code of 8 will be present. Other than status codes of 134,217,728 (TeomA) and 524,288 (TeomB) when the % loading is greater than 90%, 8 (for the ambient T/RH sensor) is normally the only allowable "warning" status once the system is operational and running properly. The "8" status will cause the warning triangle on the TEOM display to show all the time.

- When the TEOM is first turned on or rebooted, no data are recorded until the top of the next hour. Other than after a reboot, data will be recorded even when no concentration data is displayed on the screen.

- **After EVERY instrument power on or Reboot:** confirm data are being recorded after the top of the hour. Occasionally the TEOM doesn't store any data after a reboot, even though all operational parameters are normal and concentrations are reported to RPComm and the TEOM display. If this occurs, Stop and Start the instrument to start data storage. A filter change using the Wizard is a Stop and Start cycle.

- When the time is changed, the instrument reboots (after many seconds of being hung, with no information on the screen). When it reboots, no data are recorded until after the top of the next hour (see above).

- TEOM PM concentrations are in micrograms per cubic meter, at EPA STP (20.0C and 1.00 atmosphere) with the instrument configuration used in this procedure. Filter mass loading is reported in micrograms, with a resolution of 0.01 micrograms (10^{-8} grams).

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Section 3. Leak and Flow Checks and Flow Calibration for the 1405-D TEOM

A traceable flow standard capable of displaying flow at standard conditions of 20.0 C and 1.00 atm shall be used for all flow checks and flow calibrations. Facing the front of the TEOM, the left channel is PM2.5 (TeomA) and the right channel is PM-coarse (TeomB).

Leak Checks

A leak test measures the net flow as reported by the TEOM's flow sensors with no flow. Leak checks shall be done for both channels before the start and after the end of every test run. The TEOM leak test flow readings must be corrected for the TEOM flowmeter's zero offsets. To conduct a flow check, follow the procedures below for each channel:

1. With the TEOM warmed up for at least 30 minutes, read the TEOM reported flow for both channels with the pump turned off or with the TEOM in Stop mode. This is the flowmeter zero reading.
2. Close off the inlets to the TEOM sample train.
3. Turn on the TEOM pump, or set the TEOM to Run mode.
4. Wait one minute and read the flows reported by the TEOM.
5. The leak test values are the difference between the reading without and with flow.
6. The leak tests must be no greater than 0.05 lpm (net value).
7. Open the inlet to the TEOM sample train.

Flow Checks.

The TEOM sample flows for each channel shall be set to 1.00 lpm (at 20.0 C and 1.00 atm). The TEOM must be warmed up for at least 30 minutes before checking or adjusting the sample flows. The sample flows must be measured at the sample train inlet with an external NIST-traceable flow meter that reads in STP (20.0 C and 1.00 atm); measured flows must be within 2.0 % of the flow as indicated on the TEOM display for each of the two channels.

Flow Calibrations.

Flows must be calibrated for each channel with a NIST-traceable flowmeter that reads STP flow at 20.0 C and 1.00 Atm, using the TEOM wizard at Service, Calibration, Flow Calibration (page 5-41 of the Dichot TEOM manual); select "Direct Flow Device" (not FTS). A Flow Check shall be performed immediately after every flow calibration.

Flow Troubleshooting.

When a flow calibration fails, use RPComm to report the "flow offset" and "flow span" parameters [PRC 228, 229 for TeomA, and PRC 312, 313 for TeomB]. If they are not close to 0 and 1 respectively, reset the instrument's flow calibration to 0 and 1 by doing a flow cal routine but just hit "next" without entering any flows. Once that is reset, perform a normal flow calibration and then record the new offset and span parameters.

NOTE: In buildings where heavy electrical equipment is operated, the actual TEOM flows might be unstable even though the reported flow appears to be stable. This can cause erratic and poor

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agreement in the PM between the two TEOM channels. For that reason it is recommended to use a constant voltage power supply for this instrument rather than a direct 120VAC wall outlet.

Section 4. TEOM Mass Transducer K0 Check Procedure for the 1405-D TEOM

The mass transducer K0 (calibration factor) checks described here must be done before and after each set of test runs for both TEOM channels.

K0 Checks

K0 checks confirm the calibration factor for the tapered element mass transducer in use by the TEOM by weighing a clean TEOM calibration filter of known mass (nominally 0.09 grams) as supplied by Thermo. To prevent contamination of calibration filters, the red filter change tool must only be used with calibration filters, and the black filter change tool must never be used with the calibration filters

K0 verifications must be done before and after every set of test runs using the K0 Wizard. See page 5-53 of the Dichot TEOM manual. Verify that the K0 values in use by the instrument are the same as the values on the mass transducer sticker, and document the serial number of the mass transducer. The PM2.5 K0 is on the left, and the PM-coarse K0 is on the right. The transducer serial number is on the far right in the example below; the last four digits are the YYMM of manufacturer. If either of the K0 values in use are different than the original values, the date of calibration and the new values must be recorded.

Record the calibration filter ID, the calibration date, and the average mass value. Document K0 checks with an ePort screenshot of the result as shown below. If results are greater than 2% different from the values currently being used by the TEOM, or if the difference between the two channels is greater than 2%, repeat the check. If repeated checks fail either of these criteria, repeat the check with a second calibration filter. If the difference persists, the K0 values in the instrument may need to be changed from the manufacturer's value supplied with the instrument, but this must not be done without clear and robust evidence such as multiple calibrations with multiple filters that the K0 value is out of tolerance. The new values must be documented and stored with the instrument for future reference.

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K0 Verification Results

The K0 Verification Wizard has completed successfully. The instrument will be put in Run mode when this wizard is finished.

PM-2.5 (left) TEOM:
K0: 14523.0 Audit K0: 14592.7
Percent difference: 0.48
Initial frequency: 344.8019
Final frequency: 248.6712

PM-Coarse (right) TEOM:
K0: 15825.0 Audit K0: 15871.9
Percent difference: 0.30
Initial frequency: 364.9166
Final frequency: 260.5874

Section 5. Filter Change Procedure for the 1405-D TEOM

The TEOM measures the pressure drop across the filter as % of maximum (115 %), and is shown on the instrument display screen. A clean filter has a loading of about 5 % at 1.00 lpm. Filter lifetime will vary widely depending on the PM concentrations and nature of the smoke being sampled. Under typical sampling conditions, lifetime is an hour or more with concentrations in the 20 to 50 mg/m^3 range, but at very high PM concentrations (several hundred mg/m^3), filter lifetime may be less than 30 minutes. With care, filter changes can be done such that only a few minutes of data are lost. A video showing the TEOM filter change procedure is on the Thermo TEOM web page. This video does not use the "Advanced User Mode" that is required by this SOP, but is useful for training purposes. The Dichot TEOM manual has illustrated procedures for filter changes starting on page 5-6.

Note: Both TEOM filters must always be changed at the same time, even if only one channel triggers a filter change event.

Filter change procedure.

The following are filter handling procedures that shall be followed:

A. Unused clean filters must be stored in the original box and plastic bag, with the silica gel desiccant in the bag.
B. Two clean filters must be stored in the mass transducer on the posts provided.
C. Filters must only be handled with the black filter change tool.

Minimize the time the mass transducer is open to reduce the time needed to re-stabilize temperatures after the filter change.

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1. The filter change menu can be located by choosing Service, Maintenance, Replace Filter. Select the "Advanced" option, and then Next to proceed. This turns off the oscillating element which makes filter seating easier.

2. Open the TEOM cabinet door, open the box of clean filters, and open the mass transducer. Remove the old filters by sliding the filter tool onto the filter and pulling straight out. Do not twist the tool (to prevent damage to the glass tapered element).

3. For each channel, pick up a new filter that has been stored inside the mass transducer with the tool. Position it directly over the tapered element and push the filter on gently. Once the filter is on, remove the tool from the filter and fully seat the filter by pushing firmly straight down on the filter with the bottom of the tool with approximately 1 pound of force for at least two seconds (see the TEOM manual and video for more information). The filter should have a small amount of horizontal play when this is done; if not, the filter may be wedged between the tapered element and the side of the opening for the element. Store two new filters in the mass transducer (this equilibrates them to the sensor temperature).

4. Close the mass transducer, replace the filter box cover, and close the cabinet door. Restart the TEOM by completing the filter change wizard with Next, Finish. The TEOM is not restarted until the Wizard is closed with "Finish", and the Maintenance screen is shown.

5. Proper operation of the TEOM must always be confirmed after a filter change. For the PM2.5 channel, the RPComm PM plot can be used; there must not be excessive noise or large and erratic negative data. The TEOM's PM2.5 and PM-Coarse display (PM-10 is not used) as shown below is used to verify proper operation for both channels as follows.

<u>1-minute</u> after the filter change is completed:
a. Frequencies for both channels must be greater than 200 Hz.

<u>5-minutes</u> after the filter change:
b. Filter mass values for both channels must be similar and not any more negative than -1 μg.
c. Noise values for both channels must be small (< 2 ug) or if larger because of high PM concentrations, similar.

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	PM-2.5	PM-Coarse
MC (µg/m³):	0.00	8.66
30-Min MC (µg/m³):	0.00	0.00
1-Hr MC (µg/m³):	0.00	0.00
2-Hour value (µg/m³):	0.00	0.00
12-Hr MC (µg/m³):	0.00	0.00
24-Hr MC (µg/m³):	0.00	0.00
Total mass (µg):	0.07	0.11
Filter loading:	3.68 %	5.51 %
Frequency:	257.9879 Hz	270.8600 Hz
Noise:	0.028 µg	0.129 µg

If the filter change fails, the filter may need to be reseated or is defective, or the sensor latch may not be closed properly. Repeat the filter change "advanced" procedure and take the filter off and re-seat it. Push it on firmly with the back of the filter tool and make sure the sensor is properly closed and latched. If the problem persists after another 5 minutes, restart the procedure with another new filter.

Note: the PM2.5 concentrations on the TEOM display will read 0.0 after a filter change until the top of the next hour. When valid data are being collected, the RPComm graph will indicate the concentrations, and the "Total Mass" on the TEOM display will read something other than "0.00" for both channels.

Section 6: Data Storage and Download

The TEOM shall be set to store data every 60 seconds. There is storage for more than a year of data at this storage interval. Data can be downloaded while the TEOM is running.

Data are usually downloaded with the ePort software, with the "use old column names" option unchecked. If needed, data can also be downloaded to a USB thumb drive or with the RPComm TEOM software. The data file is in .CSV format for importing into a spreadsheet.

The TEOM shall be configured to record data parameters as follows. There is a limit of 20 parameters (not including the Date and Time, which are always recorded). For the lab air TEOM the list is the same but without the PM-Coarse parameters.

0. Date, Time
1. Operating mode
2. PM-2.5 raw MC
3. PM-Coarse raw MC
4. PM-2.5 total mass
5. PM-Coarse total mass

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6. Case temperature
7. Cap temperature
8. PM-2.5 flow rate
9. PM-2.5 air tube temperature
10. PM-2.5 TEOM filter load
11. PM-2.5 TEOM filter pressure
12. PM-2.5 TEOM noise
13. PM-2.5 TEOM frequency
14. PM-Coarse flow rate
15. PM-Coarse air tube temperature
16. PM-Coarse filter load
17. PM-Coarse TEOM noise
18. PM-Coarse TEOM frequency
19. Vacuum pump pressure
20. System status

The key parameters for data validation are:

1. Date and Time – reported as the end of the average interval.
2. Mode – must be 3 or 4 for valid data.
3. PM2.5 raw and PM-Coarse raw Mass Concentration in $\mu g/m^3$. A zero value or a repeating value for Mass Concentration indicates no data. These are always reported even when they are invalid. This minimizes loss of data after a filter change but also requires manual QC of the data file to remove invalid PM concentrations based on review of the data and critical parameters listed below.
4. PM2.5 and PM-Coarse total mass - the mass loading on the TEOM filter in µg since the last instrument reset, filter change, or Stop/Start cycle. A zero value indicates no data.
5. PM2.5 and PM-Coarse flow rate - Flow is lpm at 20.0 C and 1.00 atm.
6. PM2.5 and PM-coarse TEOM filter load - filter loading as % of maximum.
7. Case temperature, in degrees C. Cap and Air Tube temperatures are not used for validation.
8. PM2.5 and PM-coarse "Noise" is a mass transducer stability metric and should normally be less than 0.50 µg when PM concentrations are low or zero.
9. Agreement between the PM2.5 and PM-coarse channel PM concentration data in the data processing spreadsheet template meets QC criteria.

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Section 7. Data Validation and Calculations

TEOM data are recorded every 60 seconds. Data validation and conversion to PM rate (g/h, using actual "wet" tunnel flow) is performed on the 60 second TEOM data. PM rate data are averaged up to longer intervals for reporting use as required. A valid test run must have at least 95% data capture at the 1-minute level.

One-minute TEOM PM concentration data for each channel (and for the lab air TEOM) are valid only when all of the following parameters are met:

1. Flow reported by the instrument is within 5% of the flow setpoint (between 0.950 and 1.050 lpm)
2. Operating mode (not system status): 3 or 4
3. Noise: 3-minute running average of (100 x noise / concentration) is < 0.10
4. Case temperature: +/- 0.10 C of setpoint (32.90 to 33.10 C)
5. Concentration is not 0.00
6. Total Mass for is not 0.00
7. Concentration is different from the preceding interval.
8. Lab air PM data are available and valid.

Items 5, 6, and 7 are usually covered by item 2 (Mode) but there can be cases such as a failed filter change where mode indicates valid data but some of these parameters indicate invalid data.

When a filter change is done during a test run, the TEOM data may skip a time interval. The time sequence during a filter change must be examined using the data processing spreadsheet and corrected if needed.

Since the "wait time" is set to 0 to minimize data loss during a filter change, the TEOM never invalidates any data. Thus the data must always be reviewed and validated manually using the criteria above and the data processing spreadsheet. 1-minute intervals during the test run that do not have valid data are represented using empty spreadsheet cells for those intervals. Any longer interval calculated from the 1-minute data (such as a burn-phase) must have 75% of the possible 1-minute values. Example: a 20-minute interval must have at least 15 minutes of valid data to be valid.

Note that negative TEOM PM concentration data are considered valid data. This can occur when there is substantial mass on the TEOM filter and the burn cleans up. The filter can lose mass when this occurs, and that results in negative PM being reported.

The output of the TEOM is PM concentration in $\mu g/m^3$ at 20.0 C and 1.00 Atmosphere (29.92 inches Hg) pressure. The TEOM flow is "wet" e.g., not dried. The tunnel flow used to convert PM concentration into PM emission rate must also be "wet", without any water vapor correction.

Run validation parameters.

The Excel dichot TEOM data template calculates the following parameters for the entire run from the PM concentration data for the two channels. These values must meet these criteria for TEOM data from a run to be valid, and assume the dilution tunnel is well-mixed.

%D of run-average PM: no more than 7.5%

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Calculations.

The final product of this SOP is valid 1-minute TEOM PM concentrations using the average of both channels and with lab air PM subtracted. An Excel spreadsheet data template is provided to facilitate TEOM PM concentration calculations and TEOM data validation steps described in this section.

The 1405-D TEOM does not report the actual PM-coarse channel (TeomB) concentration because it is designed for use with a dichotomous sampler virtual impactor inlet system. The PM concentrations for the PM-Coarse channel must be calculated as follows:

PM-Coarse raw MC * (16.67/PM-Coarse flow).

For 1.00 lpm flow, the calculation is:

PM-Coarse channel ($\mu g/m^3$) = 16.67 * PM-Coarse raw MC.

The PM2.5 TEOM channel does not need any additional calculations.

Conversion to PM emission rates and other reporting metrics require data generated from other sources (wet STP tunnel flows, stove scale weights, and heat output data).

The final 1-minute TEOM PM concentrations are converted into grams/hour using the wet STP tunnel flow as follows:

g/h = 0.000001699 * (tunnel flow in wet CFM) * (net PM concentration in $\mu g/m^3$)

The values used for tunnel flow must be the actual (wet) measured values, at intervals of no greater than 10 minutes, except as follows. If the range of 10 minute tunnel flow measurements (100*(Max - Min) / average) is no greater than 5.0% of the run-average tunnel flow, the run average tunnel flow can be used for these calculations. Note that proportionality of TEOM flow to tunnel flows does not need to be maintained since emission rate data are calculated on a 1-minute basis rather than on a run-average basis, and then averaged up to the time period of interest.

For calculation of lbs/mmBtu or grams/kg, total grams PM emitted is calculated by multiplying the average g/h rate for the test period of interest times the duration (in hours) of that test period. Grams are converted to lbs by dividing grams by 453.6. Heat output calculations are in the main IDC protocol.

Section 8: TEOM Configuration Changes for Fast Response and High PM Concentrations, and List of TEOM Parameter Configuration Values.

These settings are for the 1405-D TEOM as used in this application that are different from instrument default settings. See the 1405-D manual for detailed information on how to change these values. Settings that are different for the lab air TEOM are noted in steps 2 and 3.

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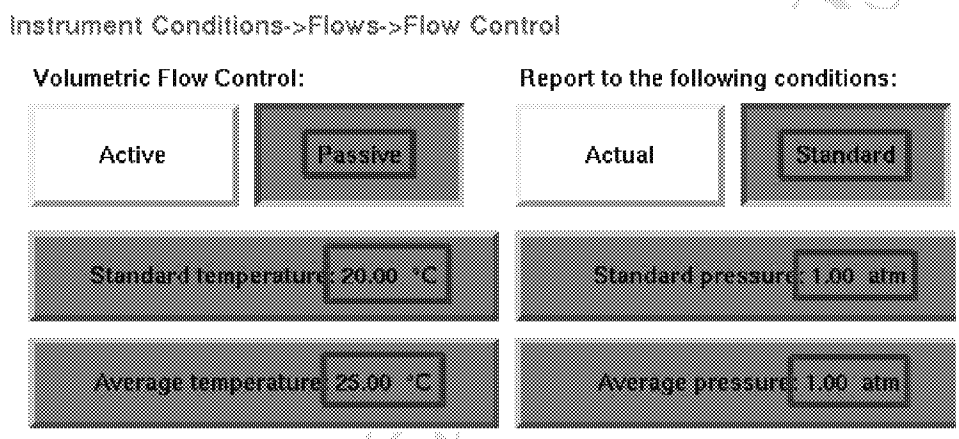
1. For both channels (TEOMA and TEOMB), confirm that all of the "Mass Constants" A and B factors are set as follows: The 3 "Mass Constant A" values are set to 0.0, and the 3 "Mass Constant B" values are set to 1.00.

2. Change system signal filtering and wait time settings:
Mass Avg time from 750 to 30 seconds (120 for lab air TEOM)
MR-MC (Mass Rate/Mass Conc) Avg time from 750 to 30 seconds (120 for lab air TEOM)
System Wait Time from 1800 to 0 seconds (disabled)

3. Change the sample flow from 3.00 to 1.00 lpm for the PM2.5 channel (3.00 lpm for lab air TEOM), and from 1.67 to 1.00 lpm for the PM-Coarse channel. Change the bypass flow to 0.00.

4. Change all four temperature zones [Case, Cap, PM2.5 Air, and PM-Coarse Air] to 33 C.

5. Set the Flow Control to Passive, and Reporting conditions to Standard. Change T/P values to 20.0 (Std) and 25 (Avg) C and 1 atm as shown below.



6. Change the Data Storage interval to 60 seconds.

A complete list of 1405-D TEOM Settings that are modified from instrument defaults are shown below. TEOMA is the PM2.5 (left) channel, and TEOMB is the "Coarse PM" (right) channel.

PRC*	Description	Value	Unit	Notes
12	storage interval	60	Sec	
28	system wait time	0	Sec	Always reports data
35	mass average time**	30	Sec	See also PRC392 (MRMC Avg)
48	case T	33.00	°C	
59	cap T	33.00	°C	
74	average T	20.0	°C	For reporting PM at 20 C

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75	standard T	25.0[3]	ºC	For reporting PM at 20 C
76	average P	1.00	ATM	For reporting PM at 29.92 "Hg
77	standard P	1.00	ATM	For reporting PM at 29.92 "Hg
115	TEOMA air tube T	33.00	ºC	
225	TEOMA flow rate**	1.00	lpm	
309	TEOMB flow rate	1.00	lpm	
321	TEOMB air tube T	33.00	ºC	
392	MRMC average time**	30	Sec	See also PRC35 (Mass Avg)
407	TEOMA mass constant A	0.0	µg	Intercept
408	TEOMA mass constant B	1.00		Slope
409	TEOMB mass constant A	0.0	µg	Intercept
410	TEOMB mass constant B	1.00		Slope

* TEOM Program Register Code
** Different for lab air TEOM

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[3] 25C is correct here for data at 20C

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1405-dichot TEOM filter change alarm setup.

This configuration uses the TEOM contact closure ("digital") outputs, and triggers alarms when either Teom channel exceeds the filter loading threshold. The male DB25 connector goes on the TEOM USER I/O connector. See pages 3-31 to 3-33 of the dichot TEOM manual.

Any kind of low voltage alarm can be used, typically a 6 to 12 volt DC alarm. The TEOM interface is only a contact closure - it does not supply any alarm power, so an external alarm power supply must be used.

Parts needed.

1. DB25-male breakout connector, such as Mouser p/n 651-2761622, Phoenix Contact p/n 2761622 https://www.mouser.com/ProductDetail/Phoenix-Contact/2761622/?qs=p6trItWzfMXZ%2FKY9Mkeclg%3D%3D or equivalent. Thermo p/n 102562-00 is a DB25 male connector cable that goes to a DB25 breakout board where you can connect alarm and power wires.

2. A low DC voltage alarm (6 to 24 volts).

3. DC power supply for alarm

Alarm wiring.

DB25 pins 12 and 13 both go to DC power positive
DB25 pin 24 and 25 both go to alarm positive power connection
DC power negative to alarm negative power connection

1405-dichot Teom contact closure alarm config:

Settings->Analog & Digital Outputs->Contact Closure

	Instrument Variable:	Compare Operator:	Compare Value:
#1:	PM-2.5 TEOM filter load	>	115.00
#2:	PM-Coarse TEOM filter load	>	115.00

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Data processing and validation review Excel Template for 1405-D dichot TEOM

The TEOM data file includes PM concentrations and related operational parameters as specified in the TEOM 1405-D SOP. The SOP contains a list of parameter limits used to determine if a 1-minute data record is valid or not. An Excel spreadsheet template is used to format the raw data output from the instrument, to remove invalid data during filter change periods, calculate PM-coarse channel PM concentrations, and to check for missing data records. The resulting 1-minute data are then manually screened to identify any additional problems. The template also generates an assessment of how well the two dichot TEOM channels agree based on 10-minute block average data. This assessment is used to determine if the run data meet specified data quality objectives.

The operator must manually review the spreadsheet data to verify that limits for flow, temperature, and instrument "noise" are met; charts are generated in the template to facilitate this review. The template also generates a "reconstructed" column of time records to facilitate the check for missing data records. The following steps are to be followed for this data review process.

1. Open the dichot tunnel TEOM data file that was downloaded from the instrument in Excel and trim the data rows to remove data before and after the actual test times. Note that the time shown for the Teom time stamp is the END of the 1-minute interval, not the start.

2. Paste the trimmed dichot tunnel TEOM data from Step 1 into the first template spreadsheet tab "Paste raw tunnel data here", including column headers. The TEOM must be configured to save data as specified in the SOP.

3. In the "1405" spreadsheet tab, if the TEOM flows are not 1.0 lpm, enter the flow setpoint flow value in cell C2, the yellow highlighted cell.

4. Verify there are no missing data records by comparing the reconstructed time with the last time reported by the TEOM in column B of the "1405 spreadsheet" tab. Missing data records can occur when the filters are changed, since no data are recorded during a filter change. If there are missing records, note the time, exit the template without saving, and insert a blank line in the original TEOM raw data file as a placeholder for the missing data record. Then copy and paste the TEOM data into the template and repeat review of time records.

5. Review the three time-series plots in the "T, F, & Noise review" tab to verify that these parameters are within the SOP limits.

6. Open the lab-air TEOM data file, remove data rows before and after the actual test run times (time stamp is the END of the minute interval), and copy the data into the lab air TEOM template. Review the data for proper operation (flow and temperatures), removing any invalid PM concentration data such as large negative values. Lab air TEOM data are simpler to validate since there are no filter changes or other interruptions to the instrument operation during the test period, and thus all the data are usually valid.

7. Paste the validated lab-air TEOM 1-minute PM data from column D into column D of the "1-min data and collo analysis" tab.

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The final 1-minute data product is in column E (1-min avg PM) of the "1-min data and collo analysis" tab. This is the average of both dichot TEOM channels with lab air PM subtracted. Results are not shown in column E unless there are valid data for both dichot TEOM channels and for the lab air PM TEOM data.

The dichot TEOM performance for the entire test run is assessed with 10-minute block average data (without lab air PM subtracted). For the test run to be valid, the performance metrics in column V of the "1-min data and collo analysis" tab must meet the criteria specified in the TEOM SOP.

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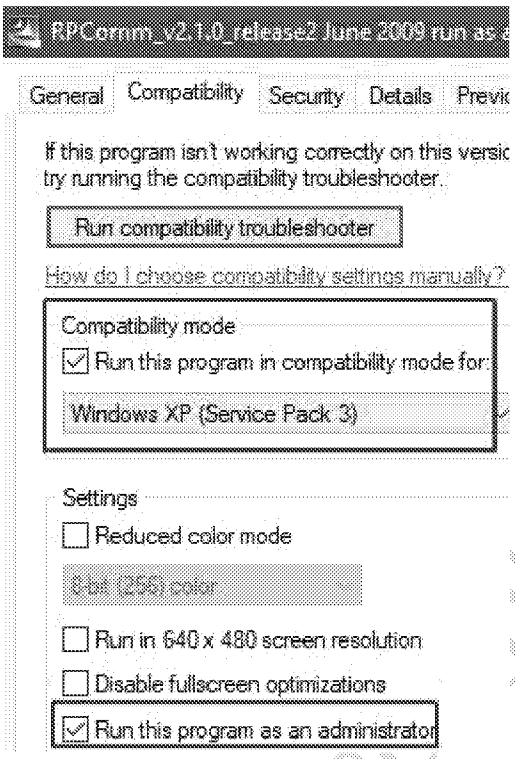
Installation of RPComm on Windows 10

1. The account you install it from must have administrator rights.

2. Right-click on the executable file for the RPComm install program, and on the compatibility tab enable settings for "Compatibility mode" and "Run as administrator". If these 2 compatibility settings are not available as shown in the screenshot below, you may not have administrator rights. RPComm may install and start, but it will crash when you try to use it.



It is recommended to create a Windows restore point or system backup before attempting to install RPComm. Things may go wrong that are not readily recovered from.

After installing but before running RPComm:
RPComm needs a parameter file that matches the firmware version installed on the TEOM. This file is included in the firmware update zip file on the 1405 web page – it is not included in the RPComm install package. Download the firmware file, open it, and copy the "RP14051.74.txt" file [or other RP14051.nn.txt file that matches the firmware version in use] to the location where RPComm is installed, usually "C:\Program Files (x86)\RPComm\" (for 64-bit windows). Then rename that file to remove the ".txt" filename extension to make the filename "RP14051.74".

Note: you must enable file explorer to show file extensions. By default they are hidden for known extensions like ".txt".

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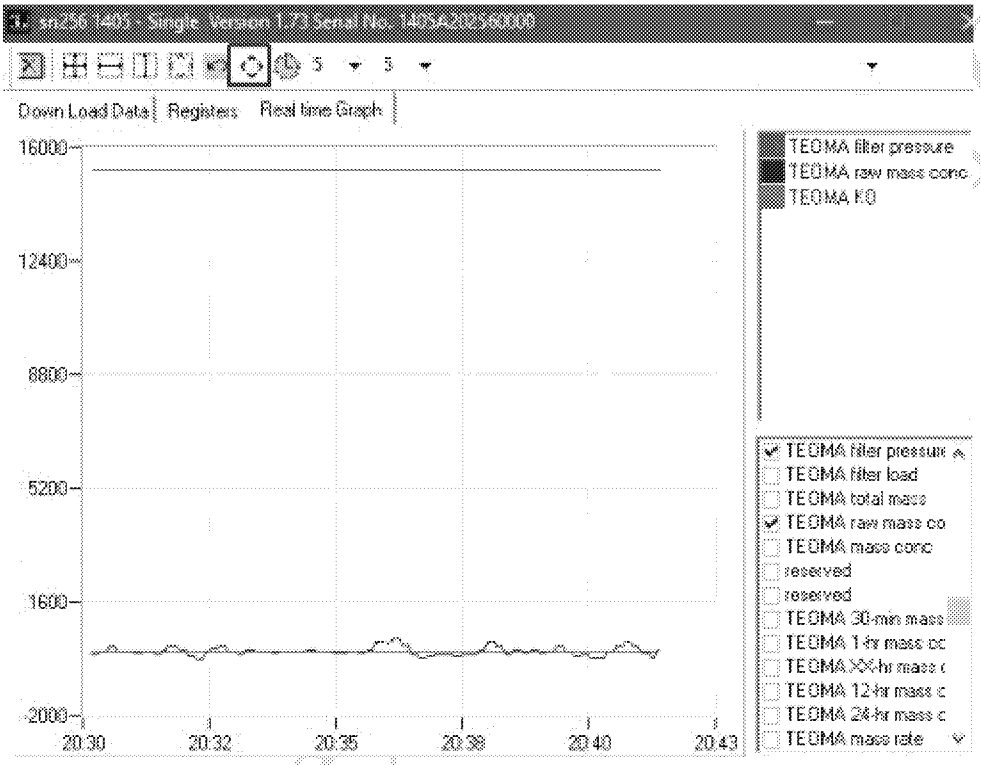
Using RPComm.

Multiple TEOMs can be accessed from a single instance of RPComm. To rename a connection in the main RPComm window, single-click it.

Below are screenshots showing how to use RPComm. These examples are from a single channel Teom.

For the plots, put a 0 [filter P] and a 15k value [K0] to anchor the scale, and the raw mass conc:



The icon circled in red auto-scales it as needed beyond these 2 values. You can also put TEOMB raw mass conc on the plot, but it's 16.7 times too low (at 1 lpm flow).

For the Register tab, set it to list key parameters - this is the only way to get a quick look at everything that matters for proper operation:

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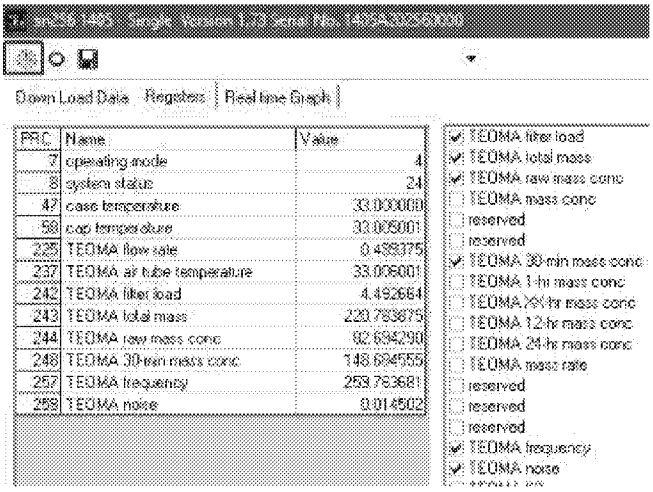

The icon circled in red refreshes the values. There is no auto-refresh in this screen. This is from a single channel Teom.

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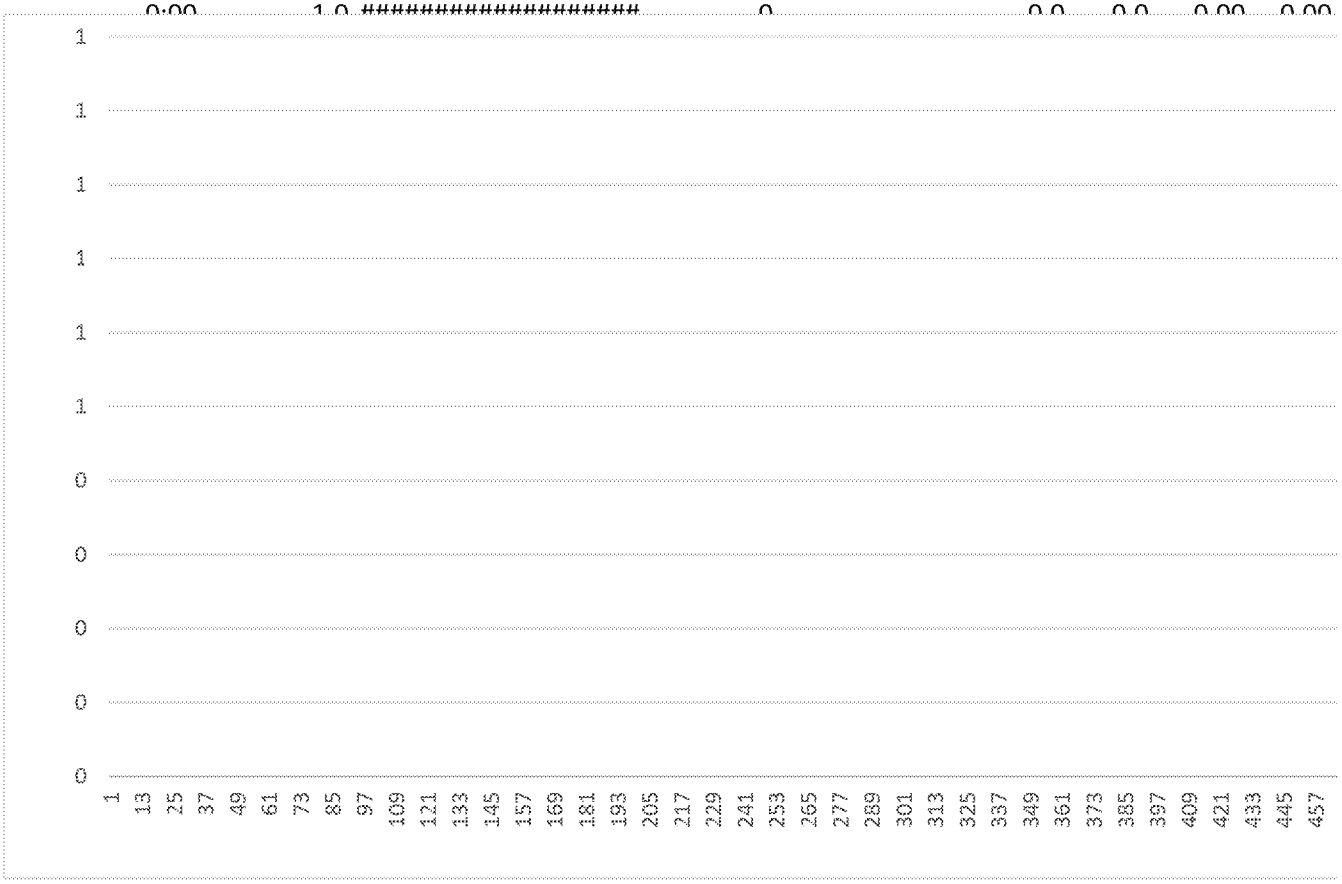
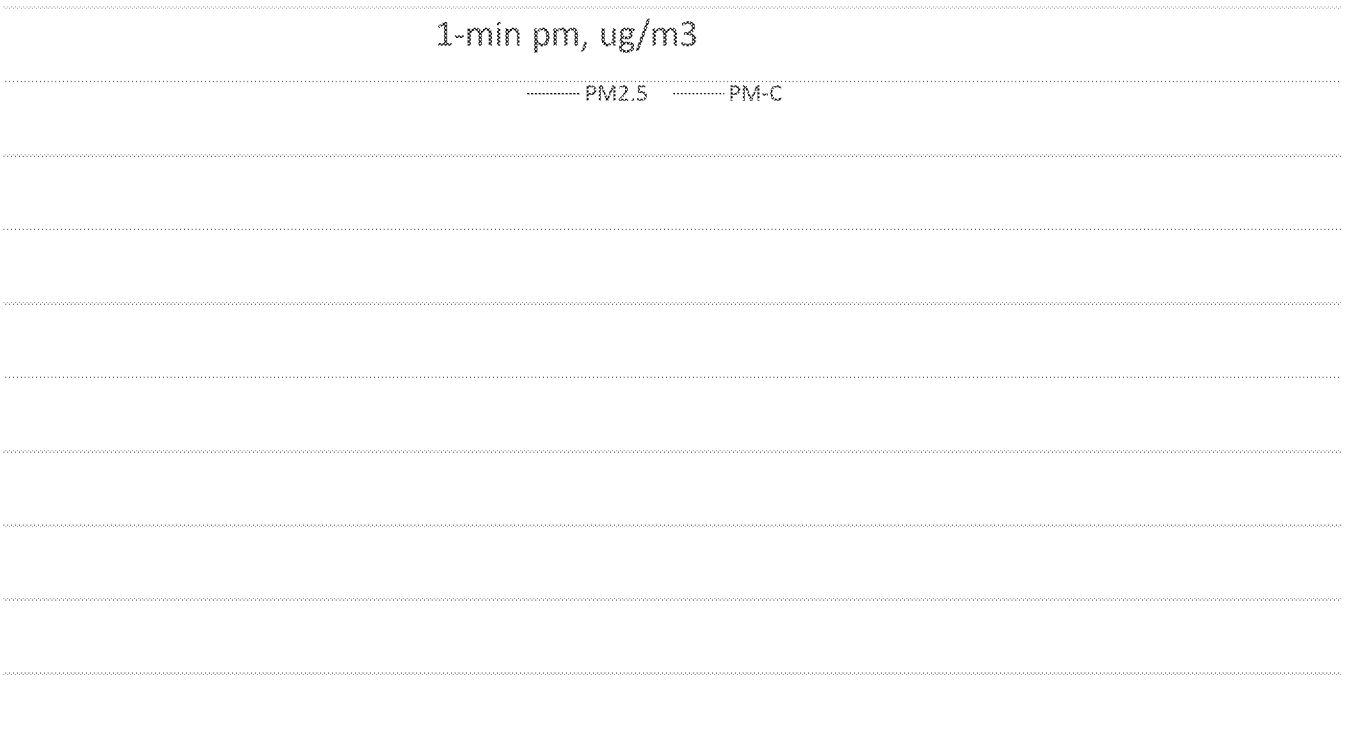
reconstructed time for QC	difference	1405-D s/n: 0 / Coarse channel flow: 1.00 Start time	Op Mode	ug/m3 PM2.5	ug/m3 PM-C	0 ug PM2.5 mass	ug PM-C mass	deg C Case T	deg C Cap T
############	0.0	###################	0			0.0	0.0	0.00	0.00
0:00	1.0	###################	0			0.0	0.0	0.00	0.00



0:23	-24.0	###################	0			0.0	0.0	0.00	0.00
0:24	-25.0	###################	0			0.0	0.0	0.00	0.00
0:25	-26.0	###################	0			0.0	0.0	0.00	0.00
0:26	-27.0	###################	0			0.0	0.0	0.00	0.00
0:27	-28.0	###################	0			0.0	0.0	0.00	0.00
0:28	-29.0	###################	0			0.0	0.0	0.00	0.00
0:29	-30.0	###################	0			0.0	0.0	0.00	0.00
0:30	-31.0	###################	0			0.0	0.0	0.00	0.00
0:31	-32.0	###################	0			0.0	0.0	0.00	0.00
0:32	-33.0	###################	0			0.0	0.0	0.00	0.00
0:33	-34.0	###################	0			0.0	0.0	0.00	0.00
0:34	-35.0	###################	0			0.0	0.0	0.00	0.00
0:35	-36.0	###################	0			0.0	0.0	0.00	0.00
0:36	-37.0	###################	0			0.0	0.0	0.00	0.00
0:37	-38.0	###################	0			0.0	0.0	0.00	0.00
0:38	-39.0	###################	0			0.0	0.0	0.00	0.00
0:39	-40.0	###################	0			0.0	0.0	0.00	0.00
0:40	-41.0	###################	0			0.0	0.0	0.00	0.00
0:41	-42.0	###################	0			0.0	0.0	0.00	0.00
0:42	-43.0	###################	0			0.0	0.0	0.00	0.00

lpm PM2.5 flow	deg C PM2.5 Air T	% PM2.5 load	Atm PM2.5 filter P	ug PM2.5 noise	Hz PM2.5 Freq	lpm PM-C flow	deg C PM-C Air T	% PM-C load	ug PM-C noise	Hz PM-C Freq	Atm Pump Vac	System Status
0.000	0.00	0.0	0	0.00	0.00	0.000	0.00	0.0	0.00	0.00	0.00	0
0.000	0.00	0.0	0		0.00	0.000	0.00	0.0		0.00	0.00	0



0.000	0.00	0.0	0		0.00	0.000	0.00	0.0		0.00	0.00	0
0.000	0.00	0.0	0		0.00	0.000	0.00	0.0		0.00	0.00	0
0.000	0.00	0.0	0		0.00	0.000	0.00	0.0		0.00	0.00	0
0.000	0.00	0.0	0		0.00	0.000	0.00	0.0		0.00	0.00	0
0.000	0.00	0.0	0		0.00	0.000	0.00	0.0		0.00	0.00	0
0.000	0.00	0.0	0		0.00	0.000	0.00	0.0		0.00	0.00	0
0.000	0.00	0.0	0		0.00	0.000	0.00	0.0		0.00	0.00	0
0.000	0.00	0.0	0		0.00	0.000	0.00	0.0		0.00	0.00	0
0.000	0.00	0.0	0		0.00	0.000	0.00	0.0		0.00	0.00	0
0.000	0.00	0.0	0		0.00	0.000	0.00	0.0		0.00	0.00	0
0.000	0.00	0.0	0		0.00	0.000	0.00	0.0		0.00	0.00	0
0.000	0.00	0.0	0		0.00	0.000	0.00	0.0		0.00	0.00	0
0.000	0.00	0.0	0		0.00	0.000	0.00	0.0		0.00	0.00	0
0.000	0.00	0.0	0		0.00	0.000	0.00	0.0		0.00	0.00	0
0.000	0.00	0.0	0		0.00	0.000	0.00	0.0		0.00	0.00	0
0.000	0.00	0.0	0		0.00	0.000	0.00	0.0		0.00	0.00	0
0.000	0.00	0.0	0		0.00	0.000	0.00	0.0		0.00	0.00	0
0.000	0.00	0.0	0		0.00	0.000	0.00	0.0		0.00	0.00	0
0.000	0.00	0.0	0		0.00	0.000	0.00	0.0		0.00	0.00	0
0.000	0.00	0.0	0		0.00	0.000	0.00	0.0		0.00	0.00	0

normalized pm2.5 noise	normalized pm-c noise	3-min avg normalized noise pm2.5 noise	pm-c noise
#VALUE!	#VALUE!		
#VALUE!	#VALUE!	#VALUE!	#VALUE!

973 985 997 1009 1021 1033 1045 1057 1069 1081 1093 1105 1117 1129 1141 1153 1165 1177 1189 1201 1213 1225 1237 1249 1261 1273 1285 1297 1309 1321 1333 1345 1357 1369 1381 1393 1405 1417 1429

#VALUE!	#VALUE!	#VALUE!	#VALUE!
#VALUE!	#VALUE!	#VALUE!	#VALUE!
#VALUE!	#VALUE!	#VALUE!	#VALUE!
#VALUE!	#VALUE!	#VALUE!	#VALUE!
#VALUE!	#VALUE!	#VALUE!	#VALUE!
#VALUE!	#VALUE!	#VALUE!	#VALUE!
#VALUE!	#VALUE!	#VALUE!	#VALUE!
#VALUE!	#VALUE!	#VALUE!	#VALUE!
#VALUE!	#VALUE!	#VALUE!	#VALUE!
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#VALUE!	#VALUE!	#VALUE!	#VALUE!
#VALUE!	#VALUE!	#VALUE!	#VALUE!
#VALUE!	#VALUE!	#VALUE!	#VALUE!
#VALUE!	#VALUE!	#VALUE!	#VALUE!

0:43	-44.0	###################	0	0.0	0.0	0.00	0.00
0:44	-45.0	###################	0	0.0	0.0	0.00	0.00
0:45	-46.0	###################	0	0.0	0.0	0.00	0.00
0:46	-47.0	###################	0	0.0	0.0	0.00	0.00
0:47	-48.0	###################	0	0.0	0.0	0.00	0.00
0:48	-49.0	###################	0	0.0	0.0	0.00	0.00
0:49	-50.0	###################	0	0.0	0.0	0.00	0.00
0:50	-51.0	###################	0	0.0	0.0	0.00	0.00
0:51	-52.0	###################	0	0.0	0.0	0.00	0.00
0:52	-53.0	###################	0	0.0	0.0	0.00	0.00
0:53	-54.0	###################	0	0.0	0.0	0.00	0.00
0:54	-55.0	###################	0	0.0	0.0	0.00	0.00
0:55	-56.0	###################	0	0.0	0.0	0.00	0.00
0:56	-57.0	###################	0	0.0	0.0	0.00	0.00
0:57	-58.0	###################	0	0.0	0.0	0.00	0.00
0:58	-59.0	###################	0	0.0	0.0	0.00	0.00
0:59	-60.0	###################	0	0.0	0.0	0.00	0.00
1:00	-61.0	###################	0	0.0	0.0	0.00	0.00
1:01	-62.0	###################	0	0.0	0.0	0.00	0.00
1:02	-63.0	###################	0	0.0	0.0	0.00	0.00
1:03	-64.0	###################	0	0.0	0.0	0.00	0.00
1:04	-65.0	###################	0	0.0	0.0	0.00	0.00
1:05	-66.0	###################	0	0.0	0.0	0.00	0.00
1:06	-67.0	###################	0	0.0	0.0	0.00	0.00
1:07	-68.0	###################	0	0.0	0.0	0.00	0.00
1:08	-69.0	###################	0	0.0	0.0	0.00	0.00
1:09	-70.0	###################	0	0.0	0.0	0.00	0.00
1:10	-71.0	###################	0	0.0	0.0	0.00	0.00
1:11	-72.0	###################	0	0.0	0.0	0.00	0.00
1:12	-73.0	###################	0	0.0	0.0	0.00	0.00
1:13	-74.0	###################	0	0.0	0.0	0.00	0.00
1:14	-75.0	###################	0	0.0	0.0	0.00	0.00
1:15	-76.0	###################	0	0.0	0.0	0.00	0.00
1:16	-77.0	###################	0	0.0	0.0	0.00	0.00
1:17	-78.0	###################	0	0.0	0.0	0.00	0.00
1:18	-79.1	###################	0	0.0	0.0	0.00	0.00
1:19	-80.1	###################	0	0.0	0.0	0.00	0.00
1:20	-81.1	###################	0	0.0	0.0	0.00	0.00
1:21	-82.1	###################	0	0.0	0.0	0.00	0.00
1:22	-83.1	###################	0	0.0	0.0	0.00	0.00
1:23	-84.1	###################	0	0.0	0.0	0.00	0.00
1:24	-85.1	###################	0	0.0	0.0	0.00	0.00
1:25	-86.1	###################	0	0.0	0.0	0.00	0.00
1:26	-87.1	###################	0	0.0	0.0	0.00	0.00
1:27	-88.1	###################	0	0.0	0.0	0.00	0.00
1:28	-89.1	###################	0	0.0	0.0	0.00	0.00
1:29	-90.1	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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1:30	-91.1	###################	0	0.0	0.0	0.00	0.00
1:31	-92.1	###################	0	0.0	0.0	0.00	0.00
1:32	-93.1	###################	0	0.0	0.0	0.00	0.00
1:33	-94.1	###################	0	0.0	0.0	0.00	0.00
1:34	-95.1	###################	0	0.0	0.0	0.00	0.00
1:35	-96.1	###################	0	0.0	0.0	0.00	0.00
1:36	-97.1	###################	0	0.0	0.0	0.00	0.00
1:37	-98.1	###################	0	0.0	0.0	0.00	0.00
1:38	-99.1	###################	0	0.0	0.0	0.00	0.00
1:39	-100.1	###################	0	0.0	0.0	0.00	0.00
1:40	-101.1	###################	0	0.0	0.0	0.00	0.00
1:41	-102.1	###################	0	0.0	0.0	0.00	0.00
1:42	-103.1	###################	0	0.0	0.0	0.00	0.00
1:43	-104.1	###################	0	0.0	0.0	0.00	0.00
1:44	-105.1	###################	0	0.0	0.0	0.00	0.00
1:45	-106.1	###################	0	0.0	0.0	0.00	0.00
1:46	-107.1	###################	0	0.0	0.0	0.00	0.00
1:47	-108.1	###################	0	0.0	0.0	0.00	0.00
1:48	-109.1	###################	0	0.0	0.0	0.00	0.00
1:49	-110.1	###################	0	0.0	0.0	0.00	0.00
1:50	-111.1	###################	0	0.0	0.0	0.00	0.00
1:51	-112.1	###################	0	0.0	0.0	0.00	0.00
1:52	-113.1	###################	0	0.0	0.0	0.00	0.00
1:53	-114.1	###################	0	0.0	0.0	0.00	0.00
1:54	-115.1	###################	0	0.0	0.0	0.00	0.00
1:55	-116.1	###################	0	0.0	0.0	0.00	0.00
1:56	-117.1	###################	0	0.0	0.0	0.00	0.00
1:57	-118.1	###################	0	0.0	0.0	0.00	0.00
1:58	-119.1	###################	0	0.0	0.0	0.00	0.00
1:59	-120.1	###################	0	0.0	0.0	0.00	0.00
2:00	-121.1	###################	0	0.0	0.0	0.00	0.00
2:01	-122.1	###################	0	0.0	0.0	0.00	0.00
2:02	-123.1	###################	0	0.0	0.0	0.00	0.00
2:03	-124.1	###################	0	0.0	0.0	0.00	0.00
2:04	-125.1	###################	0	0.0	0.0	0.00	0.00
2:05	-126.1	###################	0	0.0	0.0	0.00	0.00
2:06	-127.1	###################	0	0.0	0.0	0.00	0.00
2:07	-128.1	###################	0	0.0	0.0	0.00	0.00
2:08	-129.1	###################	0	0.0	0.0	0.00	0.00
2:09	-130.1	###################	0	0.0	0.0	0.00	0.00
2:10	-131.1	###################	0	0.0	0.0	0.00	0.00
2:11	-132.1	###################	0	0.0	0.0	0.00	0.00
2:12	-133.1	###################	0	0.0	0.0	0.00	0.00
2:13	-134.1	###################	0	0.0	0.0	0.00	0.00
2:14	-135.1	###################	0	0.0	0.0	0.00	0.00
2:15	-136.1	###################	0	0.0	0.0	0.00	0.00
2:16	-137.1	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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2:17	-138.1	###################	0	0.0	0.0	0.00	0.00
2:18	-139.1	###################	0	0.0	0.0	0.00	0.00
2:19	-140.1	###################	0	0.0	0.0	0.00	0.00
2:20	-141.1	###################	0	0.0	0.0	0.00	0.00
2:21	-142.1	###################	0	0.0	0.0	0.00	0.00
2:22	-143.1	###################	0	0.0	0.0	0.00	0.00
2:23	-144.1	###################	0	0.0	0.0	0.00	0.00
2:24	-145.1	###################	0	0.0	0.0	0.00	0.00
2:25	-146.1	###################	0	0.0	0.0	0.00	0.00
2:26	-147.1	###################	0	0.0	0.0	0.00	0.00
2:27	-148.1	###################	0	0.0	0.0	0.00	0.00
2:28	-149.1	###################	0	0.0	0.0	0.00	0.00
2:29	-150.1	###################	0	0.0	0.0	0.00	0.00
2:30	-151.1	###################	0	0.0	0.0	0.00	0.00
2:31	-152.1	###################	0	0.0	0.0	0.00	0.00
2:32	-153.1	###################	0	0.0	0.0	0.00	0.00
2:33	-154.1	###################	0	0.0	0.0	0.00	0.00
2:34	-155.1	###################	0	0.0	0.0	0.00	0.00
2:35	-156.1	###################	0	0.0	0.0	0.00	0.00
2:36	-157.1	###################	0	0.0	0.0	0.00	0.00
2:37	-158.1	###################	0	0.0	0.0	0.00	0.00
2:38	-159.1	###################	0	0.0	0.0	0.00	0.00
2:39	-160.1	###################	0	0.0	0.0	0.00	0.00
2:40	-161.1	###################	0	0.0	0.0	0.00	0.00
2:41	-162.1	###################	0	0.0	0.0	0.00	0.00
2:42	-163.1	###################	0	0.0	0.0	0.00	0.00
2:43	-164.1	###################	0	0.0	0.0	0.00	0.00
2:44	-165.1	###################	0	0.0	0.0	0.00	0.00
2:45	-166.1	###################	0	0.0	0.0	0.00	0.00
2:46	-167.1	###################	0	0.0	0.0	0.00	0.00
2:47	-168.1	###################	0	0.0	0.0	0.00	0.00
2:48	-169.1	###################	0	0.0	0.0	0.00	0.00
2:49	-170.1	###################	0	0.0	0.0	0.00	0.00
2:50	-171.1	###################	0	0.0	0.0	0.00	0.00
2:51	-172.1	###################	0	0.0	0.0	0.00	0.00
2:52	-173.1	###################	0	0.0	0.0	0.00	0.00
2:53	-174.1	###################	0	0.0	0.0	0.00	0.00
2:54	-175.1	###################	0	0.0	0.0	0.00	0.00
2:55	-176.1	###################	0	0.0	0.0	0.00	0.00
2:56	-177.1	###################	0	0.0	0.0	0.00	0.00
2:57	-178.1	###################	0	0.0	0.0	0.00	0.00
2:58	-179.1	###################	0	0.0	0.0	0.00	0.00
2:59	-180.1	###################	0	0.0	0.0	0.00	0.00
3:00	-181.1	###################	0	0.0	0.0	0.00	0.00
3:01	-182.1	###################	0	0.0	0.0	0.00	0.00
3:02	-183.1	###################	0	0.0	0.0	0.00	0.00
3:03	-184.1	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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3:04	-185.1	###################	0	0.0	0.0	0.00	0.00
3:05	-186.1	###################	0	0.0	0.0	0.00	0.00
3:06	-187.1	###################	0	0.0	0.0	0.00	0.00
3:07	-188.1	###################	0	0.0	0.0	0.00	0.00
3:08	-189.1	###################	0	0.0	0.0	0.00	0.00
3:09	-190.1	###################	0	0.0	0.0	0.00	0.00
3:10	-191.1	###################	0	0.0	0.0	0.00	0.00
3:11	-192.1	###################	0	0.0	0.0	0.00	0.00
3:12	-193.1	###################	0	0.0	0.0	0.00	0.00
3:13	-194.1	###################	0	0.0	0.0	0.00	0.00
3:14	-195.1	###################	0	0.0	0.0	0.00	0.00
3:15	-196.1	###################	0	0.0	0.0	0.00	0.00
3:16	-197.1	###################	0	0.0	0.0	0.00	0.00
3:17	-198.1	###################	0	0.0	0.0	0.00	0.00
3:18	-199.1	###################	0	0.0	0.0	0.00	0.00
3:19	-200.1	###################	0	0.0	0.0	0.00	0.00
3:20	-201.1	###################	0	0.0	0.0	0.00	0.00
3:21	-202.1	###################	0	0.0	0.0	0.00	0.00
3:22	-203.1	###################	0	0.0	0.0	0.00	0.00
3:23	-204.1	###################	0	0.0	0.0	0.00	0.00
3:24	-205.1	###################	0	0.0	0.0	0.00	0.00
3:25	-206.1	###################	0	0.0	0.0	0.00	0.00
3:26	-207.1	###################	0	0.0	0.0	0.00	0.00
3:27	-208.1	###################	0	0.0	0.0	0.00	0.00
3:28	-209.1	###################	0	0.0	0.0	0.00	0.00
3:29	-210.1	###################	0	0.0	0.0	0.00	0.00
3:30	-211.1	###################	0	0.0	0.0	0.00	0.00
3:31	-212.1	###################	0	0.0	0.0	0.00	0.00
3:32	-213.1	###################	0	0.0	0.0	0.00	0.00
3:33	-214.1	###################	0	0.0	0.0	0.00	0.00
3:34	-215.1	###################	0	0.0	0.0	0.00	0.00
3:35	-216.1	###################	0	0.0	0.0	0.00	0.00
3:36	-217.1	###################	0	0.0	0.0	0.00	0.00
3:37	-218.1	###################	0	0.0	0.0	0.00	0.00
3:38	-219.1	###################	0	0.0	0.0	0.00	0.00
3:39	-220.1	###################	0	0.0	0.0	0.00	0.00
3:40	-221.1	###################	0	0.0	0.0	0.00	0.00
3:41	-222.1	###################	0	0.0	0.0	0.00	0.00
3:42	-223.1	###################	0	0.0	0.0	0.00	0.00
3:43	-224.1	###################	0	0.0	0.0	0.00	0.00
3:44	-225.1	###################	0	0.0	0.0	0.00	0.00
3:45	-226.1	###################	0	0.0	0.0	0.00	0.00
3:46	-227.1	###################	0	0.0	0.0	0.00	0.00
3:47	-228.1	###################	0	0.0	0.0	0.00	0.00
3:48	-229.1	###################	0	0.0	0.0	0.00	0.00
3:49	-230.1	###################	0	0.0	0.0	0.00	0.00
3:50	-231.1	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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3:51	-232.1	###################	0	0.0	0.0	0.00	0.00
3:52	-233.1	###################	0	0.0	0.0	0.00	0.00
3:53	-234.1	###################	0	0.0	0.0	0.00	0.00
3:54	-235.2	###################	0	0.0	0.0	0.00	0.00
3:55	-236.2	###################	0	0.0	0.0	0.00	0.00
3:56	-237.2	###################	0	0.0	0.0	0.00	0.00
3:57	-238.2	###################	0	0.0	0.0	0.00	0.00
3:58	-239.2	###################	0	0.0	0.0	0.00	0.00
3:59	-240.2	###################	0	0.0	0.0	0.00	0.00
4:00	-241.2	###################	0	0.0	0.0	0.00	0.00
4:01	-242.2	###################	0	0.0	0.0	0.00	0.00
4:02	-243.2	###################	0	0.0	0.0	0.00	0.00
4:03	-244.2	###################	0	0.0	0.0	0.00	0.00
4:04	-245.2	###################	0	0.0	0.0	0.00	0.00
4:05	-246.2	###################	0	0.0	0.0	0.00	0.00
4:06	-247.2	###################	0	0.0	0.0	0.00	0.00
4:07	-248.2	###################	0	0.0	0.0	0.00	0.00
4:08	-249.2	###################	0	0.0	0.0	0.00	0.00
4:09	-250.2	###################	0	0.0	0.0	0.00	0.00
4:10	-251.2	###################	0	0.0	0.0	0.00	0.00
4:11	-252.2	###################	0	0.0	0.0	0.00	0.00
4:12	-253.2	###################	0	0.0	0.0	0.00	0.00
4:13	-254.2	###################	0	0.0	0.0	0.00	0.00
4:14	-255.2	###################	0	0.0	0.0	0.00	0.00
4:15	-256.2	###################	0	0.0	0.0	0.00	0.00
4:16	-257.2	###################	0	0.0	0.0	0.00	0.00
4:17	-258.2	###################	0	0.0	0.0	0.00	0.00
4:18	-259.2	###################	0	0.0	0.0	0.00	0.00
4:19	-260.2	###################	0	0.0	0.0	0.00	0.00
4:20	-261.2	###################	0	0.0	0.0	0.00	0.00
4:21	-262.2	###################	0	0.0	0.0	0.00	0.00
4:22	-263.2	###################	0	0.0	0.0	0.00	0.00
4:23	-264.2	###################	0	0.0	0.0	0.00	0.00
4:24	-265.2	###################	0	0.0	0.0	0.00	0.00
4:25	-266.2	###################	0	0.0	0.0	0.00	0.00
4:26	-267.2	###################	0	0.0	0.0	0.00	0.00
4:27	-268.2	###################	0	0.0	0.0	0.00	0.00
4:28	-269.2	###################	0	0.0	0.0	0.00	0.00
4:29	-270.2	###################	0	0.0	0.0	0.00	0.00
4:30	-271.2	###################	0	0.0	0.0	0.00	0.00
4:31	-272.2	###################	0	0.0	0.0	0.00	0.00
4:32	-273.2	###################	0	0.0	0.0	0.00	0.00
4:33	-274.2	###################	0	0.0	0.0	0.00	0.00
4:34	-275.2	###################	0	0.0	0.0	0.00	0.00
4:35	-276.2	###################	0	0.0	0.0	0.00	0.00
4:36	-277.2	###################	0	0.0	0.0	0.00	0.00
4:37	-278.2	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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4:38	-279.2	###################	0	0.0	0.0	0.00	0.00
4:39	-280.2	###################	0	0.0	0.0	0.00	0.00
4:40	-281.2	###################	0	0.0	0.0	0.00	0.00
4:41	-282.2	###################	0	0.0	0.0	0.00	0.00
4:42	-283.2	###################	0	0.0	0.0	0.00	0.00
4:43	-284.2	###################	0	0.0	0.0	0.00	0.00
4:44	-285.2	###################	0	0.0	0.0	0.00	0.00
4:45	-286.2	###################	0	0.0	0.0	0.00	0.00
4:46	-287.2	###################	0	0.0	0.0	0.00	0.00
4:47	-288.2	###################	0	0.0	0.0	0.00	0.00
4:48	-289.2	###################	0	0.0	0.0	0.00	0.00
4:49	-290.2	###################	0	0.0	0.0	0.00	0.00
4:50	-291.2	###################	0	0.0	0.0	0.00	0.00
4:51	-292.2	###################	0	0.0	0.0	0.00	0.00
4:52	-293.2	###################	0	0.0	0.0	0.00	0.00
4:53	-294.2	###################	0	0.0	0.0	0.00	0.00
4:54	-295.2	###################	0	0.0	0.0	0.00	0.00
4:55	-296.2	###################	0	0.0	0.0	0.00	0.00
4:56	-297.2	###################	0	0.0	0.0	0.00	0.00
4:57	-298.2	###################	0	0.0	0.0	0.00	0.00
4:58	-299.2	###################	0	0.0	0.0	0.00	0.00
4:59	-300.2	###################	0	0.0	0.0	0.00	0.00
5:00	-301.2	###################	0	0.0	0.0	0.00	0.00
5:01	-302.2	###################	0	0.0	0.0	0.00	0.00
5:02	-303.2	###################	0	0.0	0.0	0.00	0.00
5:03	-304.2	###################	0	0.0	0.0	0.00	0.00
5:04	-305.2	###################	0	0.0	0.0	0.00	0.00
5:05	-306.2	###################	0	0.0	0.0	0.00	0.00
5:06	-307.2	###################	0	0.0	0.0	0.00	0.00
5:07	-308.2	###################	0	0.0	0.0	0.00	0.00
5:08	-309.2	###################	0	0.0	0.0	0.00	0.00
5:09	-310.2	###################	0	0.0	0.0	0.00	0.00
5:10	-311.2	###################	0	0.0	0.0	0.00	0.00
5:11	-312.2	###################	0	0.0	0.0	0.00	0.00
5:12	-313.2	###################	0	0.0	0.0	0.00	0.00
5:13	-314.2	###################	0	0.0	0.0	0.00	0.00
5:14	-315.2	###################	0	0.0	0.0	0.00	0.00
5:15	-316.2	###################	0	0.0	0.0	0.00	0.00
5:16	-317.2	###################	0	0.0	0.0	0.00	0.00
5:17	-318.2	###################	0	0.0	0.0	0.00	0.00
5:18	-319.2	###################	0	0.0	0.0	0.00	0.00
5:19	-320.2	###################	0	0.0	0.0	0.00	0.00
5:20	-321.2	###################	0	0.0	0.0	0.00	0.00
5:21	-322.2	###################	0	0.0	0.0	0.00	0.00
5:22	-323.2	###################	0	0.0	0.0	0.00	0.00
5:23	-324.2	###################	0	0.0	0.0	0.00	0.00
5:24	-325.2	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0

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5:25	-326.2	###################	0	0.0	0.0	0.00	0.00
5:26	-327.2	###################	0	0.0	0.0	0.00	0.00
5:27	-328.2	###################	0	0.0	0.0	0.00	0.00
5:28	-329.2	###################	0	0.0	0.0	0.00	0.00
5:29	-330.2	###################	0	0.0	0.0	0.00	0.00
5:30	-331.2	###################	0	0.0	0.0	0.00	0.00
5:31	-332.2	###################	0	0.0	0.0	0.00	0.00
5:32	-333.2	###################	0	0.0	0.0	0.00	0.00
5:33	-334.2	###################	0	0.0	0.0	0.00	0.00
5:34	-335.2	###################	0	0.0	0.0	0.00	0.00
5:35	-336.2	###################	0	0.0	0.0	0.00	0.00
5:36	-337.2	###################	0	0.0	0.0	0.00	0.00
5:37	-338.2	###################	0	0.0	0.0	0.00	0.00
5:38	-339.2	###################	0	0.0	0.0	0.00	0.00
5:39	-340.2	###################	0	0.0	0.0	0.00	0.00
5:40	-341.2	###################	0	0.0	0.0	0.00	0.00
5:41	-342.2	###################	0	0.0	0.0	0.00	0.00
5:42	-343.2	###################	0	0.0	0.0	0.00	0.00
5:43	-344.2	###################	0	0.0	0.0	0.00	0.00
5:44	-345.2	###################	0	0.0	0.0	0.00	0.00
5:45	-346.2	###################	0	0.0	0.0	0.00	0.00
5:46	-347.2	###################	0	0.0	0.0	0.00	0.00
5:47	-348.2	###################	0	0.0	0.0	0.00	0.00
5:48	-349.2	###################	0	0.0	0.0	0.00	0.00
5:49	-350.2	###################	0	0.0	0.0	0.00	0.00
5:50	-351.2	###################	0	0.0	0.0	0.00	0.00
5:51	-352.2	###################	0	0.0	0.0	0.00	0.00
5:52	-353.2	###################	0	0.0	0.0	0.00	0.00
5:53	-354.2	###################	0	0.0	0.0	0.00	0.00
5:54	-355.2	###################	0	0.0	0.0	0.00	0.00
5:55	-356.2	###################	0	0.0	0.0	0.00	0.00
5:56	-357.2	###################	0	0.0	0.0	0.00	0.00
5:57	-358.2	###################	0	0.0	0.0	0.00	0.00
5:58	-359.2	###################	0	0.0	0.0	0.00	0.00
5:59	-360.2	###################	0	0.0	0.0	0.00	0.00
6:00	-361.2	###################	0	0.0	0.0	0.00	0.00
6:01	-362.2	###################	0	0.0	0.0	0.00	0.00
6:02	-363.2	###################	0	0.0	0.0	0.00	0.00
6:03	-364.2	###################	0	0.0	0.0	0.00	0.00
6:04	-365.2	###################	0	0.0	0.0	0.00	0.00
6:05	-366.2	###################	0	0.0	0.0	0.00	0.00
6:06	-367.2	###################	0	0.0	0.0	0.00	0.00
6:07	-368.2	###################	0	0.0	0.0	0.00	0.00
6:08	-369.2	###################	0	0.0	0.0	0.00	0.00
6:09	-370.2	###################	0	0.0	0.0	0.00	0.00
6:10	-371.2	###################	0	0.0	0.0	0.00	0.00
6:11	-372.2	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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6:12	-373.2	###################	0	0.0	0.0	0.00	0.00
6:13	-374.2	###################	0	0.0	0.0	0.00	0.00
6:14	-375.2	###################	0	0.0	0.0	0.00	0.00
6:15	-376.2	###################	0	0.0	0.0	0.00	0.00
6:16	-377.2	###################	0	0.0	0.0	0.00	0.00
6:17	-378.2	###################	0	0.0	0.0	0.00	0.00
6:18	-379.2	###################	0	0.0	0.0	0.00	0.00
6:19	-380.2	###################	0	0.0	0.0	0.00	0.00
6:20	-381.2	###################	0	0.0	0.0	0.00	0.00
6:21	-382.2	###################	0	0.0	0.0	0.00	0.00
6:22	-383.2	###################	0	0.0	0.0	0.00	0.00
6:23	-384.2	###################	0	0.0	0.0	0.00	0.00
6:24	-385.2	###################	0	0.0	0.0	0.00	0.00
6:25	-386.2	###################	0	0.0	0.0	0.00	0.00
6:26	-387.2	###################	0	0.0	0.0	0.00	0.00
6:27	-388.2	###################	0	0.0	0.0	0.00	0.00
6:28	-389.2	###################	0	0.0	0.0	0.00	0.00
6:29	-390.2	###################	0	0.0	0.0	0.00	0.00
6:30	-391.3	###################	0	0.0	0.0	0.00	0.00
6:31	-392.3	###################	0	0.0	0.0	0.00	0.00
6:32	-393.3	###################	0	0.0	0.0	0.00	0.00
6:33	-394.3	###################	0	0.0	0.0	0.00	0.00
6:34	-395.3	###################	0	0.0	0.0	0.00	0.00
6:35	-396.3	###################	0	0.0	0.0	0.00	0.00
6:36	-397.3	###################	0	0.0	0.0	0.00	0.00
6:37	-398.3	###################	0	0.0	0.0	0.00	0.00
6:38	-399.3	###################	0	0.0	0.0	0.00	0.00
6:39	-400.3	###################	0	0.0	0.0	0.00	0.00
6:40	-401.3	###################	0	0.0	0.0	0.00	0.00
6:41	-402.3	###################	0	0.0	0.0	0.00	0.00
6:42	-403.3	###################	0	0.0	0.0	0.00	0.00
6:43	-404.3	###################	0	0.0	0.0	0.00	0.00
6:44	-405.3	###################	0	0.0	0.0	0.00	0.00
6:45	-406.3	###################	0	0.0	0.0	0.00	0.00
6:46	-407.3	###################	0	0.0	0.0	0.00	0.00
6:47	-408.3	###################	0	0.0	0.0	0.00	0.00
6:48	-409.3	###################	0	0.0	0.0	0.00	0.00
6:49	-410.3	###################	0	0.0	0.0	0.00	0.00
6:50	-411.3	###################	0	0.0	0.0	0.00	0.00
6:51	-412.3	###################	0	0.0	0.0	0.00	0.00
6:52	-413.3	###################	0	0.0	0.0	0.00	0.00
6:53	-414.3	###################	0	0.0	0.0	0.00	0.00
6:54	-415.3	###################	0	0.0	0.0	0.00	0.00
6:55	-416.3	###################	0	0.0	0.0	0.00	0.00
6:56	-417.3	###################	0	0.0	0.0	0.00	0.00
6:57	-418.3	###################	0	0.0	0.0	0.00	0.00
6:58	-419.3	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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6:59	-420.3	###################	0	0.0	0.0	0.00	0.00
7:00	-421.3	###################	0	0.0	0.0	0.00	0.00
7:01	-422.3	###################	0	0.0	0.0	0.00	0.00
7:02	-423.3	###################	0	0.0	0.0	0.00	0.00
7:03	-424.3	###################	0	0.0	0.0	0.00	0.00
7:04	-425.3	###################	0	0.0	0.0	0.00	0.00
7:05	-426.3	###################	0	0.0	0.0	0.00	0.00
7:06	-427.3	###################	0	0.0	0.0	0.00	0.00
7:07	-428.3	###################	0	0.0	0.0	0.00	0.00
7:08	-429.3	###################	0	0.0	0.0	0.00	0.00
7:09	-430.3	###################	0	0.0	0.0	0.00	0.00
7:10	-431.3	###################	0	0.0	0.0	0.00	0.00
7:11	-432.3	###################	0	0.0	0.0	0.00	0.00
7:12	-433.3	###################	0	0.0	0.0	0.00	0.00
7:13	-434.3	###################	0	0.0	0.0	0.00	0.00
7:14	-435.3	###################	0	0.0	0.0	0.00	0.00
7:15	-436.3	###################	0	0.0	0.0	0.00	0.00
7:16	-437.3	###################	0	0.0	0.0	0.00	0.00
7:17	-438.3	###################	0	0.0	0.0	0.00	0.00
7:18	-439.3	###################	0	0.0	0.0	0.00	0.00
7:19	-440.3	###################	0	0.0	0.0	0.00	0.00
7:20	-441.3	###################	0	0.0	0.0	0.00	0.00
7:21	-442.3	###################	0	0.0	0.0	0.00	0.00
7:22	-443.3	###################	0	0.0	0.0	0.00	0.00
7:23	-444.3	###################	0	0.0	0.0	0.00	0.00
7:24	-445.3	###################	0	0.0	0.0	0.00	0.00
7:25	-446.3	###################	0	0.0	0.0	0.00	0.00
7:26	-447.3	###################	0	0.0	0.0	0.00	0.00
7:27	-448.3	###################	0	0.0	0.0	0.00	0.00
7:28	-449.3	###################	0	0.0	0.0	0.00	0.00
7:29	-450.3	###################	0	0.0	0.0	0.00	0.00
7:30	-451.3	###################	0	0.0	0.0	0.00	0.00
7:31	-452.3	###################	0	0.0	0.0	0.00	0.00
7:32	-453.3	###################	0	0.0	0.0	0.00	0.00
7:33	-454.3	###################	0	0.0	0.0	0.00	0.00
7:34	-455.3	###################	0	0.0	0.0	0.00	0.00
7:35	-456.3	###################	0	0.0	0.0	0.00	0.00
7:36	-457.3	###################	0	0.0	0.0	0.00	0.00
7:37	-458.3	###################	0	0.0	0.0	0.00	0.00
7:38	-459.3	###################	0	0.0	0.0	0.00	0.00
7:39	-460.3	###################	0	0.0	0.0	0.00	0.00
7:40	-461.3	###################	0	0.0	0.0	0.00	0.00
7:41	-462.3	###################	0	0.0	0.0	0.00	0.00
7:42	-463.3	###################	0	0.0	0.0	0.00	0.00
7:43	-464.3	###################	0	0.0	0.0	0.00	0.00
7:44	-465.3	###################	0	0.0	0.0	0.00	0.00
7:45	-466.3	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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7:46	-467.3	###################	0	0.0	0.0	0.00	0.00
7:47	-468.3	###################	0	0.0	0.0	0.00	0.00
7:48	-469.3	###################	0	0.0	0.0	0.00	0.00
7:49	-470.3	###################	0	0.0	0.0	0.00	0.00
7:50	-471.3	###################	0	0.0	0.0	0.00	0.00
7:51	-472.3	###################	0	0.0	0.0	0.00	0.00
7:52	-473.3	###################	0	0.0	0.0	0.00	0.00
7:53	-474.3	###################	0	0.0	0.0	0.00	0.00
7:54	-475.3	###################	0	0.0	0.0	0.00	0.00
7:55	-476.3	###################	0	0.0	0.0	0.00	0.00
7:56	-477.3	###################	0	0.0	0.0	0.00	0.00
7:57	-478.3	###################	0	0.0	0.0	0.00	0.00
7:58	-479.3	###################	0	0.0	0.0	0.00	0.00
7:59	-480.3	###################	0	0.0	0.0	0.00	0.00
8:00	-481.3	###################	0	0.0	0.0	0.00	0.00
8:01	-482.3	###################	0	0.0	0.0	0.00	0.00
8:02	-483.3	###################	0	0.0	0.0	0.00	0.00
8:03	-484.3	###################	0	0.0	0.0	0.00	0.00
8:04	-485.3	###################	0	0.0	0.0	0.00	0.00
8:05	-486.3	###################	0	0.0	0.0	0.00	0.00
8:06	-487.3	###################	0	0.0	0.0	0.00	0.00
8:07	-488.3	###################	0	0.0	0.0	0.00	0.00
8:08	-489.3	###################	0	0.0	0.0	0.00	0.00
8:09	-490.3	###################	0	0.0	0.0	0.00	0.00
8:10	-491.3	###################	0	0.0	0.0	0.00	0.00
8:11	-492.3	###################	0	0.0	0.0	0.00	0.00
8:12	-493.3	###################	0	0.0	0.0	0.00	0.00
8:13	-494.3	###################	0	0.0	0.0	0.00	0.00
8:14	-495.3	###################	0	0.0	0.0	0.00	0.00
8:15	-496.3	###################	0	0.0	0.0	0.00	0.00
8:16	-497.3	###################	0	0.0	0.0	0.00	0.00
8:17	-498.3	###################	0	0.0	0.0	0.00	0.00
8:18	-499.3	###################	0	0.0	0.0	0.00	0.00
8:19	-500.3	###################	0	0.0	0.0	0.00	0.00
8:20	-501.3	###################	0	0.0	0.0	0.00	0.00
8:21	-502.3	###################	0	0.0	0.0	0.00	0.00
8:22	-503.3	###################	0	0.0	0.0	0.00	0.00
8:23	-504.3	###################	0	0.0	0.0	0.00	0.00
8:24	-505.3	###################	0	0.0	0.0	0.00	0.00
8:25	-506.3	###################	0	0.0	0.0	0.00	0.00
8:26	-507.3	###################	0	0.0	0.0	0.00	0.00
8:27	-508.3	###################	0	0.0	0.0	0.00	0.00
8:28	-509.3	###################	0	0.0	0.0	0.00	0.00
8:29	-510.3	###################	0	0.0	0.0	0.00	0.00
8:30	-511.3	###################	0	0.0	0.0	0.00	0.00
8:31	-512.3	###################	0	0.0	0.0	0.00	0.00
8:32	-513.3	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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8:33	-514.3	###################	0	0.0	0.0	0.00	0.00
8:34	-515.3	###################	0	0.0	0.0	0.00	0.00
8:35	-516.3	###################	0	0.0	0.0	0.00	0.00
8:36	-517.3	###################	0	0.0	0.0	0.00	0.00
8:37	-518.3	###################	0	0.0	0.0	0.00	0.00
8:38	-519.3	###################	0	0.0	0.0	0.00	0.00
8:39	-520.3	###################	0	0.0	0.0	0.00	0.00
8:40	-521.3	###################	0	0.0	0.0	0.00	0.00
8:41	-522.3	###################	0	0.0	0.0	0.00	0.00
8:42	-523.3	###################	0	0.0	0.0	0.00	0.00
8:43	-524.3	###################	0	0.0	0.0	0.00	0.00
8:44	-525.3	###################	0	0.0	0.0	0.00	0.00
8:45	-526.3	###################	0	0.0	0.0	0.00	0.00
8:46	-527.3	###################	0	0.0	0.0	0.00	0.00
8:47	-528.3	###################	0	0.0	0.0	0.00	0.00
8:48	-529.3	###################	0	0.0	0.0	0.00	0.00
8:49	-530.3	###################	0	0.0	0.0	0.00	0.00
8:50	-531.3	###################	0	0.0	0.0	0.00	0.00
8:51	-532.3	###################	0	0.0	0.0	0.00	0.00
8:52	-533.3	###################	0	0.0	0.0	0.00	0.00
8:53	-534.3	###################	0	0.0	0.0	0.00	0.00
8:54	-535.3	###################	0	0.0	0.0	0.00	0.00
8:55	-536.3	###################	0	0.0	0.0	0.00	0.00
8:56	-537.3	###################	0	0.0	0.0	0.00	0.00
8:57	-538.3	###################	0	0.0	0.0	0.00	0.00
8:58	-539.3	###################	0	0.0	0.0	0.00	0.00
8:59	-540.3	###################	0	0.0	0.0	0.00	0.00
9:00	-541.3	###################	0	0.0	0.0	0.00	0.00
9:01	-542.3	###################	0	0.0	0.0	0.00	0.00
9:02	-543.3	###################	0	0.0	0.0	0.00	0.00
9:03	-544.3	###################	0	0.0	0.0	0.00	0.00
9:04	-545.3	###################	0	0.0	0.0	0.00	0.00
9:05	-546.3	###################	0	0.0	0.0	0.00	0.00
9:06	-547.4	###################	0	0.0	0.0	0.00	0.00
9:07	-548.4	###################	0	0.0	0.0	0.00	0.00
9:08	-549.4	###################	0	0.0	0.0	0.00	0.00
9:09	-550.4	###################	0	0.0	0.0	0.00	0.00
9:10	-551.4	###################	0	0.0	0.0	0.00	0.00
9:11	-552.4	###################	0	0.0	0.0	0.00	0.00
9:12	-553.4	###################	0	0.0	0.0	0.00	0.00
9:13	-554.4	###################	0	0.0	0.0	0.00	0.00
9:14	-555.4	###################	0	0.0	0.0	0.00	0.00
9:15	-556.4	###################	0	0.0	0.0	0.00	0.00
9:16	-557.4	###################	0	0.0	0.0	0.00	0.00
9:17	-558.4	###################	0	0.0	0.0	0.00	0.00
9:18	-559.4	###################	0	0.0	0.0	0.00	0.00
9:19	-560.4	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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9:20	-561.4	###################	0	0.0	0.0	0.00	0.00
9:21	-562.4	###################	0	0.0	0.0	0.00	0.00
9:22	-563.4	###################	0	0.0	0.0	0.00	0.00
9:23	-564.4	###################	0	0.0	0.0	0.00	0.00
9:24	-565.4	###################	0	0.0	0.0	0.00	0.00
9:25	-566.4	###################	0	0.0	0.0	0.00	0.00
9:26	-567.4	###################	0	0.0	0.0	0.00	0.00
9:27	-568.4	###################	0	0.0	0.0	0.00	0.00
9:28	-569.4	###################	0	0.0	0.0	0.00	0.00
9:29	-570.4	###################	0	0.0	0.0	0.00	0.00
9:30	-571.4	###################	0	0.0	0.0	0.00	0.00
9:31	-572.4	###################	0	0.0	0.0	0.00	0.00
9:32	-573.4	###################	0	0.0	0.0	0.00	0.00
9:33	-574.4	###################	0	0.0	0.0	0.00	0.00
9:34	-575.4	###################	0	0.0	0.0	0.00	0.00
9:35	-576.4	###################	0	0.0	0.0	0.00	0.00
9:36	-577.4	###################	0	0.0	0.0	0.00	0.00
9:37	-578.4	###################	0	0.0	0.0	0.00	0.00
9:38	-579.4	###################	0	0.0	0.0	0.00	0.00
9:39	-580.4	###################	0	0.0	0.0	0.00	0.00
9:40	-581.4	###################	0	0.0	0.0	0.00	0.00
9:41	-582.4	###################	0	0.0	0.0	0.00	0.00
9:42	-583.4	###################	0	0.0	0.0	0.00	0.00
9:43	-584.4	###################	0	0.0	0.0	0.00	0.00
9:44	-585.4	###################	0	0.0	0.0	0.00	0.00
9:45	-586.4	###################	0	0.0	0.0	0.00	0.00
9:46	-587.4	###################	0	0.0	0.0	0.00	0.00
9:47	-588.4	###################	0	0.0	0.0	0.00	0.00
9:48	-589.4	###################	0	0.0	0.0	0.00	0.00
9:49	-590.4	###################	0	0.0	0.0	0.00	0.00
9:50	-591.4	###################	0	0.0	0.0	0.00	0.00
9:51	-592.4	###################	0	0.0	0.0	0.00	0.00
9:52	-593.4	###################	0	0.0	0.0	0.00	0.00
9:53	-594.4	###################	0	0.0	0.0	0.00	0.00
9:54	-595.4	###################	0	0.0	0.0	0.00	0.00
9:55	-596.4	###################	0	0.0	0.0	0.00	0.00
9:56	-597.4	###################	0	0.0	0.0	0.00	0.00
9:57	-598.4	###################	0	0.0	0.0	0.00	0.00
9:58	-599.4	###################	0	0.0	0.0	0.00	0.00
9:59	-600.4	###################	0	0.0	0.0	0.00	0.00
10:00	-601.4	###################	0	0.0	0.0	0.00	0.00
10:01	-602.4	###################	0	0.0	0.0	0.00	0.00
10:02	-603.4	###################	0	0.0	0.0	0.00	0.00
10:03	-604.4	###################	0	0.0	0.0	0.00	0.00
10:04	-605.4	###################	0	0.0	0.0	0.00	0.00
10:05	-606.4	###################	0	0.0	0.0	0.00	0.00
10:06	-607.4	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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10:07	-608.4	###################	0	0.0	0.0	0.00	0.00
10:08	-609.4	###################	0	0.0	0.0	0.00	0.00
10:09	-610.4	###################	0	0.0	0.0	0.00	0.00
10:10	-611.4	###################	0	0.0	0.0	0.00	0.00
10:11	-612.4	###################	0	0.0	0.0	0.00	0.00
10:12	-613.4	###################	0	0.0	0.0	0.00	0.00
10:13	-614.4	###################	0	0.0	0.0	0.00	0.00
10:14	-615.4	###################	0	0.0	0.0	0.00	0.00
10:15	-616.4	###################	0	0.0	0.0	0.00	0.00
10:16	-617.4	###################	0	0.0	0.0	0.00	0.00
10:17	-618.4	###################	0	0.0	0.0	0.00	0.00
10:18	-619.4	###################	0	0.0	0.0	0.00	0.00
10:19	-620.4	###################	0	0.0	0.0	0.00	0.00
10:20	-621.4	###################	0	0.0	0.0	0.00	0.00
10:21	-622.4	###################	0	0.0	0.0	0.00	0.00
10:22	-623.4	###################	0	0.0	0.0	0.00	0.00
10:23	-624.4	###################	0	0.0	0.0	0.00	0.00
10:24	-625.4	###################	0	0.0	0.0	0.00	0.00
10:25	-626.4	###################	0	0.0	0.0	0.00	0.00
10:26	-627.4	###################	0	0.0	0.0	0.00	0.00
10:27	-628.4	###################	0	0.0	0.0	0.00	0.00
10:28	-629.4	###################	0	0.0	0.0	0.00	0.00
10:29	-630.4	###################	0	0.0	0.0	0.00	0.00
10:30	-631.4	###################	0	0.0	0.0	0.00	0.00
10:31	-632.4	###################	0	0.0	0.0	0.00	0.00
10:32	-633.4	###################	0	0.0	0.0	0.00	0.00
10:33	-634.4	###################	0	0.0	0.0	0.00	0.00
10:34	-635.4	###################	0	0.0	0.0	0.00	0.00
10:35	-636.4	###################	0	0.0	0.0	0.00	0.00
10:36	-637.4	###################	0	0.0	0.0	0.00	0.00
10:37	-638.4	###################	0	0.0	0.0	0.00	0.00
10:38	-639.4	###################	0	0.0	0.0	0.00	0.00
10:39	-640.4	###################	0	0.0	0.0	0.00	0.00
10:40	-641.4	###################	0	0.0	0.0	0.00	0.00
10:41	-642.4	###################	0	0.0	0.0	0.00	0.00
10:42	-643.4	###################	0	0.0	0.0	0.00	0.00
10:43	-644.4	###################	0	0.0	0.0	0.00	0.00
10:44	-645.4	###################	0	0.0	0.0	0.00	0.00
10:45	-646.4	###################	0	0.0	0.0	0.00	0.00
10:46	-647.4	###################	0	0.0	0.0	0.00	0.00
10:47	-648.4	###################	0	0.0	0.0	0.00	0.00
10:48	-649.4	###################	0	0.0	0.0	0.00	0.00
10:49	-650.4	###################	0	0.0	0.0	0.00	0.00
10:50	-651.4	###################	0	0.0	0.0	0.00	0.00
10:51	-652.4	###################	0	0.0	0.0	0.00	0.00
10:52	-653.4	###################	0	0.0	0.0	0.00	0.00
10:53	-654.4	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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10:54	-655.4	###################	0	0.0	0.0	0.00	0.00
10:55	-656.4	###################	0	0.0	0.0	0.00	0.00
10:56	-657.4	###################	0	0.0	0.0	0.00	0.00
10:57	-658.4	###################	0	0.0	0.0	0.00	0.00
10:58	-659.4	###################	0	0.0	0.0	0.00	0.00
10:59	-660.4	###################	0	0.0	0.0	0.00	0.00
11:00	-661.4	###################	0	0.0	0.0	0.00	0.00
11:01	-662.4	###################	0	0.0	0.0	0.00	0.00
11:02	-663.4	###################	0	0.0	0.0	0.00	0.00
11:03	-664.4	###################	0	0.0	0.0	0.00	0.00
11:04	-665.4	###################	0	0.0	0.0	0.00	0.00
11:05	-666.4	###################	0	0.0	0.0	0.00	0.00
11:06	-667.4	###################	0	0.0	0.0	0.00	0.00
11:07	-668.4	###################	0	0.0	0.0	0.00	0.00
11:08	-669.4	###################	0	0.0	0.0	0.00	0.00
11:09	-670.4	###################	0	0.0	0.0	0.00	0.00
11:10	-671.4	###################	0	0.0	0.0	0.00	0.00
11:11	-672.4	###################	0	0.0	0.0	0.00	0.00
11:12	-673.4	###################	0	0.0	0.0	0.00	0.00
11:13	-674.4	###################	0	0.0	0.0	0.00	0.00
11:14	-675.4	###################	0	0.0	0.0	0.00	0.00
11:15	-676.4	###################	0	0.0	0.0	0.00	0.00
11:16	-677.4	###################	0	0.0	0.0	0.00	0.00
11:17	-678.4	###################	0	0.0	0.0	0.00	0.00
11:18	-679.4	###################	0	0.0	0.0	0.00	0.00
11:19	-680.4	###################	0	0.0	0.0	0.00	0.00
11:20	-681.4	###################	0	0.0	0.0	0.00	0.00
11:21	-682.4	###################	0	0.0	0.0	0.00	0.00
11:22	-683.4	###################	0	0.0	0.0	0.00	0.00
11:23	-684.4	###################	0	0.0	0.0	0.00	0.00
11:24	-685.4	###################	0	0.0	0.0	0.00	0.00
11:25	-686.4	###################	0	0.0	0.0	0.00	0.00
11:26	-687.4	###################	0	0.0	0.0	0.00	0.00
11:27	-688.4	###################	0	0.0	0.0	0.00	0.00
11:28	-689.4	###################	0	0.0	0.0	0.00	0.00
11:29	-690.4	###################	0	0.0	0.0	0.00	0.00
11:30	-691.4	###################	0	0.0	0.0	0.00	0.00
11:31	-692.4	###################	0	0.0	0.0	0.00	0.00
11:32	-693.4	###################	0	0.0	0.0	0.00	0.00
11:33	-694.4	###################	0	0.0	0.0	0.00	0.00
11:34	-695.4	###################	0	0.0	0.0	0.00	0.00
11:35	-696.4	###################	0	0.0	0.0	0.00	0.00
11:36	-697.4	###################	0	0.0	0.0	0.00	0.00
11:37	-698.4	###################	0	0.0	0.0	0.00	0.00
11:38	-699.4	###################	0	0.0	0.0	0.00	0.00
11:39	-700.4	###################	0	0.0	0.0	0.00	0.00
11:40	-701.4	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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11:41	-702.4	###################	0	0.0	0.0	0.00	0.00
11:42	-703.5	###################	0	0.0	0.0	0.00	0.00
11:43	-704.5	###################	0	0.0	0.0	0.00	0.00
11:44	-705.5	###################	0	0.0	0.0	0.00	0.00
11:45	-706.5	###################	0	0.0	0.0	0.00	0.00
11:46	-707.5	###################	0	0.0	0.0	0.00	0.00
11:47	-708.5	###################	0	0.0	0.0	0.00	0.00
11:48	-709.5	###################	0	0.0	0.0	0.00	0.00
11:49	-710.5	###################	0	0.0	0.0	0.00	0.00
11:50	-711.5	###################	0	0.0	0.0	0.00	0.00
11:51	-712.5	###################	0	0.0	0.0	0.00	0.00
11:52	-713.5	###################	0	0.0	0.0	0.00	0.00
11:53	-714.5	###################	0	0.0	0.0	0.00	0.00
11:54	-715.5	###################	0	0.0	0.0	0.00	0.00
11:55	-716.5	###################	0	0.0	0.0	0.00	0.00
11:56	-717.5	###################	0	0.0	0.0	0.00	0.00
11:57	-718.5	###################	0	0.0	0.0	0.00	0.00
11:58	-719.5	###################	0	0.0	0.0	0.00	0.00
11:59	-720.5	###################	0	0.0	0.0	0.00	0.00
12:00	-721.5	###################	0	0.0	0.0	0.00	0.00
12:01	-722.5	###################	0	0.0	0.0	0.00	0.00
12:02	-723.5	###################	0	0.0	0.0	0.00	0.00
12:03	-724.5	###################	0	0.0	0.0	0.00	0.00
12:04	-725.5	###################	0	0.0	0.0	0.00	0.00
12:05	-726.5	###################	0	0.0	0.0	0.00	0.00
12:06	-727.5	###################	0	0.0	0.0	0.00	0.00
12:07	-728.5	###################	0	0.0	0.0	0.00	0.00
12:08	-729.5	###################	0	0.0	0.0	0.00	0.00
12:09	-730.5	###################	0	0.0	0.0	0.00	0.00
12:10	-731.5	###################	0	0.0	0.0	0.00	0.00
12:11	-732.5	###################	0	0.0	0.0	0.00	0.00
12:12	-733.5	###################	0	0.0	0.0	0.00	0.00
12:13	-734.5	###################	0	0.0	0.0	0.00	0.00
12:14	-735.5	###################	0	0.0	0.0	0.00	0.00
12:15	-736.5	###################	0	0.0	0.0	0.00	0.00
12:16	-737.5	###################	0	0.0	0.0	0.00	0.00
12:17	-738.5	###################	0	0.0	0.0	0.00	0.00
12:18	-739.5	###################	0	0.0	0.0	0.00	0.00
12:19	-740.5	###################	0	0.0	0.0	0.00	0.00
12:20	-741.5	###################	0	0.0	0.0	0.00	0.00
12:21	-742.5	###################	0	0.0	0.0	0.00	0.00
12:22	-743.5	###################	0	0.0	0.0	0.00	0.00
12:23	-744.5	###################	0	0.0	0.0	0.00	0.00
12:24	-745.5	###################	0	0.0	0.0	0.00	0.00
12:25	-746.5	###################	0	0.0	0.0	0.00	0.00
12:26	-747.5	###################	0	0.0	0.0	0.00	0.00
12:27	-748.5	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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12:28	-749.5	###################	0	0.0	0.0	0.00	0.00
12:29	-750.5	###################	0	0.0	0.0	0.00	0.00
12:30	-751.5	###################	0	0.0	0.0	0.00	0.00
12:31	-752.5	###################	0	0.0	0.0	0.00	0.00
12:32	-753.5	###################	0	0.0	0.0	0.00	0.00
12:33	-754.5	###################	0	0.0	0.0	0.00	0.00
12:34	-755.5	###################	0	0.0	0.0	0.00	0.00
12:35	-756.5	###################	0	0.0	0.0	0.00	0.00
12:36	-757.5	###################	0	0.0	0.0	0.00	0.00
12:37	-758.5	###################	0	0.0	0.0	0.00	0.00
12:38	-759.5	###################	0	0.0	0.0	0.00	0.00
12:39	-760.5	###################	0	0.0	0.0	0.00	0.00
12:40	-761.5	###################	0	0.0	0.0	0.00	0.00
12:41	-762.5	###################	0	0.0	0.0	0.00	0.00
12:42	-763.5	###################	0	0.0	0.0	0.00	0.00
12:43	-764.5	###################	0	0.0	0.0	0.00	0.00
12:44	-765.5	###################	0	0.0	0.0	0.00	0.00
12:45	-766.5	###################	0	0.0	0.0	0.00	0.00
12:46	-767.5	###################	0	0.0	0.0	0.00	0.00
12:47	-768.5	###################	0	0.0	0.0	0.00	0.00
12:48	-769.5	###################	0	0.0	0.0	0.00	0.00
12:49	-770.5	###################	0	0.0	0.0	0.00	0.00
12:50	-771.5	###################	0	0.0	0.0	0.00	0.00
12:51	-772.5	###################	0	0.0	0.0	0.00	0.00
12:52	-773.5	###################	0	0.0	0.0	0.00	0.00
12:53	-774.5	###################	0	0.0	0.0	0.00	0.00
12:54	-775.5	###################	0	0.0	0.0	0.00	0.00
12:55	-776.5	###################	0	0.0	0.0	0.00	0.00
12:56	-777.5	###################	0	0.0	0.0	0.00	0.00
12:57	-778.5	###################	0	0.0	0.0	0.00	0.00
12:58	-779.5	###################	0	0.0	0.0	0.00	0.00
12:59	-780.5	###################	0	0.0	0.0	0.00	0.00
13:00	-781.5	###################	0	0.0	0.0	0.00	0.00
13:01	-782.5	###################	0	0.0	0.0	0.00	0.00
13:02	-783.5	###################	0	0.0	0.0	0.00	0.00
13:03	-784.5	###################	0	0.0	0.0	0.00	0.00
13:04	-785.5	###################	0	0.0	0.0	0.00	0.00
13:05	-786.5	###################	0	0.0	0.0	0.00	0.00
13:06	-787.5	###################	0	0.0	0.0	0.00	0.00
13:07	-788.5	###################	0	0.0	0.0	0.00	0.00
13:08	-789.5	###################	0	0.0	0.0	0.00	0.00
13:09	-790.5	###################	0	0.0	0.0	0.00	0.00
13:10	-791.5	###################	0	0.0	0.0	0.00	0.00
13:11	-792.5	###################	0	0.0	0.0	0.00	0.00
13:12	-793.5	###################	0	0.0	0.0	0.00	0.00
13:13	-794.5	###################	0	0.0	0.0	0.00	0.00
13:14	-795.5	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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13:15	-796.5	###################	0	0.0	0.0	0.00	0.00
13:16	-797.5	###################	0	0.0	0.0	0.00	0.00
13:17	-798.5	###################	0	0.0	0.0	0.00	0.00
13:18	-799.5	###################	0	0.0	0.0	0.00	0.00
13:19	-800.5	###################	0	0.0	0.0	0.00	0.00
13:20	-801.5	###################	0	0.0	0.0	0.00	0.00
13:21	-802.5	###################	0	0.0	0.0	0.00	0.00
13:22	-803.5	###################	0	0.0	0.0	0.00	0.00
13:23	-804.5	###################	0	0.0	0.0	0.00	0.00
13:24	-805.5	###################	0	0.0	0.0	0.00	0.00
13:25	-806.5	###################	0	0.0	0.0	0.00	0.00
13:26	-807.5	###################	0	0.0	0.0	0.00	0.00
13:27	-808.5	###################	0	0.0	0.0	0.00	0.00
13:28	-809.5	###################	0	0.0	0.0	0.00	0.00
13:29	-810.5	###################	0	0.0	0.0	0.00	0.00
13:30	-811.5	###################	0	0.0	0.0	0.00	0.00
13:31	-812.5	###################	0	0.0	0.0	0.00	0.00
13:32	-813.5	###################	0	0.0	0.0	0.00	0.00
13:33	-814.5	###################	0	0.0	0.0	0.00	0.00
13:34	-815.5	###################	0	0.0	0.0	0.00	0.00
13:35	-816.5	###################	0	0.0	0.0	0.00	0.00
13:36	-817.5	###################	0	0.0	0.0	0.00	0.00
13:37	-818.5	###################	0	0.0	0.0	0.00	0.00
13:38	-819.5	###################	0	0.0	0.0	0.00	0.00
13:39	-820.5	###################	0	0.0	0.0	0.00	0.00
13:40	-821.5	###################	0	0.0	0.0	0.00	0.00
13:41	-822.5	###################	0	0.0	0.0	0.00	0.00
13:42	-823.5	###################	0	0.0	0.0	0.00	0.00
13:43	-824.5	###################	0	0.0	0.0	0.00	0.00
13:44	-825.5	###################	0	0.0	0.0	0.00	0.00
13:45	-826.5	###################	0	0.0	0.0	0.00	0.00
13:46	-827.5	###################	0	0.0	0.0	0.00	0.00
13:47	-828.5	###################	0	0.0	0.0	0.00	0.00
13:48	-829.5	###################	0	0.0	0.0	0.00	0.00
13:49	-830.5	###################	0	0.0	0.0	0.00	0.00
13:50	-831.5	###################	0	0.0	0.0	0.00	0.00
13:51	-832.5	###################	0	0.0	0.0	0.00	0.00
13:52	-833.5	###################	0	0.0	0.0	0.00	0.00
13:53	-834.5	###################	0	0.0	0.0	0.00	0.00
13:54	-835.5	###################	0	0.0	0.0	0.00	0.00
13:55	-836.5	###################	0	0.0	0.0	0.00	0.00
13:56	-837.5	###################	0	0.0	0.0	0.00	0.00
13:57	-838.5	###################	0	0.0	0.0	0.00	0.00
13:58	-839.5	###################	0	0.0	0.0	0.00	0.00
13:59	-840.5	###################	0	0.0	0.0	0.00	0.00
14:00	-841.5	###################	0	0.0	0.0	0.00	0.00
14:01	-842.5	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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14:02	-843.5	###################	0	0.0	0.0	0.00	0.00
14:03	-844.5	###################	0	0.0	0.0	0.00	0.00
14:04	-845.5	###################	0	0.0	0.0	0.00	0.00
14:05	-846.5	###################	0	0.0	0.0	0.00	0.00
14:06	-847.5	###################	0	0.0	0.0	0.00	0.00
14:07	-848.5	###################	0	0.0	0.0	0.00	0.00
14:08	-849.5	###################	0	0.0	0.0	0.00	0.00
14:09	-850.5	###################	0	0.0	0.0	0.00	0.00
14:10	-851.5	###################	0	0.0	0.0	0.00	0.00
14:11	-852.5	###################	0	0.0	0.0	0.00	0.00
14:12	-853.5	###################	0	0.0	0.0	0.00	0.00
14:13	-854.5	###################	0	0.0	0.0	0.00	0.00
14:14	-855.5	###################	0	0.0	0.0	0.00	0.00
14:15	-856.5	###################	0	0.0	0.0	0.00	0.00
14:16	-857.5	###################	0	0.0	0.0	0.00	0.00
14:17	-858.5	###################	0	0.0	0.0	0.00	0.00
14:18	-859.6	###################	0	0.0	0.0	0.00	0.00
14:19	-860.6	###################	0	0.0	0.0	0.00	0.00
14:20	-861.6	###################	0	0.0	0.0	0.00	0.00
14:21	-862.6	###################	0	0.0	0.0	0.00	0.00
14:22	-863.6	###################	0	0.0	0.0	0.00	0.00
14:23	-864.6	###################	0	0.0	0.0	0.00	0.00
14:24	-865.6	###################	0	0.0	0.0	0.00	0.00
14:25	-866.6	###################	0	0.0	0.0	0.00	0.00
14:26	-867.6	###################	0	0.0	0.0	0.00	0.00
14:27	-868.6	###################	0	0.0	0.0	0.00	0.00
14:28	-869.6	###################	0	0.0	0.0	0.00	0.00
14:29	-870.6	###################	0	0.0	0.0	0.00	0.00
14:30	-871.6	###################	0	0.0	0.0	0.00	0.00
14:31	-872.6	###################	0	0.0	0.0	0.00	0.00
14:32	-873.6	###################	0	0.0	0.0	0.00	0.00
14:33	-874.6	###################	0	0.0	0.0	0.00	0.00
14:34	-875.6	###################	0	0.0	0.0	0.00	0.00
14:35	-876.6	###################	0	0.0	0.0	0.00	0.00
14:36	-877.6	###################	0	0.0	0.0	0.00	0.00
14:37	-878.6	###################	0	0.0	0.0	0.00	0.00
14:38	-879.6	###################	0	0.0	0.0	0.00	0.00
14:39	-880.6	###################	0	0.0	0.0	0.00	0.00
14:40	-881.6	###################	0	0.0	0.0	0.00	0.00
14:41	-882.6	###################	0	0.0	0.0	0.00	0.00
14:42	-883.6	###################	0	0.0	0.0	0.00	0.00
14:43	-884.6	###################	0	0.0	0.0	0.00	0.00
14:44	-885.6	###################	0	0.0	0.0	0.00	0.00
14:45	-886.6	###################	0	0.0	0.0	0.00	0.00
14:46	-887.6	###################	0	0.0	0.0	0.00	0.00
14:47	-888.6	###################	0	0.0	0.0	0.00	0.00
14:48	-889.6	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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14:49	-890.6	###################	0	0.0	0.0	0.00	0.00
14:50	-891.6	###################	0	0.0	0.0	0.00	0.00
14:51	-892.6	###################	0	0.0	0.0	0.00	0.00
14:52	-893.6	###################	0	0.0	0.0	0.00	0.00
14:53	-894.6	###################	0	0.0	0.0	0.00	0.00
14:54	-895.6	###################	0	0.0	0.0	0.00	0.00
14:55	-896.6	###################	0	0.0	0.0	0.00	0.00
14:56	-897.6	###################	0	0.0	0.0	0.00	0.00
14:57	-898.6	###################	0	0.0	0.0	0.00	0.00
14:58	-899.6	###################	0	0.0	0.0	0.00	0.00
14:59	-900.6	###################	0	0.0	0.0	0.00	0.00
15:00	-901.6	###################	0	0.0	0.0	0.00	0.00
15:01	-902.6	###################	0	0.0	0.0	0.00	0.00
15:02	-903.6	###################	0	0.0	0.0	0.00	0.00
15:03	-904.6	###################	0	0.0	0.0	0.00	0.00
15:04	-905.6	###################	0	0.0	0.0	0.00	0.00
15:05	-906.6	###################	0	0.0	0.0	0.00	0.00
15:06	-907.6	###################	0	0.0	0.0	0.00	0.00
15:07	-908.6	###################	0	0.0	0.0	0.00	0.00
15:08	-909.6	###################	0	0.0	0.0	0.00	0.00
15:09	-910.6	###################	0	0.0	0.0	0.00	0.00
15:10	-911.6	###################	0	0.0	0.0	0.00	0.00
15:11	-912.6	###################	0	0.0	0.0	0.00	0.00
15:12	-913.6	###################	0	0.0	0.0	0.00	0.00
15:13	-914.6	###################	0	0.0	0.0	0.00	0.00
15:14	-915.6	###################	0	0.0	0.0	0.00	0.00
15:15	-916.6	###################	0	0.0	0.0	0.00	0.00
15:16	-917.6	###################	0	0.0	0.0	0.00	0.00
15:17	-918.6	###################	0	0.0	0.0	0.00	0.00
15:18	-919.6	###################	0	0.0	0.0	0.00	0.00
15:19	-920.6	###################	0	0.0	0.0	0.00	0.00
15:20	-921.6	###################	0	0.0	0.0	0.00	0.00
15:21	-922.6	###################	0	0.0	0.0	0.00	0.00
15:22	-923.6	###################	0	0.0	0.0	0.00	0.00
15:23	-924.6	###################	0	0.0	0.0	0.00	0.00
15:24	-925.6	###################	0	0.0	0.0	0.00	0.00
15:25	-926.6	###################	0	0.0	0.0	0.00	0.00
15:26	-927.6	###################	0	0.0	0.0	0.00	0.00
15:27	-928.6	###################	0	0.0	0.0	0.00	0.00
15:28	-929.6	###################	0	0.0	0.0	0.00	0.00
15:29	-930.6	###################	0	0.0	0.0	0.00	0.00
15:30	-931.6	###################	0	0.0	0.0	0.00	0.00
15:31	-932.6	###################	0	0.0	0.0	0.00	0.00
15:32	-933.6	###################	0	0.0	0.0	0.00	0.00
15:33	-934.6	###################	0	0.0	0.0	0.00	0.00
15:34	-935.6	###################	0	0.0	0.0	0.00	0.00
15:35	-936.6	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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#VALUE!	#VALUE!	#VALUE!	#VALUE!

15:36	-937.6	###################	0	0.0	0.0	0.00	0.00
15:37	-938.6	###################	0	0.0	0.0	0.00	0.00
15:38	-939.6	###################	0	0.0	0.0	0.00	0.00
15:39	-940.6	###################	0	0.0	0.0	0.00	0.00
15:40	-941.6	###################	0	0.0	0.0	0.00	0.00
15:41	-942.6	###################	0	0.0	0.0	0.00	0.00
15:42	-943.6	###################	0	0.0	0.0	0.00	0.00
15:43	-944.6	###################	0	0.0	0.0	0.00	0.00
15:44	-945.6	###################	0	0.0	0.0	0.00	0.00
15:45	-946.6	###################	0	0.0	0.0	0.00	0.00
15:46	-947.6	###################	0	0.0	0.0	0.00	0.00
15:47	-948.6	###################	0	0.0	0.0	0.00	0.00
15:48	-949.6	###################	0	0.0	0.0	0.00	0.00
15:49	-950.6	###################	0	0.0	0.0	0.00	0.00
15:50	-951.6	###################	0	0.0	0.0	0.00	0.00
15:51	-952.6	###################	0	0.0	0.0	0.00	0.00
15:52	-953.6	###################	0	0.0	0.0	0.00	0.00
15:53	-954.6	###################	0	0.0	0.0	0.00	0.00
15:54	-955.6	###################	0	0.0	0.0	0.00	0.00
15:55	-956.6	###################	0	0.0	0.0	0.00	0.00
15:56	-957.6	###################	0	0.0	0.0	0.00	0.00
15:57	-958.6	###################	0	0.0	0.0	0.00	0.00
15:58	-959.6	###################	0	0.0	0.0	0.00	0.00
15:59	-960.6	###################	0	0.0	0.0	0.00	0.00
16:00	-961.6	###################	0	0.0	0.0	0.00	0.00
16:01	-962.6	###################	0	0.0	0.0	0.00	0.00
16:02	-963.6	###################	0	0.0	0.0	0.00	0.00
16:03	-964.6	###################	0	0.0	0.0	0.00	0.00
16:04	-965.6	###################	0	0.0	0.0	0.00	0.00
16:05	-966.6	###################	0	0.0	0.0	0.00	0.00
16:06	-967.6	###################	0	0.0	0.0	0.00	0.00
16:07	-968.6	###################	0	0.0	0.0	0.00	0.00
16:08	-969.6	###################	0	0.0	0.0	0.00	0.00
16:09	-970.6	###################	0	0.0	0.0	0.00	0.00
16:10	-971.6	###################	0	0.0	0.0	0.00	0.00
16:11	-972.6	###################	0	0.0	0.0	0.00	0.00
16:12	-973.6	###################	0	0.0	0.0	0.00	0.00
16:13	-974.6	###################	0	0.0	0.0	0.00	0.00
16:14	-975.6	###################	0	0.0	0.0	0.00	0.00
16:15	-976.6	###################	0	0.0	0.0	0.00	0.00
16:16	-977.6	###################	0	0.0	0.0	0.00	0.00
16:17	-978.6	###################	0	0.0	0.0	0.00	0.00
16:18	-979.6	###################	0	0.0	0.0	0.00	0.00
16:19	-980.6	###################	0	0.0	0.0	0.00	0.00
16:20	-981.6	###################	0	0.0	0.0	0.00	0.00
16:21	-982.6	###################	0	0.0	0.0	0.00	0.00
16:22	-983.6	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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16:23	-984.6	###################	0	0.0	0.0	0.00	0.00
16:24	-985.6	###################	0	0.0	0.0	0.00	0.00
16:25	-986.6	###################	0	0.0	0.0	0.00	0.00
16:26	-987.6	###################	0	0.0	0.0	0.00	0.00
16:27	-988.6	###################	0	0.0	0.0	0.00	0.00
16:28	-989.6	###################	0	0.0	0.0	0.00	0.00
16:29	-990.6	###################	0	0.0	0.0	0.00	0.00
16:30	-991.6	###################	0	0.0	0.0	0.00	0.00
16:31	-992.6	###################	0	0.0	0.0	0.00	0.00
16:32	-993.6	###################	0	0.0	0.0	0.00	0.00
16:33	-994.6	###################	0	0.0	0.0	0.00	0.00
16:34	-995.6	###################	0	0.0	0.0	0.00	0.00
16:35	-996.6	###################	0	0.0	0.0	0.00	0.00
16:36	-997.6	###################	0	0.0	0.0	0.00	0.00
16:37	-998.6	###################	0	0.0	0.0	0.00	0.00
16:38	-999.6	###################	0	0.0	0.0	0.00	0.00
16:39	-1000.6	###################	0	0.0	0.0	0.00	0.00
16:40	-1001.6	###################	0	0.0	0.0	0.00	0.00
16:41	-1002.6	###################	0	0.0	0.0	0.00	0.00
16:42	-1003.6	###################	0	0.0	0.0	0.00	0.00
16:43	-1004.6	###################	0	0.0	0.0	0.00	0.00
16:44	-1005.6	###################	0	0.0	0.0	0.00	0.00
16:45	-1006.6	###################	0	0.0	0.0	0.00	0.00
16:46	-1007.6	###################	0	0.0	0.0	0.00	0.00
16:47	-1008.6	###################	0	0.0	0.0	0.00	0.00
16:48	-1009.6	###################	0	0.0	0.0	0.00	0.00
16:49	-1010.6	###################	0	0.0	0.0	0.00	0.00
16:50	-1011.6	###################	0	0.0	0.0	0.00	0.00
16:51	-1012.6	###################	0	0.0	0.0	0.00	0.00
16:52	-1013.6	###################	0	0.0	0.0	0.00	0.00
16:53	-1014.6	###################	0	0.0	0.0	0.00	0.00
16:54	-1015.7	###################	0	0.0	0.0	0.00	0.00
16:55	-1016.7	###################	0	0.0	0.0	0.00	0.00
16:56	-1017.7	###################	0	0.0	0.0	0.00	0.00
16:57	-1018.7	###################	0	0.0	0.0	0.00	0.00
16:58	-1019.7	###################	0	0.0	0.0	0.00	0.00
16:59	-1020.7	###################	0	0.0	0.0	0.00	0.00
17:00	-1021.7	###################	0	0.0	0.0	0.00	0.00
17:01	-1022.7	###################	0	0.0	0.0	0.00	0.00
17:02	-1023.7	###################	0	0.0	0.0	0.00	0.00
17:03	-1024.7	###################	0	0.0	0.0	0.00	0.00
17:04	-1025.7	###################	0	0.0	0.0	0.00	0.00
17:05	-1026.7	###################	0	0.0	0.0	0.00	0.00
17:06	-1027.7	###################	0	0.0	0.0	0.00	0.00
17:07	-1028.7	###################	0	0.0	0.0	0.00	0.00
17:08	-1029.7	###################	0	0.0	0.0	0.00	0.00
17:09	-1030.7	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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17:10	-1031.7	###################	0	0.0	0.0	0.00	0.00
17:11	-1032.7	###################	0	0.0	0.0	0.00	0.00
17:12	-1033.7	###################	0	0.0	0.0	0.00	0.00
17:13	-1034.7	###################	0	0.0	0.0	0.00	0.00
17:14	-1035.7	###################	0	0.0	0.0	0.00	0.00
17:15	-1036.7	###################	0	0.0	0.0	0.00	0.00
17:16	-1037.7	###################	0	0.0	0.0	0.00	0.00
17:17	-1038.7	###################	0	0.0	0.0	0.00	0.00
17:18	-1039.7	###################	0	0.0	0.0	0.00	0.00
17:19	-1040.7	###################	0	0.0	0.0	0.00	0.00
17:20	-1041.7	###################	0	0.0	0.0	0.00	0.00
17:21	-1042.7	###################	0	0.0	0.0	0.00	0.00
17:22	-1043.7	###################	0	0.0	0.0	0.00	0.00
17:23	-1044.7	###################	0	0.0	0.0	0.00	0.00
17:24	-1045.7	###################	0	0.0	0.0	0.00	0.00
17:25	-1046.7	###################	0	0.0	0.0	0.00	0.00
17:26	-1047.7	###################	0	0.0	0.0	0.00	0.00
17:27	-1048.7	###################	0	0.0	0.0	0.00	0.00
17:28	-1049.7	###################	0	0.0	0.0	0.00	0.00
17:29	-1050.7	###################	0	0.0	0.0	0.00	0.00
17:30	-1051.7	###################	0	0.0	0.0	0.00	0.00
17:31	-1052.7	###################	0	0.0	0.0	0.00	0.00
17:32	-1053.7	###################	0	0.0	0.0	0.00	0.00
17:33	-1054.7	###################	0	0.0	0.0	0.00	0.00
17:34	-1055.7	###################	0	0.0	0.0	0.00	0.00
17:35	-1056.7	###################	0	0.0	0.0	0.00	0.00
17:36	-1057.7	###################	0	0.0	0.0	0.00	0.00
17:37	-1058.7	###################	0	0.0	0.0	0.00	0.00
17:38	-1059.7	###################	0	0.0	0.0	0.00	0.00
17:39	-1060.7	###################	0	0.0	0.0	0.00	0.00
17:40	-1061.7	###################	0	0.0	0.0	0.00	0.00
17:41	-1062.7	###################	0	0.0	0.0	0.00	0.00
17:42	-1063.7	###################	0	0.0	0.0	0.00	0.00
17:43	-1064.7	###################	0	0.0	0.0	0.00	0.00
17:44	-1065.7	###################	0	0.0	0.0	0.00	0.00
17:45	-1066.7	###################	0	0.0	0.0	0.00	0.00
17:46	-1067.7	###################	0	0.0	0.0	0.00	0.00
17:47	-1068.7	###################	0	0.0	0.0	0.00	0.00
17:48	-1069.7	###################	0	0.0	0.0	0.00	0.00
17:49	-1070.7	###################	0	0.0	0.0	0.00	0.00
17:50	-1071.7	###################	0	0.0	0.0	0.00	0.00
17:51	-1072.7	###################	0	0.0	0.0	0.00	0.00
17:52	-1073.7	###################	0	0.0	0.0	0.00	0.00
17:53	-1074.7	###################	0	0.0	0.0	0.00	0.00
17:54	-1075.7	###################	0	0.0	0.0	0.00	0.00
17:55	-1076.7	###################	0	0.0	0.0	0.00	0.00
17:56	-1077.7	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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17:57	-1078.7	###################	0	0.0	0.0	0.00	0.00
17:58	-1079.7	###################	0	0.0	0.0	0.00	0.00
17:59	-1080.7	###################	0	0.0	0.0	0.00	0.00
18:00	-1081.7	###################	0	0.0	0.0	0.00	0.00
18:01	-1082.7	###################	0	0.0	0.0	0.00	0.00
18:02	-1083.7	###################	0	0.0	0.0	0.00	0.00
18:03	-1084.7	###################	0	0.0	0.0	0.00	0.00
18:04	-1085.7	###################	0	0.0	0.0	0.00	0.00
18:05	-1086.7	###################	0	0.0	0.0	0.00	0.00
18:06	-1087.7	###################	0	0.0	0.0	0.00	0.00
18:07	-1088.7	###################	0	0.0	0.0	0.00	0.00
18:08	-1089.7	###################	0	0.0	0.0	0.00	0.00
18:09	-1090.7	###################	0	0.0	0.0	0.00	0.00
18:10	-1091.7	###################	0	0.0	0.0	0.00	0.00
18:11	-1092.7	###################	0	0.0	0.0	0.00	0.00
18:12	-1093.7	###################	0	0.0	0.0	0.00	0.00
18:13	-1094.7	###################	0	0.0	0.0	0.00	0.00
18:14	-1095.7	###################	0	0.0	0.0	0.00	0.00
18:15	-1096.7	###################	0	0.0	0.0	0.00	0.00
18:16	-1097.7	###################	0	0.0	0.0	0.00	0.00
18:17	-1098.7	###################	0	0.0	0.0	0.00	0.00
18:18	-1099.7	###################	0	0.0	0.0	0.00	0.00
18:19	-1100.7	###################	0	0.0	0.0	0.00	0.00
18:20	-1101.7	###################	0	0.0	0.0	0.00	0.00
18:21	-1102.7	###################	0	0.0	0.0	0.00	0.00
18:22	-1103.7	###################	0	0.0	0.0	0.00	0.00
18:23	-1104.7	###################	0	0.0	0.0	0.00	0.00
18:24	-1105.7	###################	0	0.0	0.0	0.00	0.00
18:25	-1106.7	###################	0	0.0	0.0	0.00	0.00
18:26	-1107.7	###################	0	0.0	0.0	0.00	0.00
18:27	-1108.7	###################	0	0.0	0.0	0.00	0.00
18:28	-1109.7	###################	0	0.0	0.0	0.00	0.00
18:29	-1110.7	###################	0	0.0	0.0	0.00	0.00
18:30	-1111.7	###################	0	0.0	0.0	0.00	0.00
18:31	-1112.7	###################	0	0.0	0.0	0.00	0.00
18:32	-1113.7	###################	0	0.0	0.0	0.00	0.00
18:33	-1114.7	###################	0	0.0	0.0	0.00	0.00
18:34	-1115.7	###################	0	0.0	0.0	0.00	0.00
18:35	-1116.7	###################	0	0.0	0.0	0.00	0.00
18:36	-1117.7	###################	0	0.0	0.0	0.00	0.00
18:37	-1118.7	###################	0	0.0	0.0	0.00	0.00
18:38	-1119.7	###################	0	0.0	0.0	0.00	0.00
18:39	-1120.7	###################	0	0.0	0.0	0.00	0.00
18:40	-1121.7	###################	0	0.0	0.0	0.00	0.00
18:41	-1122.7	###################	0	0.0	0.0	0.00	0.00
18:42	-1123.7	###################	0	0.0	0.0	0.00	0.00
18:43	-1124.7	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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18:44	-1125.7	###################	0	0.0	0.0	0.00	0.00
18:45	-1126.7	###################	0	0.0	0.0	0.00	0.00
18:46	-1127.7	###################	0	0.0	0.0	0.00	0.00
18:47	-1128.7	###################	0	0.0	0.0	0.00	0.00
18:48	-1129.7	###################	0	0.0	0.0	0.00	0.00
18:49	-1130.7	###################	0	0.0	0.0	0.00	0.00
18:50	-1131.7	###################	0	0.0	0.0	0.00	0.00
18:51	-1132.7	###################	0	0.0	0.0	0.00	0.00
18:52	-1133.7	###################	0	0.0	0.0	0.00	0.00
18:53	-1134.7	###################	0	0.0	0.0	0.00	0.00
18:54	-1135.7	###################	0	0.0	0.0	0.00	0.00
18:55	-1136.7	###################	0	0.0	0.0	0.00	0.00
18:56	-1137.7	###################	0	0.0	0.0	0.00	0.00
18:57	-1138.7	###################	0	0.0	0.0	0.00	0.00
18:58	-1139.7	###################	0	0.0	0.0	0.00	0.00
18:59	-1140.7	###################	0	0.0	0.0	0.00	0.00
19:00	-1141.7	###################	0	0.0	0.0	0.00	0.00
19:01	-1142.7	###################	0	0.0	0.0	0.00	0.00
19:02	-1143.7	###################	0	0.0	0.0	0.00	0.00
19:03	-1144.7	###################	0	0.0	0.0	0.00	0.00
19:04	-1145.7	###################	0	0.0	0.0	0.00	0.00
19:05	-1146.7	###################	0	0.0	0.0	0.00	0.00
19:06	-1147.7	###################	0	0.0	0.0	0.00	0.00
19:07	-1148.7	###################	0	0.0	0.0	0.00	0.00
19:08	-1149.7	###################	0	0.0	0.0	0.00	0.00
19:09	-1150.7	###################	0	0.0	0.0	0.00	0.00
19:10	-1151.7	###################	0	0.0	0.0	0.00	0.00
19:11	-1152.7	###################	0	0.0	0.0	0.00	0.00
19:12	-1153.7	###################	0	0.0	0.0	0.00	0.00
19:13	-1154.7	###################	0	0.0	0.0	0.00	0.00
19:14	-1155.7	###################	0	0.0	0.0	0.00	0.00
19:15	-1156.7	###################	0	0.0	0.0	0.00	0.00
19:16	-1157.7	###################	0	0.0	0.0	0.00	0.00
19:17	-1158.7	###################	0	0.0	0.0	0.00	0.00
19:18	-1159.7	###################	0	0.0	0.0	0.00	0.00
19:19	-1160.7	###################	0	0.0	0.0	0.00	0.00
19:20	-1161.7	###################	0	0.0	0.0	0.00	0.00
19:21	-1162.7	###################	0	0.0	0.0	0.00	0.00
19:22	-1163.7	###################	0	0.0	0.0	0.00	0.00
19:23	-1164.7	###################	0	0.0	0.0	0.00	0.00
19:24	-1165.7	###################	0	0.0	0.0	0.00	0.00
19:25	-1166.7	###################	0	0.0	0.0	0.00	0.00
19:26	-1167.7	###################	0	0.0	0.0	0.00	0.00
19:27	-1168.7	###################	0	0.0	0.0	0.00	0.00
19:28	-1169.7	###################	0	0.0	0.0	0.00	0.00
19:29	-1170.7	###################	0	0.0	0.0	0.00	0.00
19:30	-1171.7	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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19:31	-1172.8	###################	0	0.0	0.0	0.00	0.00
19:32	-1173.8	###################	0	0.0	0.0	0.00	0.00
19:33	-1174.8	###################	0	0.0	0.0	0.00	0.00
19:34	-1175.8	###################	0	0.0	0.0	0.00	0.00
19:35	-1176.8	###################	0	0.0	0.0	0.00	0.00
19:36	-1177.8	###################	0	0.0	0.0	0.00	0.00
19:37	-1178.8	###################	0	0.0	0.0	0.00	0.00
19:38	-1179.8	###################	0	0.0	0.0	0.00	0.00
19:39	-1180.8	###################	0	0.0	0.0	0.00	0.00
19:40	-1181.8	###################	0	0.0	0.0	0.00	0.00
19:41	-1182.8	###################	0	0.0	0.0	0.00	0.00
19:42	-1183.8	###################	0	0.0	0.0	0.00	0.00
19:43	-1184.8	###################	0	0.0	0.0	0.00	0.00
19:44	-1185.8	###################	0	0.0	0.0	0.00	0.00
19:45	-1186.8	###################	0	0.0	0.0	0.00	0.00
19:46	-1187.8	###################	0	0.0	0.0	0.00	0.00
19:47	-1188.8	###################	0	0.0	0.0	0.00	0.00
19:48	-1189.8	###################	0	0.0	0.0	0.00	0.00
19:49	-1190.8	###################	0	0.0	0.0	0.00	0.00
19:50	-1191.8	###################	0	0.0	0.0	0.00	0.00
19:51	-1192.8	###################	0	0.0	0.0	0.00	0.00
19:52	-1193.8	###################	0	0.0	0.0	0.00	0.00
19:53	-1194.8	###################	0	0.0	0.0	0.00	0.00
19:54	-1195.8	###################	0	0.0	0.0	0.00	0.00
19:55	-1196.8	###################	0	0.0	0.0	0.00	0.00
19:56	-1197.8	###################	0	0.0	0.0	0.00	0.00
19:57	-1198.8	###################	0	0.0	0.0	0.00	0.00
19:58	-1199.8	###################	0	0.0	0.0	0.00	0.00
19:59	-1200.8	###################	0	0.0	0.0	0.00	0.00
20:00	-1201.8	###################	0	0.0	0.0	0.00	0.00
20:01	-1202.8	###################	0	0.0	0.0	0.00	0.00
20:02	-1203.8	###################	0	0.0	0.0	0.00	0.00
20:03	-1204.8	###################	0	0.0	0.0	0.00	0.00
20:04	-1205.8	###################	0	0.0	0.0	0.00	0.00
20:05	-1206.8	###################	0	0.0	0.0	0.00	0.00
20:06	-1207.8	###################	0	0.0	0.0	0.00	0.00
20:07	-1208.8	###################	0	0.0	0.0	0.00	0.00
20:08	-1209.8	###################	0	0.0	0.0	0.00	0.00
20:09	-1210.8	###################	0	0.0	0.0	0.00	0.00
20:10	-1211.8	###################	0	0.0	0.0	0.00	0.00
20:11	-1212.8	###################	0	0.0	0.0	0.00	0.00
20:12	-1213.8	###################	0	0.0	0.0	0.00	0.00
20:13	-1214.8	###################	0	0.0	0.0	0.00	0.00
20:14	-1215.8	###################	0	0.0	0.0	0.00	0.00
20:15	-1216.8	###################	0	0.0	0.0	0.00	0.00
20:16	-1217.8	###################	0	0.0	0.0	0.00	0.00
20:17	-1218.8	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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20:18	-1219.8	###################	0	0.0	0.0	0.00	0.00
20:19	-1220.8	###################	0	0.0	0.0	0.00	0.00
20:20	-1221.8	###################	0	0.0	0.0	0.00	0.00
20:21	-1222.8	###################	0	0.0	0.0	0.00	0.00
20:22	-1223.8	###################	0	0.0	0.0	0.00	0.00
20:23	-1224.8	###################	0	0.0	0.0	0.00	0.00
20:24	-1225.8	###################	0	0.0	0.0	0.00	0.00
20:25	-1226.8	###################	0	0.0	0.0	0.00	0.00
20:26	-1227.8	###################	0	0.0	0.0	0.00	0.00
20:27	-1228.8	###################	0	0.0	0.0	0.00	0.00
20:28	-1229.8	###################	0	0.0	0.0	0.00	0.00
20:29	-1230.8	###################	0	0.0	0.0	0.00	0.00
20:30	-1231.8	###################	0	0.0	0.0	0.00	0.00
20:31	-1232.8	###################	0	0.0	0.0	0.00	0.00
20:32	-1233.8	###################	0	0.0	0.0	0.00	0.00
20:33	-1234.8	###################	0	0.0	0.0	0.00	0.00
20:34	-1235.8	###################	0	0.0	0.0	0.00	0.00
20:35	-1236.8	###################	0	0.0	0.0	0.00	0.00
20:36	-1237.8	###################	0	0.0	0.0	0.00	0.00
20:37	-1238.8	###################	0	0.0	0.0	0.00	0.00
20:38	-1239.8	###################	0	0.0	0.0	0.00	0.00
20:39	-1240.8	###################	0	0.0	0.0	0.00	0.00
20:40	-1241.8	###################	0	0.0	0.0	0.00	0.00
20:41	-1242.8	###################	0	0.0	0.0	0.00	0.00
20:42	-1243.8	###################	0	0.0	0.0	0.00	0.00
20:43	-1244.8	###################	0	0.0	0.0	0.00	0.00
20:44	-1245.8	###################	0	0.0	0.0	0.00	0.00
20:45	-1246.8	###################	0	0.0	0.0	0.00	0.00
20:46	-1247.8	###################	0	0.0	0.0	0.00	0.00
20:47	-1248.8	###################	0	0.0	0.0	0.00	0.00
20:48	-1249.8	###################	0	0.0	0.0	0.00	0.00
20:49	-1250.8	###################	0	0.0	0.0	0.00	0.00
20:50	-1251.8	###################	0	0.0	0.0	0.00	0.00
20:51	-1252.8	###################	0	0.0	0.0	0.00	0.00
20:52	-1253.8	###################	0	0.0	0.0	0.00	0.00
20:53	-1254.8	###################	0	0.0	0.0	0.00	0.00
20:54	-1255.8	###################	0	0.0	0.0	0.00	0.00
20:55	-1256.8	###################	0	0.0	0.0	0.00	0.00
20:56	-1257.8	###################	0	0.0	0.0	0.00	0.00
20:57	-1258.8	###################	0	0.0	0.0	0.00	0.00
20:58	-1259.8	###################	0	0.0	0.0	0.00	0.00
20:59	-1260.8	###################	0	0.0	0.0	0.00	0.00
21:00	-1261.8	###################	0	0.0	0.0	0.00	0.00
21:01	-1262.8	###################	0	0.0	0.0	0.00	0.00
21:02	-1263.8	###################	0	0.0	0.0	0.00	0.00
21:03	-1264.8	###################	0	0.0	0.0	0.00	0.00
21:04	-1265.8	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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21:05	-1266.8	###################	0	0.0	0.0	0.00	0.00
21:06	-1267.8	###################	0	0.0	0.0	0.00	0.00
21:07	-1268.8	###################	0	0.0	0.0	0.00	0.00
21:08	-1269.8	###################	0	0.0	0.0	0.00	0.00
21:09	-1270.8	###################	0	0.0	0.0	0.00	0.00
21:10	-1271.8	###################	0	0.0	0.0	0.00	0.00
21:11	-1272.8	###################	0	0.0	0.0	0.00	0.00
21:12	-1273.8	###################	0	0.0	0.0	0.00	0.00
21:13	-1274.8	###################	0	0.0	0.0	0.00	0.00
21:14	-1275.8	###################	0	0.0	0.0	0.00	0.00
21:15	-1276.8	###################	0	0.0	0.0	0.00	0.00
21:16	-1277.8	###################	0	0.0	0.0	0.00	0.00
21:17	-1278.8	###################	0	0.0	0.0	0.00	0.00
21:18	-1279.8	###################	0	0.0	0.0	0.00	0.00
21:19	-1280.8	###################	0	0.0	0.0	0.00	0.00
21:20	-1281.8	###################	0	0.0	0.0	0.00	0.00
21:21	-1282.8	###################	0	0.0	0.0	0.00	0.00
21:22	-1283.8	###################	0	0.0	0.0	0.00	0.00
21:23	-1284.8	###################	0	0.0	0.0	0.00	0.00
21:24	-1285.8	###################	0	0.0	0.0	0.00	0.00
21:25	-1286.8	###################	0	0.0	0.0	0.00	0.00
21:26	-1287.8	###################	0	0.0	0.0	0.00	0.00
21:27	-1288.8	###################	0	0.0	0.0	0.00	0.00
21:28	-1289.8	###################	0	0.0	0.0	0.00	0.00
21:29	-1290.8	###################	0	0.0	0.0	0.00	0.00
21:30	-1291.8	###################	0	0.0	0.0	0.00	0.00
21:31	-1292.8	###################	0	0.0	0.0	0.00	0.00
21:32	-1293.8	###################	0	0.0	0.0	0.00	0.00
21:33	-1294.8	###################	0	0.0	0.0	0.00	0.00
21:34	-1295.8	###################	0	0.0	0.0	0.00	0.00
21:35	-1296.8	###################	0	0.0	0.0	0.00	0.00
21:36	-1297.8	###################	0	0.0	0.0	0.00	0.00
21:37	-1298.8	###################	0	0.0	0.0	0.00	0.00
21:38	-1299.8	###################	0	0.0	0.0	0.00	0.00
21:39	-1300.8	###################	0	0.0	0.0	0.00	0.00
21:40	-1301.8	###################	0	0.0	0.0	0.00	0.00
21:41	-1302.8	###################	0	0.0	0.0	0.00	0.00
21:42	-1303.8	###################	0	0.0	0.0	0.00	0.00
21:43	-1304.8	###################	0	0.0	0.0	0.00	0.00
21:44	-1305.8	###################	0	0.0	0.0	0.00	0.00
21:45	-1306.8	###################	0	0.0	0.0	0.00	0.00
21:46	-1307.8	###################	0	0.0	0.0	0.00	0.00
21:47	-1308.8	###################	0	0.0	0.0	0.00	0.00
21:48	-1309.8	###################	0	0.0	0.0	0.00	0.00
21:49	-1310.8	###################	0	0.0	0.0	0.00	0.00
21:50	-1311.8	###################	0	0.0	0.0	0.00	0.00
21:51	-1312.8	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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21:52	-1313.8	###################	0	0.0	0.0	0.00	0.00
21:53	-1314.8	###################	0	0.0	0.0	0.00	0.00
21:54	-1315.8	###################	0	0.0	0.0	0.00	0.00
21:55	-1316.8	###################	0	0.0	0.0	0.00	0.00
21:56	-1317.8	###################	0	0.0	0.0	0.00	0.00
21:57	-1318.8	###################	0	0.0	0.0	0.00	0.00
21:58	-1319.8	###################	0	0.0	0.0	0.00	0.00
21:59	-1320.8	###################	0	0.0	0.0	0.00	0.00
22:00	-1321.8	###################	0	0.0	0.0	0.00	0.00
22:01	-1322.8	###################	0	0.0	0.0	0.00	0.00
22:02	-1323.8	###################	0	0.0	0.0	0.00	0.00
22:03	-1324.8	###################	0	0.0	0.0	0.00	0.00
22:04	-1325.8	###################	0	0.0	0.0	0.00	0.00
22:05	-1326.8	###################	0	0.0	0.0	0.00	0.00
22:06	-1327.8	###################	0	0.0	0.0	0.00	0.00
22:07	-1328.9	###################	0	0.0	0.0	0.00	0.00
22:08	-1329.9	###################	0	0.0	0.0	0.00	0.00
22:09	-1330.9	###################	0	0.0	0.0	0.00	0.00
22:10	-1331.9	###################	0	0.0	0.0	0.00	0.00
22:11	-1332.9	###################	0	0.0	0.0	0.00	0.00
22:12	-1333.9	###################	0	0.0	0.0	0.00	0.00
22:13	-1334.9	###################	0	0.0	0.0	0.00	0.00
22:14	-1335.9	###################	0	0.0	0.0	0.00	0.00
22:15	-1336.9	###################	0	0.0	0.0	0.00	0.00
22:16	-1337.9	###################	0	0.0	0.0	0.00	0.00
22:17	-1338.9	###################	0	0.0	0.0	0.00	0.00
22:18	-1339.9	###################	0	0.0	0.0	0.00	0.00
22:19	-1340.9	###################	0	0.0	0.0	0.00	0.00
22:20	-1341.9	###################	0	0.0	0.0	0.00	0.00
22:21	-1342.9	###################	0	0.0	0.0	0.00	0.00
22:22	-1343.9	###################	0	0.0	0.0	0.00	0.00
22:23	-1344.9	###################	0	0.0	0.0	0.00	0.00
22:24	-1345.9	###################	0	0.0	0.0	0.00	0.00
22:25	-1346.9	###################	0	0.0	0.0	0.00	0.00
22:26	-1347.9	###################	0	0.0	0.0	0.00	0.00
22:27	-1348.9	###################	0	0.0	0.0	0.00	0.00
22:28	-1349.9	###################	0	0.0	0.0	0.00	0.00
22:29	-1350.9	###################	0	0.0	0.0	0.00	0.00
22:30	-1351.9	###################	0	0.0	0.0	0.00	0.00
22:31	-1352.9	###################	0	0.0	0.0	0.00	0.00
22:32	-1353.9	###################	0	0.0	0.0	0.00	0.00
22:33	-1354.9	###################	0	0.0	0.0	0.00	0.00
22:34	-1355.9	###################	0	0.0	0.0	0.00	0.00
22:35	-1356.9	###################	0	0.0	0.0	0.00	0.00
22:36	-1357.9	###################	0	0.0	0.0	0.00	0.00
22:37	-1358.9	###################	0	0.0	0.0	0.00	0.00
22:38	-1359.9	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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22:39	-1360.9	###################	0	0.0	0.0	0.00	0.00
22:40	-1361.9	###################	0	0.0	0.0	0.00	0.00
22:41	-1362.9	###################	0	0.0	0.0	0.00	0.00
22:42	-1363.9	###################	0	0.0	0.0	0.00	0.00
22:43	-1364.9	###################	0	0.0	0.0	0.00	0.00
22:44	-1365.9	###################	0	0.0	0.0	0.00	0.00
22:45	-1366.9	###################	0	0.0	0.0	0.00	0.00
22:46	-1367.9	###################	0	0.0	0.0	0.00	0.00
22:47	-1368.9	###################	0	0.0	0.0	0.00	0.00
22:48	-1369.9	###################	0	0.0	0.0	0.00	0.00
22:49	-1370.9	###################	0	0.0	0.0	0.00	0.00
22:50	-1371.9	###################	0	0.0	0.0	0.00	0.00
22:51	-1372.9	###################	0	0.0	0.0	0.00	0.00
22:52	-1373.9	###################	0	0.0	0.0	0.00	0.00
22:53	-1374.9	###################	0	0.0	0.0	0.00	0.00
22:54	-1375.9	###################	0	0.0	0.0	0.00	0.00
22:55	-1376.9	###################	0	0.0	0.0	0.00	0.00
22:56	-1377.9	###################	0	0.0	0.0	0.00	0.00
22:57	-1378.9	###################	0	0.0	0.0	0.00	0.00
22:58	-1379.9	###################	0	0.0	0.0	0.00	0.00
22:59	-1380.9	###################	0	0.0	0.0	0.00	0.00
23:00	-1381.9	###################	0	0.0	0.0	0.00	0.00
23:01	-1382.9	###################	0	0.0	0.0	0.00	0.00
23:02	-1383.9	###################	0	0.0	0.0	0.00	0.00
23:03	-1384.9	###################	0	0.0	0.0	0.00	0.00
23:04	-1385.9	###################	0	0.0	0.0	0.00	0.00
23:05	-1386.9	###################	0	0.0	0.0	0.00	0.00
23:06	-1387.9	###################	0	0.0	0.0	0.00	0.00
23:07	-1388.9	###################	0	0.0	0.0	0.00	0.00
23:08	-1389.9	###################	0	0.0	0.0	0.00	0.00
23:09	-1390.9	###################	0	0.0	0.0	0.00	0.00
23:10	-1391.9	###################	0	0.0	0.0	0.00	0.00
23:11	-1392.9	###################	0	0.0	0.0	0.00	0.00
23:12	-1393.9	###################	0	0.0	0.0	0.00	0.00
23:13	-1394.9	###################	0	0.0	0.0	0.00	0.00
23:14	-1395.9	###################	0	0.0	0.0	0.00	0.00
23:15	-1396.9	###################	0	0.0	0.0	0.00	0.00
23:16	-1397.9	###################	0	0.0	0.0	0.00	0.00
23:17	-1398.9	###################	0	0.0	0.0	0.00	0.00
23:18	-1399.9	###################	0	0.0	0.0	0.00	0.00
23:19	-1400.9	###################	0	0.0	0.0	0.00	0.00
23:20	-1401.9	###################	0	0.0	0.0	0.00	0.00
23:21	-1402.9	###################	0	0.0	0.0	0.00	0.00
23:22	-1403.9	###################	0	0.0	0.0	0.00	0.00
23:23	-1404.9	###################	0	0.0	0.0	0.00	0.00
23:24	-1405.9	###################	0	0.0	0.0	0.00	0.00
23:25	-1406.9	###################	0	0.0	0.0	0.00	0.00

0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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23:26	-1407.9	###################	0	0.0	0.0	0.00	0.00
23:27	-1408.9	###################	0	0.0	0.0	0.00	0.00
23:28	-1409.9	###################	0	0.0	0.0	0.00	0.00
23:29	-1410.9	###################	0	0.0	0.0	0.00	0.00
23:30	-1411.9	###################	0	0.0	0.0	0.00	0.00
23:31	-1412.9	###################	0	0.0	0.0	0.00	0.00
23:32	-1413.9	###################	0	0.0	0.0	0.00	0.00
23:33	-1414.9	###################	0	0.0	0.0	0.00	0.00
23:34	-1415.9	###################	0	0.0	0.0	0.00	0.00
23:35	-1416.9	###################	0	0.0	0.0	0.00	0.00
23:36	-1417.9	###################	0	0.0	0.0	0.00	0.00
23:37	-1418.9	###################	0	0.0	0.0	0.00	0.00
23:38	-1419.9	###################	0	0.0	0.0	0.00	0.00
23:39	-1420.9	###################	0	0.0	0.0	0.00	0.00
23:40	-1421.9	###################	0	0.0	0.0	0.00	0.00
23:41	-1422.9	###################	0	0.0	0.0	0.00	0.00
23:42	-1423.9	###################	0	0.0	0.0	0.00	0.00
23:43	-1424.9	###################	0	0.0	0.0	0.00	0.00
23:44	-1425.9	###################	0	0.0	0.0	0.00	0.00
23:45	-1426.9	###################	0	0.0	0.0	0.00	0.00
23:46	-1427.9	###################	0	0.0	0.0	0.00	0.00
23:47	-1428.9	###################	0	0.0	0.0	0.00	0.00
23:48	-1429.9	###################	0	0.0	0.0	0.00	0.00
23:49	-1430.9	###################	0	0.0	0.0	0.00	0.00
23:50	-1431.9	###################	0	0.0	0.0	0.00	0.00
23:51	-1432.9	###################	0	0.0	0.0	0.00	0.00
23:52	-1433.9	###################	0	0.0	0.0	0.00	0.00
23:53	-1434.9	###################	0	0.0	0.0	0.00	0.00
23:54	-1435.9	###################	0	0.0	0.0	0.00	0.00
23:55	-1436.9	###################	0	0.0	0.0	0.00	0.00
23:56	-1437.9	###################	0	0.0	0.0	0.00	0.00
23:57	-1438.9	###################	0	0.0	0.0	0.00	0.00
23:58	-1439.9	###################	0	0.0	0.0	0.00	0.00

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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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0.000	0.00	0.0	0	0.00	0.000	0.00	0.0	0.00	0.00	0
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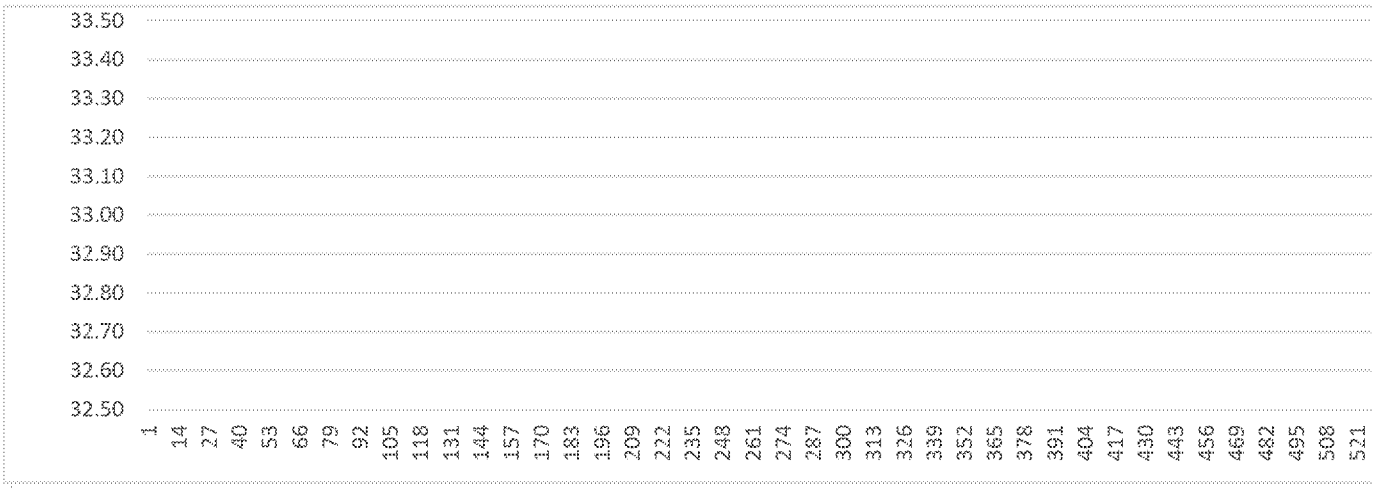
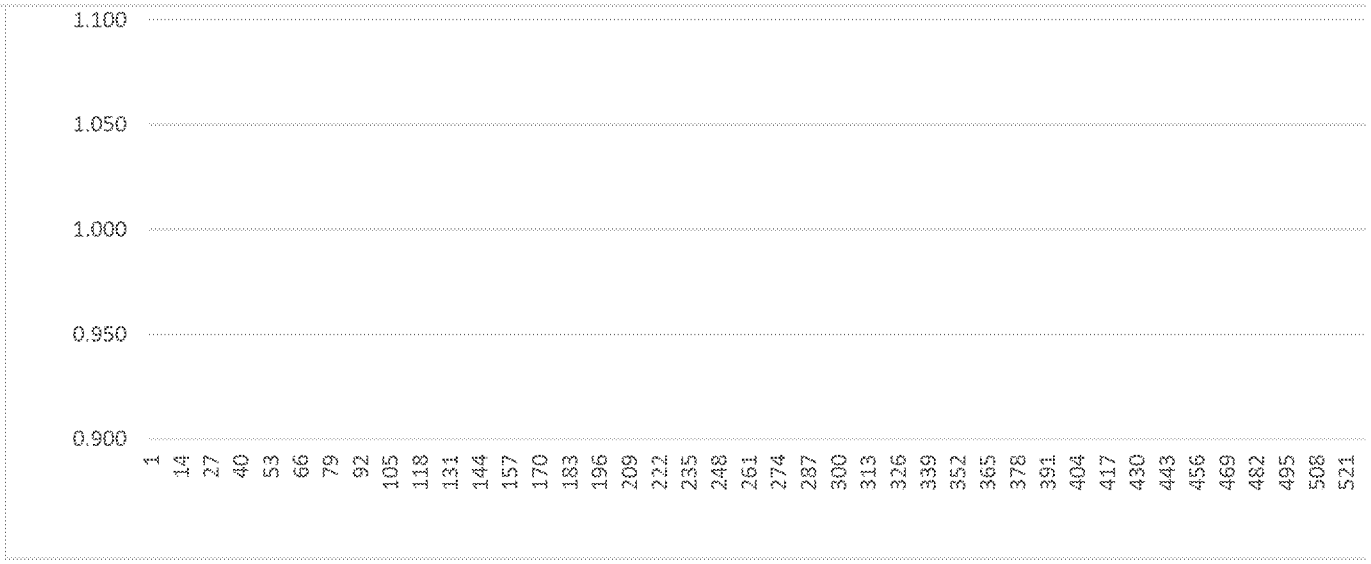
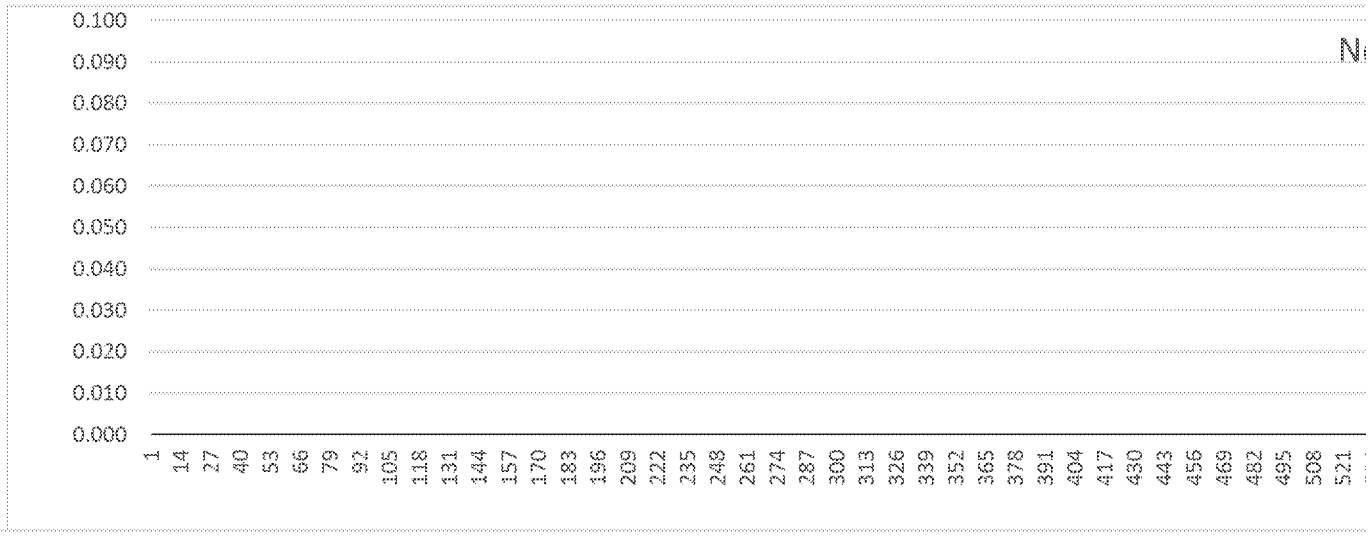
Cell: D2
Comment: If not 1.0, enter here.

Review these 3 plots to verify that Case T, Flows, and "Noise" parameters are within limits.







Case T: 32.9 to 33.1 Deg. C

534 547 560 573 586 599 612 625 638 651 664 677 690 703 716 729 742 755 768 781 794 807 820 833 846 859 872 885 898 911 924 937 950 963 976 989 1002 1015 1028 1041 1054 1067 1080 1093 1106

PM2.5 and PM-Coarse Flows: 0.95 to 1.05 lpm

534 547 560 573 586 599 612 625 638 651 664 677 690 703 716 729 742 755 768 781 794 807 820 833 846 859 872 885 898 911 924 937 950 963 976 989 1002 1015 1028 1041 1054 1067 1080 1093 1106

flow flow

ormalized PM2.5 and PM-Coarse Noise: less than 0.10

534 547 560 573 586 599 612 625 638 651 664 677 690 703 716 729 742 755 768 781 794 807 820 833 846 859 872 885 898 911 924 937 950 963 976 989 1002 1015 1028 1041 1054 1067 1080 1093 1106

1-min pm, ug/m3

PM2.5 PM-C

1106
1119
1132
1145
1158
1171
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pm2.5 noise
pm-c noise
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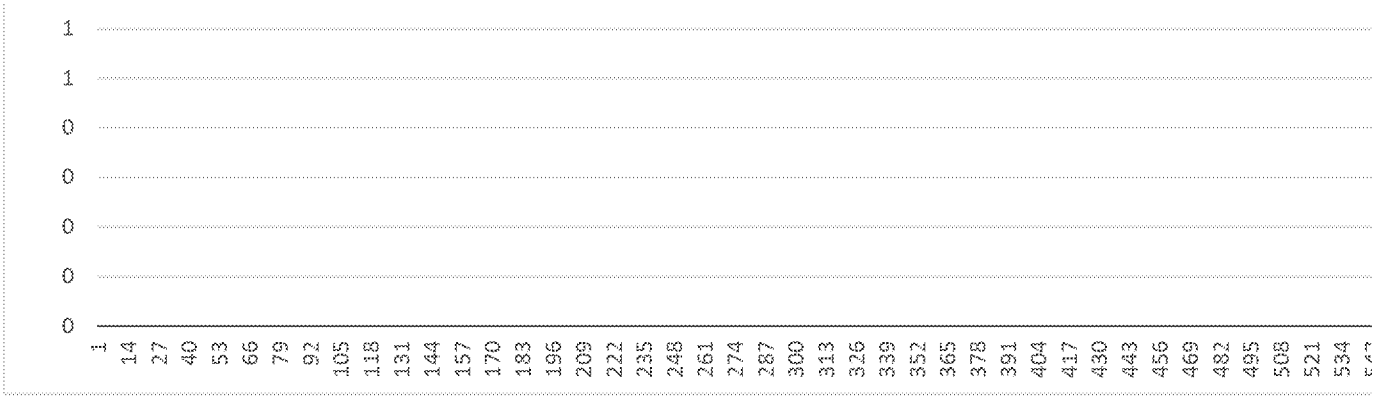
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Start Time	1-min PM2.5	1-min PM-c	Lab air PM	***1-min avg PM***	10-min average PM2.5	PM-c	PM2.5 count	PM-c count	avg: 10-min	#DIV/0! PM2.5
####					#DIV/0!	#DIV/0!	0	0		
####					#DIV/0!	#DIV/0!	0	0		
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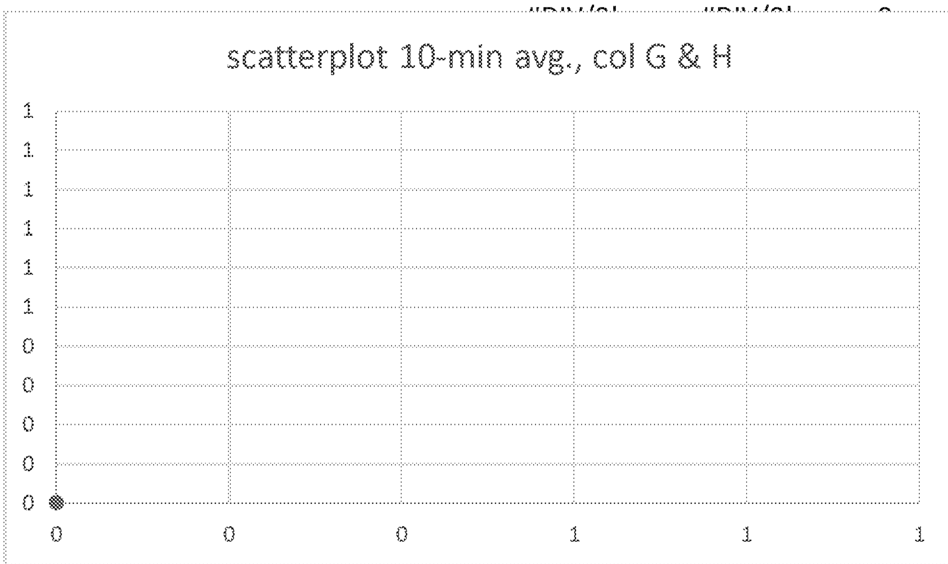

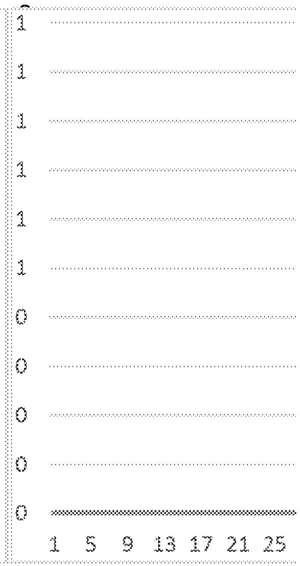

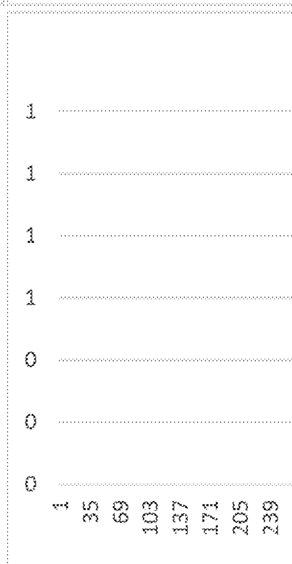

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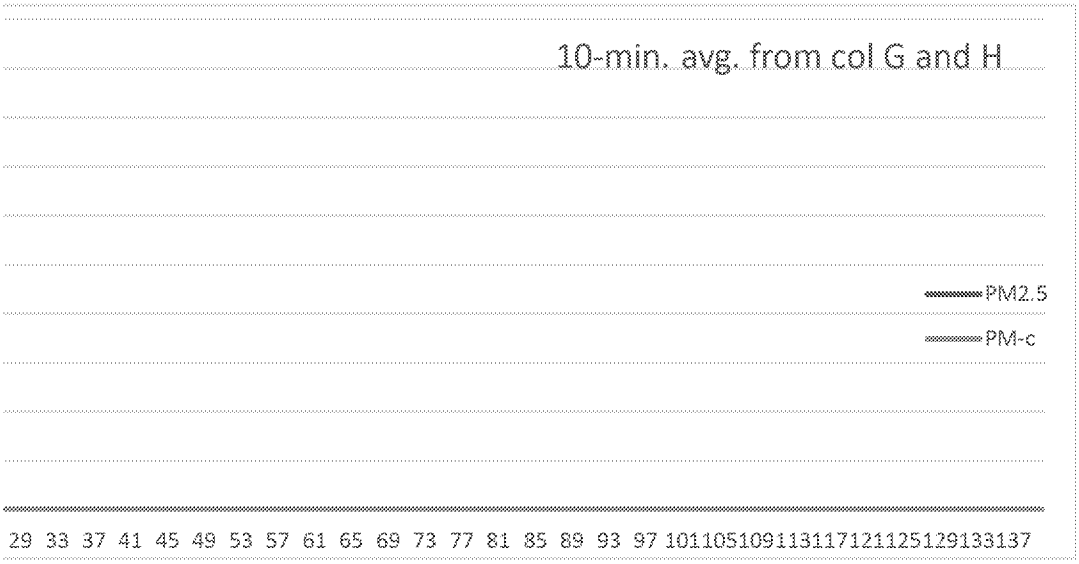

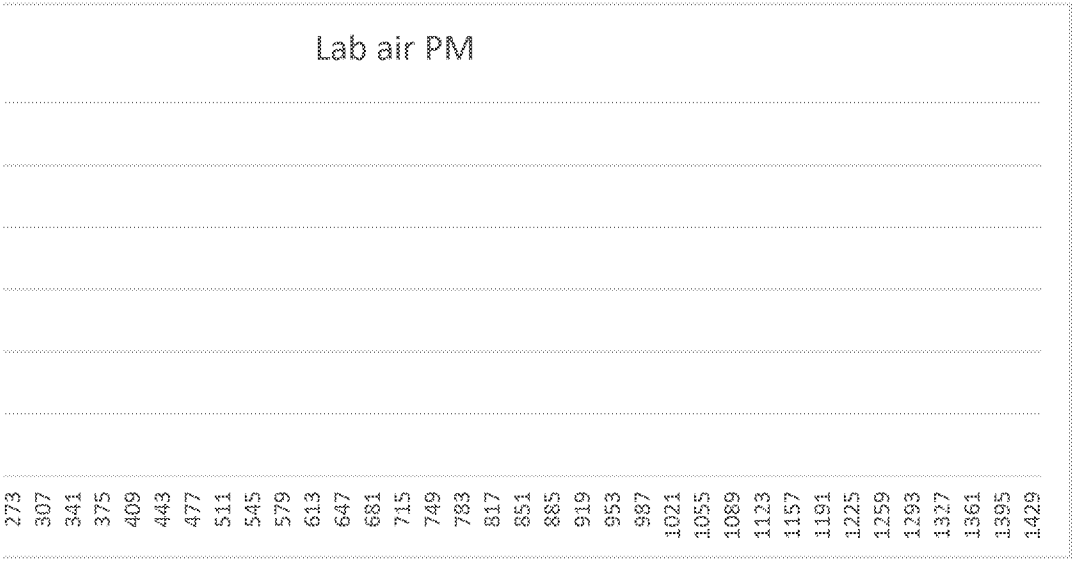

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Cell: E2
Comment: This is the final dataset, ug/m3

Cell: D3
Comment: Paste valid lab PM data here, ug/m3.

Cell: T5
Comment: These are run evaluation criteria.

Rev 0.9, 5/25/21
For up to 24 hours of 1405-Dichot 1-minute data, using parameter order as specified in the 1405-D SOP (as shown below)
See detailed instructions in TEOM SOP.

If RPComm is used for download, do not paste headers, and do not paste date column [just time].

Parameter order must be as shown here:
Time Stamp

SUMMARY OF INSTRUCTIONS:
Before pasting raw data, remove all data rows prior to the start of the test, leaving all the header rows [unless RPComm c

Trim the end of the data to remove all rows after the end of the test.
Enter pm-coarse flow setpoint in 1405 tab, cell B2 if not 1.00 lpm.
Enter lab air PM in column C of "1-min data and collo analysis" tab, and review in the Lab Air PM plot.

Notes:
Data with mode < 3 are automatically removed.
10-minute Average Results start in column J of 10-min tab.
All PM units are ug/m3, 68F and 29.92" Hg pressure, wet volume.
"reconstructed time" column A and B in 1405 tab is to detect any missing records.

, and downloaded with ePort, not RPComm.

Operating mode

download is used].

Note that the time in the raw data is "end of the minute" (not start), so remove up to and including the record with the ti

G. Allen, NESCAUM

PM-2.5 raw MC	PM-Coarse raw MC	PM-2.5 total mass	PM-Coarse total mass	Case temperature

me of the test start.

Cap temperature PM-2.5 flow rate PM-2.5 air tube temp PM-2.5 TEOM filter load

PM-2.5 TEOM filter pressure PM-2.5 TEOM noise PM-2.5 TEOM frequency PM-Coarse flow rate

PM-Coarse air tube temp PM-Coarse TEOM filter load PM-Coarse TEOM noise PM-Coarse TEOM frequency

Vacuum pump pressure System status

Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 9/8/2021 12:36:32 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
CC: gallen@nescaum.org
Subject: TEOM Ruggedness parameters

Stef, I am looking at the EPA testing overview spreadsheet because we have some questions about EPA's TEOM ruggedness assessment. Does EPA still plan to assess the ruggedness parameters for the TEOM below (taken from the EPA spreadsheet-TEOM validation tab)? Are you planning any tests at PFS with cordwood for TEOM ruggedness parameters, or will that work be done solely at ORD? For the CS work, we are contemplating some additional measurements to obtain data for TEOM ruggedness if that would be useful for EPA assessment work. Can we set up a time next week to discuss this work? Thanks!

1	**TEOM /DEKATI Diluter Validation Study**		
2			
3	**Appliance type**		
4			
5	Pellet Stove	7 Test Runs to determine precision of paired diluter/teom arrangements	To be conducted at ORD RTP
6	Pellet Stove	7 Test Runs to determine precision of paired diluter/teom arrangements	To be conducted at ORD RTP - Different fuel
7	Pellet Stove	14 Test runs to determine ruggedness of diluter/teom arrangments*	To be conducted at ORD RTP
8			
9	Wood Heater - Cordwood	7 Test Runs to determine precision of paired diluter/teom arrangements	To coinncide with IDC Stove validation work in EPA Approved lab
10	Wood Heater - Cordwood	7 Test Runs to determine precision of paired diluter/teom arrangements	To coinncide with IDC Stove validation work in EPA Approved lab - Different fuel
11	Wood Heater - Cordwood	14 Test runs to determine ruggedness of diluter/teom arrangments*	To coinncide with IDC Stove validation work in EPA Approved lab
12			
13	Wood Heater - Catalytic Cordwood	7 Test Runs to determine precision of paired diluter/teom arrangements	To coinncide with IDC Stove validation work in EPA Approved lab
14	Wood Heater - Catalytic Cordwood	7 Test Runs to determine precision of paired diluter/teom arrangements	To coinncide with IDC Stove validation work in EPA Approved lab
15			
16		70 **Total test runs** (Many may be accomplished concurrently with other validation testing)	
17			
18			

19	**ASTM E1169: Ruggedness parameters to be evaluated:**	**Condition High**	**Condition Low**	**Reference**
20	Dilution temperature	+50 deg F	-50 deg F	TBD
21	Dilution ratio	+10%	-10%	TBD
22	Sampling rate	+20%	-20%	TBD
23	Dilution Air	HEPA	Room	Quartz filter
24	Dilution moisture	Room	NAFION	Drierite
25	Filter temperature	95	75	85 deg F
26	TEOM Filter Change	3 hrs	dP trip	As needed

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Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 3/18/2021 12:57:10 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
Subject: east coast testing spreadsheet
Attachments: East coast testing.xlsx

Stef, attached is my spreadsheet laying out what I think EPA detailed for east coast RWH testing. Please check my numbers because they disagree with your spreadsheet that you sent to Ellen in fall 2020. I have double the number of tests. Perhaps I am confused.

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Cordwood Stove	Test Method
HS Castleton #1	IDC -est time 6-8 hrs
HS Castleton #1	IDC -est time 6-8 hrs
HS Castleton #2	IDC -est time 6-8 hrs
HS Castleton #2	IDC est time 6-8 hrs
Jotul v602 #1	IDC -est time 3-5 hrs
Jotul v602 #1	IDC est time 3-5 hrs
Jotul v602 #2	IDC -est time 3-5 hrs
Jotul v602 #2	IDC est time 3-5 hrs
FPI 3500 #1	IDC -est time 8-10 hrs
FPI 3500 #1	IDC est time 8-10 hrs
FPI 3500 #2	IDC -est time 8-10 hrs
FPI 3500 #2	IDC est time 8-10 hrs
Other costs/reporting for 52 stove runs - East Coast lab	

Pellet Stove	
HHT P68C #1	IDC -est time 6-8 hrs
HHT P68C #2	IDC est time 6-8 hrs
PS? #1	IDC -est time 6-8 hrs
PS? #2	IDC est time 6-8 hrs
Other costs/reporting for 28 pellet stove runs - East Coast lab	

Furnace	Test Method
SBI Commander #1	IDC -est time 8-10 hrs
SBI Commander #2	IDC est time 8-10 hrs
Furnace #2-1	IDC -est time 8-10 hrs
Furnace #2-2	IDC est time 8-10 hrs
Other costs/reporting for 28 furnace runs East coast lab	

Cordwood Boiler	Test Method
560 #1	IDC -est time 11-14 hrs
560 #2	IDC est time 11-14 hrs
CB #2-1	IDC -est time 11-14 hrs
CB #2-2	IDC est time 11-14 hrs

*TEOM ONLY

Fuel	# of runs	Cost per run*	Stove setup cost	Cost
maple	7			
birch/poplar/pine	7			
maple	7			
birch/poplar/pine	7			
maple	3			
birch/poplar/pine	3			
maple	3			
birch/poplar/pine	3			
maple	3			
birch/poplar/pine	3			
maple	3			
birch/poplar/pine	3			
	52		Test Report	
			Fuel	
			Break in Tests Budget	
			Total Budgeted	

hardwood	7			$ -
softwood	7			$ -
hardwood	7			$ -
softwood	7			$ -
	28		Test Report	
			Fuel	
			Break in Tests Budget	
			Total Budgeted	

Fuel	# of runs	Cost per run	Stove setup cost	Cost
maple	7			
birch/poplar/pine	7			
maple	7			
birch/poplar/pine	7			
	28		Test Report	
			Fuel	
			Break in Tests Budget	
			Aging	
			Total Budgeted	

Fuel	# of runs	Cost per run	Stove setup cost	Cost
maple	3			
birch/poplar/pine	3			
maple	3			
birch/poplar/pine	3			

1) Setup cc
purchase f

2) shake d
with that t
tests per fu

3) PM mea

140

Notes
›sts include time for install, any accessories to be installed as needed, parts to or install, changes to test stand ›wn tests are budgeted based on the advanced level of the technology and experience echnology. Budgeted 2 shake down test runs per stove and pellet stove, 4 shake down ırnace, cordwood boiler and pellet boiler.
surements are TEOM only, CO measurements with analyzer

total # of runs East Coast Lab

Other costs/reporting for 12 boiler runs East Coast lab	

Pellet Boiler	**Test Method**
Froling PE1-1	IDC TS-est time 8-10 hrs
Froling PE1-1	IDC TS-est time 8-10 hrs
Other costs/reporting for 6 PB runs east Coast lab	

PB with TS	**Test Method**
Windhager BioWin 2	IDC TS-est time 8-10 hrs
	IDC no TS-est time 8-10 hrs
Other costs/reporting for 14 PB TS runs - East Cost lab	

	12		Test Report	
			Fuel	
			Break in Tests Budget	
			Aging	
			Total Budgeted	

Fuel	# of runs	Cost per run	Stove setup cost	Cost
hardwood	3			
softwood	3			
	6		Test Report	
			Fuel	
			Break in Tests Budget	
			Aging	
			Total Budgeted	

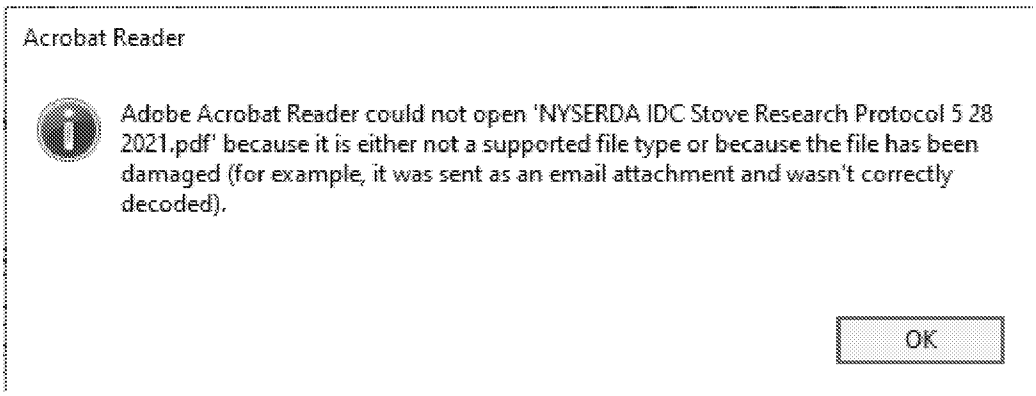
Fuel	# of runs			
hardwood	7			
softwood	7			
	14		Test Report	
			Fuel	
			Break in Tests Budget	
			Aging	
			Total Budgeted	

Message

From: Johnson, Steffan [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=EBA5C0DFC5FC4593AFA62CE7C3DD6F02-JOHNSON, STEFFAN]
Sent: 5/28/2021 2:05:23 PM
To: Lisa Rector [lrector@nescaum.org]; Burkhard, Ellen G (NYSERDA) [Ellen.Burkhard@nyserda.ny.gov]
CC: Garnett, Kim [Garnett.Kim@epa.gov]; Nash, Dave [Nash.Dave@epa.gov]
Subject: RE: protocol and calculator

Lisa,

In trying to open the .pdf of the IDC we all receive this error:



Might you be able to send a revised copy??

Thank you!

Stef

From: Lisa Rector <lrector@nescaum.org>
Sent: Friday, May 28, 2021 8:06 AM
To: Johnson, Steffan <johnson.steffan@epa.gov>; Burkhard, Ellen G (NYSERDA) <Ellen.Burkhard@nyserda.ny.gov>
Subject: protocol and calculator

Stef and Ellen, attached are the updated protocol and calculator for the IDC Stove test method. The password to unlock the calculator is **nescaum123456** which will allow you to review code from the calculator.

Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 5/25/2021 4:03:53 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
Subject: question

Is this the type of information you were looking for:

While TEOM data is only reported for the first hour of PM emissions, a comparison of the full run data using filter measurement versus TEOM data with no adjustments for the grams per hour metric was completed (should we also assess g/kg?). The analysis found that the first four valid test runs had a +11% deviation between the filter and TEOM measurements, with the TEOM providing higher values than the filter measurements. These second four valid runs had an average deviation of -14%, with the filter measurements reporting higher values. The variability in comparing TEOM and filter data is expected due to a variety of reasons. There is uncertainty due to the fixed 2% water correction for tunnel flow in the ASTM calculations, while the TEOM doesn't use any water correction. TEOM filters do not undergo desiccation, which leads to a higher TEOM value since the sample includes SVOC lost in the desiccation process. Finally, the TEOM does not have a recovery requirement for probes or tubing, which can lead to TEOM values that are less than filter measurements.

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| lrector@nescaum.org

Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 9/8/2021 4:23:00 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
Subject: filters and QAPP

Stef, IDC validation testing question - since filter measurements aren't in the QAPP, what guidance should I give Clearstak for those measurements?

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Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 11/16/2020 1:53:00 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
Subject: RE: paired dichot

Yes, it would be good to have that sooner rather than later. I am having Mark complete testing using different fuel placement and piece length on a non-cat – the most prone to changes. It would be good to know, if this data is useful for ruggedness testing.

From: Johnson, Steffan <johnson.steffan@epa.gov>
Sent: Monday, November 16, 2020 8:51 AM
To: Lisa Rector <lrector@nescaum.org>
Subject: RE: paired dichot

Lisa,

You are not wrong in that thinking. We intend to do ruggedness testing for the TEOM here in ORD, but will also need to evaluate different IDC parameters to limit the operating windows some. We are still trying to lay out the criteria there, with respect to the moving parts of the IDC. A good conversation to have.

Stef

From: Lisa Rector <lrector@nescaum.org>
Sent: Monday, November 16, 2020 8:41 AM
To: Johnson, Steffan <johnson.steffan@epa.gov>
Subject: RE: paired dichot

I also have questions about ruggedness testing. The work plan only includes replicate testing, but I thought data on ruggedness testing was also required. I am wrong in that thinking?

From: Johnson, Steffan <johnson.steffan@epa.gov>
Sent: Monday, November 16, 2020 8:28 AM
To: Lisa Rector <lrector@nescaum.org>
Subject: RE: paired dichot

Lisa,

We will meet.

Just understand that at no time do we envision the need for 4 dichot TEOMs.

Stef

From: Lisa Rector <lrector@nescaum.org>
Sent: Monday, November 16, 2020 8:08 AM
To: Johnson, Steffan <johnson.steffan@epa.gov>
Subject: RE: paired dichot

Thanks Stef, sorry, but I am confused. I think Graham has reached out to set up a meeting, and I would concur with his request.

From: Johnson, Steffan <johnson.steffan@epa.gov>
Sent: Monday, November 16, 2020 8:02 AM
To: Lisa Rector <lrector@nescaum.org>
Subject: RE: paired dichot

Lisa,

To be clear, this should not be confused with paired tunnels /appliances. In such instances a dichot in each is the goal. But where there is a single appliance, a paired dichot is the expectation, to provide precision criteria for the dichot on that IDC.

I hope this is helpful and I also hope my earlier reply was not confusing.

STef

From: Lisa Rector <lrector@nescaum.org>
Sent: Friday, November 13, 2020 11:30 AM
To: Johnson, Steffan <johnson.steffan@epa.gov>
Subject: paired dichot

Hi Stef, quick question on the EPA data needs. When the file states paired dichot teoms, do anticipate two dichots on the same tunnel?

NESCAUM

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| lrector@nescaum.org

Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 11/16/2020 1:39:57 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
Subject: RE: paired dichot

Okay, thanks for the clarification.

From: Johnson, Steffan <johnson.steffan@epa.gov>
Sent: Monday, November 16, 2020 8:28 AM
To: Lisa Rector <lrector@nescaum.org>
Subject: RE: paired dichot

Lisa,

We will meet.

Just understand that at no time do we envision the need for 4 dichot TEOMs.

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To: Johnson, Steffan <johnson.steffan@epa.gov>
Subject: RE: paired dichot

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To: Lisa Rector <lrector@nescaum.org>
Subject: RE: paired dichot

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From: Lisa Rector <lrector@nescaum.org>
Sent: Friday, November 13, 2020 11:30 AM
To: Johnson, Steffan <johnson.steffan@epa.gov>
Subject: paired dichot

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| lrector@nescaum.org

Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 3/5/2021 12:59:48 PM
To: Burkhard, Ellen G (NYSERDA) [Ellen.Burkhard@nyserda.ny.gov]; butcher@bnl.gov; Johnson, Steffan [johnson.steffan@epa.gov]
CC: Kelli O'Brien (kelli@clearstak.com) [kelli@clearstak.com]; Brian Vinal [brian@clearstak.com]; gallen@nescaum.org; Mark Champion [mark@hearthlabsolutions.com]
Subject: draft IDC furnace protocol
Attachments: Cordwood Furnace IDC FIRST DRAFT 03052021.docx

Good morning, for our call at 10 am today I have attached the first draft of the furnace protocol. I look forward to talking to you soon.

Lisa

NESCAUM

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Integrated Duty Cycle (IDC) Test Method for Certification of Thermostatically Controlled Central Warm Air Appliances: Measurement of Particulate Matter (PM), Carbon Monoxide (CO) Emissions and Heating Efficiency

Note: This method does not include all the specifications (e.g. equipment and supplies) and procedures (e.g., sample and analytical) essential to its performance. Some material is incorporated by reference from other methods. Therefore, to obtain reliable results, persons using this method shall have a thorough knowledge of at least the following EPA Tests

- Method 1- Sample and Velocity Traverses for Stationary Sources
- Method 2- Determination of Stack Gas Velocity and Volumetric Flow Rate
- Method 3 – Gas Analysis for the Determination of Dry Molecular Weight
- Method 4 – Determination of Moisture Content in Stack Gases
- Method 5G – Determination of Particulate Matter from Appliances (Dilution Tunnel Sampling Location)
- Method 10 - Carbon Monoxide - Instrumental Analyzer

1. *Scope and Application*

1.1. This test method applies to thermostatically controlled central warm air appliances that deliver heat through the circulation of a heated medium such air to remote areas through ducting.

1.2. This test method measures particulate matter (PM) emissions, carbon monoxide, and delivered heating efficiency at specified heat demands based on the appliances rated heat capacity.

1.3. Particulate emissions are measured by the dilution tunnel method as specified in ASTM E2515 *Standard Test Method for Determination of Particulate Matter Emissions Collected in a Dilution Tunnel* using only Emfab Pallflex filters. Additional particulate matter emissions measurements use the Tapered Element Oscillating Microbalance (TEOM) continuous PM method, as detailed in this test method. OR Particulate emissions are measured using the dilution tunnel method as specified in ASTM E2515 Standard Test Method for Determination of Particulate Matter Emissions Collected in a Dilution Tunnel.

Commented [LR1]: Should we be writing as TEOM only? Filter sections highlighted in yellow and can be removed.

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Particulate matter emissions measurements use the Tapered Element Oscillating Microbalance (TEOM) continuous PM method, as detailed in this test method.

1.4. Steady-state Heat Demand efficiency, which is reflective of efficiency measurements in current EPA Federal reference methods is determined by calculating the delivered efficiency at the high and low load steady heat demand periods of the test run (Phase 2 and 3, 5, and 6). Delivered annual fuel use efficiency is determined by measurement of the usable heat output (determined through measurement of the flow rate and temperature change of air) and the heat input (determined from the mass of dry fuel burned and its higher heating value) over the entire test run. Changes in the temperature of the appliance from the start to the end of the run are considered in the heat output determination. Delivered efficiency does not attempt to account for energy loss in the between the system and the building heat distribution system. Energy loss from the connected ducting to the surrounding test lab are included efficiency determination.

1.5. Products covered by this test method include thermostatically controlled central warm air appliances intended to be fired with wood and for which the manufacturer specifies for indoor or outdoor installation. The system is commonly connected to ducting normally includes an inlet air fan to circulate heated air. These systems are used to heat structures such as homes, barns, schools, and greenhouses.

1.6. Distinguishing features of products covered by this standard include:

1.6.1. The manufacturer specifies installation either inside a building or outside.

1.6.2. Products that automatically feed fuels, such as pelletized wood or wood chips.

1.6.3. Products that require manually feed fuels, such as cordwood.

1.6.4. A thermostat that controls the feed rate and combustion air supply to maintain the heating media in the appliance within a predetermined temperature range.

1.6.5. A chimney or vent that exhausts combustion products from the appliance.

1.7. The values stated are to be regarded as the standard, whether in I-P or SI units. The values given in parentheses are for information only.

1.8. Analyte. Particulate matter (PM). No CAS number assigned. Carbon monoxide (CO). No CAS number assigned.

1.9. Data Quality Objectives.

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1.9.1. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods.

1.9.2. Measurement of emissions and heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

1.9.3. This is a laboratory method intended to capture operating periods that are representative of actual field use without excessive test burden.

2. *Referenced Methods*

2.1. ASTM E2515: Standard Test Method for Determination of Particulate matter Emissions Collected in a Dilution Tunnel or latest approved EPA version.

2.2. NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel

2.3. NIST Monograph 175, Standard Limits of Error

3. *Definitions*

3.1. Appliance – an indoor or outdoor woodburning thermostatically controlled warm air heater capable of and intended for central heating through ducting or a plenum, as defined in the applicable regulation. Appliance includes combustion chamber, operating controls, an inlet and outlet air duct, and any other accessory required for standard operation, such as a barometric damper and a thermostat.

3.2. Catch - any mass from the sample probe system including PM on the front filter, back filter, and front half sample probe.

3.3. Certification or audit test - a series of at least three test runs conducted for certification or audit purposes that meets the specifications detailed in Section 8.

3.4. Coal-bed Stirring – prior to adding a new fuel charge, using a poker or piece of wood to stir or level the coal bed of the appliance for the sole purpose of ensuring ease of loading of the fuel charge. No special formations can be made, such as creating coal bed formations or pushing coals to one side or creating slopes with the coals.

3.5. Cordwood – Conventional firewood that comes from the splitting of logwood.

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3.6. Delivered Efficiency – The percentage of heat available in a test fuel charge that the appliance delivers to a simulated heating demand as specified in this test method.

3.7. Delivered Heat – Useful heat supplied by the thermostatically controlled central heating appliance through warm air ducting. Delivered heat does not include heat losses through appliance surfaces or stack pipe to the space the appliance is installed.

3.8. Draft – Potential for air flow or air through an appliance and its ducting system, normally measured as static pressure.

3.9. Emission Factor – the emission of a pollutant expressed in mass per unit of energy (typically) output from the appliance.

3.10. Emission Index – the emission of a pollutant expressed in mass per unit mass of fuel used.

3.11. Emission Rate – the emission of a pollutant expressed in mass per unit time.

3.12. Failed Test Run – any complete or partial test that does not meet the specifications detailed in this test method.

3.13. Firebox - the chamber in the appliance in which the test fuel charge is fed or loaded into and combusted.

3.14. Firebox Depth - the horizontal length of the fire chamber dimension measured perpendicular to the loading door. If the manufacturer believes that a portion of the firebox depth is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.15. Firebox Height - the vertical distance extending above the top of the firebox to the floor of the firebox. Firebox height is not necessarily uniform. The measurement must account for variations caused by internal baffles, air channels, or other permanent obstructions. If the manufacturer believes that a portion of the firebox height is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.16. Firebox Length - the longest horizontal fire chamber dimension that is parallel to a wall of the chamber. If the manufacturer believes that a portion of the firebox length is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.17. Firebox Width - the horizontal fire chamber dimension that is parallel to the loading door. If the manufacturer believes that a portion of the firebox width is not usable for

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firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.18. Fuel Adjustment –manipulations to the fuel charge to reflect typical owner practices that will allow the cordwood fuel to burn appropriately during the test period. A fuel adjustment does not include chopping the wood or stirring the coal bed. A fuel adjustment is minimal movement of a fuel charge piece or pieces that require no more than 30 seconds of time to complete.

3.19. Fuel Load Calculator – The locked excel spreadsheet tool that determines the allowable test fuel load weights and required piece sizes for each individual cordwood load.

3.20. Fuel Loading Direction – Fuel shall be loaded parallel to the greater of the width and depth dimensions. Crisscross is allowed for start-up phase, but cannot be used as a load configuration. If the firebox length and width are within 2" fuel shall be loaded in an east/west fashion, parallel to the loading door.

3.21. Heat Demand: Rate of transfer of heat from the inlet air of the appliance to the outlet air through the ducting, Btu/hr. (MJ/hr.)

3.22. Heat Output Rate – The average rate of energy output from the appliance during a specific test period, Btu/hr. (MJ/hr.).

Commented [LR2]: What definitions do we need to put around this item. Reviewers to note

3.23. Furnace– Same as appliance.

3.24. Idle – A control state where the thermostat signals that the appliance has "no call for heat". This can be achieved by either manually switching the thermostat off or manually reducing the thermostat setting below the inlet air temperature".

3.25. Kindling Pieces – small pieces of wood less than 1" in diameter. No bark or moisture requirements for these pieces, however kindling pieces shall not be dried or stored anywhere but in laboratory ambient conditions. Kindling length shall be of the same as the fuel charge length. and shall represent weights that would enable 8 to 12 pieces equal one pound.

3.26. Large Fuel Pieces – pieces that are larger for the appliance as defined by the fuel load calculator.

3.27. Manufacturer's Rated Heat Output Capacity –The value in Btu/hr. (MJ/hr.) that the manufacturer specifies that a particular model of warm air furnace is capable of supplying in steady state at its design capacity as verified by testing during Phase 2, 5 and Phase 6 of the test protocol.

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3.28. Phase – A distinct period in the test run with its own operational procedures and conditions.

3.29. Phase X Delivered Efficiency – The delivered efficiency of individual phases (X), specifically for Phase 2, Phase 3, and Phase 6 per test run.

3.30. Phase X Delivered Efficiency Average – Average delivered efficiency of individual phases (X) per test series specifically Phase 2, Phase 3, and Phase 6

Commented [LR3]: What efficiencies do we need to report – overall, high load, multiple loads?

3.31. NIST – National Institute of Standards and Technology

3.32. Secondary Air Supply - Air supply that introduces air to the appliance such that the burn rate is not altered by more than 10 percent when the secondary air supply is adjusted during the test run. The appliance manufacturer or test facility can document this through design drawings that show the secondary air is introduced only into a mixing chamber or secondary chamber outside the firebox.

3.33. Series Delivered Efficiency – The overall average delivered efficiency of each test run completed.

3.34. Small fuel pieces - pieces that are small for the appliance as defined by the fuel load calculator.

3.35. Starter fuel – pieces of cordwood that can be smaller than small and large pieces but larger than kindling, as defined by the fuel load calculator.

3.36. Thermostat – A control device that opens or closes a circuit to control the status of the burner in response to the temperature of the heating media in the heating appliance.

3.37. Temperature, Inlet – Temperature of the air supplied to the appliance for heating.

3.38. Temperature, Outlet – Average temperature of the delivered heat through the ducting.

3.39. Test Series– means the data for all test runs conducted on the heating appliance.

3.40. Test Facility - the area in which the heating appliance is installed, operated, and sampled for emissions.

3.41. Test fuel charge - the collection of test fuel pieces placed in the wood heater during the four phases of the test run. Each test fuel load shall have at least 75% of the individual pieces with at least 80% bark on one side of the fuel piece.

3.42. Test Run - An individual emission test, which encompasses the time required to complete all specified phases of the test profile.

3.43. Test Run Delivered Efficiency –The delivered efficiency of a test run.

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3.44. Thermopile - A device consisting of a number of thermocouples connected in series, used for measuring average temperature of the delivered heat in the ducting.

3.45. Usable firebox volume - the volume of the firebox determined using its height, length, and width as defined in this section, and as defined in section XXX.

3.46. Valid Test Run – a complete test run that complies with all requirements detailed in this test method.

3.47. X – Insert Phase number 1; 2; 3; 4; 5; 6.

Commented [LR4]: Please provide input on whether or not we need to provide full information, phase run information, and/or group phase information?

4. Interferences

None.

5. Summary of Test Method

5.1. Particulate matter emissions are measured from a wood burning cordwood test fuel in a test facility maintained at a set of prescribed ambient conditions. Procedures for operating the appliance, measuring PM and CO emission rates, and methods for reducing data and calculating results are provided.

5.2. *Dilution Tunnel.* A dilution tunnel following the specifications detailed in ASTM E2515-11 shall be used for particulate matter measurements.

5.3. *Particulate Matter:* PM emissions are measured in a dilution tunnel with a Thermo model 1405-D 2-channel TEOM using NESCAUM Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel with a dilution tunnel as specified in ASTM 2515 with modifications discussed in Section 10.

5.3.1. Filter-based method. Samples of the dilution tunnel flow stream are extracted at a constant flow rate and drawn through high-efficiency filters as defined in ASTM E2515-11 using Teflon coated filters such as Pallflex Emfab (TX40) with a maximum diameter of 47 mm, without organic binder, exhibiting at least 99.95 percent efficiency. The filters are equilibrated and weighed before and after the test to determine the emissions collected and this value is multiplied by the ratio of tunnel flow to filter flow to determine the total particulate emissions produced in the test cycle.

Commented [KO'B5]: All yellow high lite comes from ASTM E2515 and can be removed

5.4. *Carbon Monoxide.* The CO measured in the dilution tunnel and used to calculate efficiency determination.

5.5. *Delivered Efficiency.* Efficiency is measured by determining the fuel energy input and appliance output.

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5.6. Operation. Appliance operation is conducted on a cold-to-hot test cycle, meaning that the appliance starts the first test run at room temperature and ends with the appliance in fully heated state. The second and third test runs are started a slightly warmer temperature. The appliance is operated at a variety of heat demand loads, through the cycling of the thermostat, representing start-up emissions, high heat demand, low heat demand, cycling, idling, and recovery from nighttime set back. The appliance is operated through six heating phases during the test run. To complete the certification test, a minimum of three full test runs are averaged to determine the test results. For automatic feed systems, fuel is fed as determined by appliance delivery systems.

5.7. Repeatability. A series of at least three test runs comprised of six different heat demands or phases conducted for certification or audit purposes.

6. *Significance and Use*

6.1. The measurement of particulate matter emission rates is an important test method widely used in the practice of air pollution control.

6.1.1. These measurements, when approved by state or federal agencies, are often required for the purpose of determining compliance with regulations and statutes.

6.1.2. The measurements made before and after design modifications are necessary to demonstrate the effectiveness of design changes in reducing emissions and make this standard an important tool in manufacturers' research and development programs.

6.2. Measurement of heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

7. *Safety*

7.1. Disclaimer. This method may involve hazardous materials, operations, and equipment. This test method may not address all the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to performing this test method.

7.2. These tests involve combustion of wood, which releases substantial amounts of heat and combustion products. Appropriate precautions must be taken to protect personnel from burn hazards and respiration of products of combustion. Exposure of personnel to unsafe

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levels of carbon monoxide must be avoided, and the use of continuous ambient carbon monoxide monitoring is strongly recommended.

8. ***Equipment and Supplies***. The following items are required for sample collection:

8.1. Anemometer. A device capable of detecting air velocities less than 0.10 m/sec (20 ft/min), for measuring air velocities near the test appliance.

8.2. Appliance Flue.

8.2.1. Steel flue pipe extending to 8.5 ±0.5 ft. (2.6 ±0.15 m) above the top of the platform scale, and above this level, insulated solid pack type chimney extending to 15 ±1 ft (4.6 ±0.3 m) above the platform scale, and of the size specified by the appliance manufacturer. This applies to both freestanding and inserts type appliances.

8.2.2. Other chimney types (e.g., solid pack insulated pipe) may be used in place of the steel flue pipe if the appliance manufacturer's written appliance specifications require such chimney for home installation (e.g., zero clearance appliance inserts). Such alternative chimney or flue pipe must remain and be sealed with the appliance following the certification test.

8.2.3. Insulated Solid Pack Chimney. For installation of appliances. Solid pack insulated chimneys shall have a minimum of 2.5 cm (1 in.) solid-pack insulating material surrounding the entire flue and possess a label demonstrating conformance to U.L. 103

8.3. Appliance Platform Scale and Monitor. platform scale capable of weighing the appliance under test and associated parts and accessories when completely filled with water to an accuracy of ± 1 pound (± 0.45 kg) and a readout resolution of ± 0.2 pound (± 0.1 kg).

8.4. Barometer. Aneroid or other barometer capable of measuring atmospheric pressure to within 0.1 in. Hg (2.5 mm Hg).

8.5. Differential Pressure Gauges. An *inclined manometer*. Or equivalent devices sufficient for measuring flow and static pressure in the warm air duct and a resolution of 0.005 in WC (1.24 Pa).

8.6. Dilution Tunnel must meet the requirements of ASTM E2515, clauses 6.1.6 and 9.2.

8.7. Dilution Tunnel temperature and relative humidity measurement. A probe capable of measuring tunnel temperature to within 0.9 ˚F (0.5 ˚C)) and tunnel RH to within 2%, such as the Omega HX85-A or equivalent.

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8.8. *Flue Gas Temperature Measurement*. A type K- thermocouple or equivalent located in the centroid of the stack located 8.0 +/- 0.5 ft (2.44 m +/- 150 mm) above the platform scale. Capable of measuring with an accuracy of 4.0˚F (2.2˚C) or 0.75% of reading, whichever is greater.

8.9. *Flue Gas Composition Measurement*. A sample probe and continuous infrared analyzer or equivalent capable of measuring span of carbon monoxide (CO) and carbon dioxide (CO_2) in the flue gas produced by the appliance tested. Continuous analyzers (or equivalent) shall have maximum zero and span drift, over a 24 h period, of 1% of full scale

8.10. *Flow Straighteners.* Flow straighteners may be fitted at the beginning of the outlet air duct to improve flow characteristics.

8.11. *Fuel Scale*. Balance capable of weighing the test fuel charge to within 0.02 kg (0.05 lb.) and calibrated to NIST traceable standards at least annually.

8.12. *Humidity Gauge*. Psychrometer or hygrometer for measuring Relative humidity measurement in lab with accuracy of 2% RH

8.13. *Inlet Air Temperature Measurement.* Thermocouple or other temperature sensor located centrally in the inlet duct to measure air entering the inlet duct.

8.14. *Ionizing air blower (or 210Polonium alpha sources).* For reducing static charge build up on beakers and/or filter media.

8.15. *Moisture Meter.* Calibrated electrical resistance meter for measuring test fuel moisture to within 1 percent moisture content.

8.16. *Outlet Air Temperature Measurement.* The outlet air temperature shall be measured centrally in the warm air duct and be located approximately eight duct diameters downstream and at least 0.8 in. (20 mm) downstream of the velocity measuring probe. The outlet air duct.

8.17. *Standard Pitot tubes*. Pitot tubes will have an assumed Pitot coefficient of 0.99.

8.17.1. For measuring flow velocity in the outlet duct at least 8 duct diameters downstream of duct inlet or flow straighteners, and continuing at least 2 duct diameters past the outlet duct temperature measurement.

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8.17.2. For measuring flow velocity in the dilution tunnel at least 8 duct diameters downstream of the 90˚ bend in the sampling section.

Commented [LR6]: EPA Method 2 is referenced in CSA but it should be used for ducting less than 12". Do reviewers have a better alternative for measuring duct flow?

8.18. Test Facility Temperature Monitor. A thermistor, RTD, or other equivalent device, located centrally in a vertically oriented 150 mm (6 in.) long, 50 mm (2 in.) diameter pipe shield that is open at both ends, capable of measuring temperature to within 1.0˚F (0.56˚C) of expected temperatures.

8.19. TEOM – Thermo Fisher Scientific TEOM model 1405-D (Thermo part # 1405D-ANF, excluding models 1405, 1405-DF, or 1405-F) to measure and report continuous particulate matter (PM) measurements in an ASTM 2515 dilution tunnel or equivalent dilution method, and operated according to the NESCAUM Dichot TEOM Standard Operating Procedures.

9. *Calibration, Standardization and Quality Control*

9.1. Anemometer. Calibrate the anemometer as specified by the manufacturer's instructions before the first certification test and semiannually thereafter.

9.2. Appliance Platform Scale. Perform a multi-point calibration (at least five points spanning the operational range) of the platform scale before its initial use. The scale manufacturer's calibration results are sufficient for this purpose. Before each certification test, audit the scale with the wood heater in place by weighing at least one calibration weight (Class F) that corresponds to between 20 percent and 80 percent of the expected test fuel charge weight. If the scale cannot reproduce the value of the calibration weight within 0.0045 kg (0.01 lb.) or 1 percent of the expected test fuel charge weight, whichever is greater, recalibrate the scale before use with at least five calibration weights spanning the operational range of the scale.

9.3. ASTM E2515-11. Perform all calibrations required by ASTM E2515-11

Commented [LR7]: Should we revise and not reference ASTM 2515?

9.4. Barometer. Calibrate before initial use and semiannually thereafter.

9.5. Differential Pressure Gauges. Electronic gauges or equivalent shall be calibrated before the first certification test and semiannually thereafter. For inclined manometers use oil gauge fluid with a specific gauge of 0.826.

9.6. Flue Gas Analyzers. In accordance with CSA B415.1-2010, Clause 6.8.

Commented [LR8]: Should we revise and draft our on narrative on flue gas analysis or reference an EPA method?

9.7. Fuel Scale. Calibrate as described in 9.2.

9.8. Humidity Gauge. Calibrate before the first certification test and semiannually thereafter.

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9.9. Moisture Meter. Calibrate as per the manufacturer's instructions before the first certification test and semiannually thereafter.

9.10. Temperature Sensors. Calibrate using at least five points within operating range within specification and in compliance with NIST Monograph 175. To be calibrated before the first certification test and semiannually thereafter.

10. Sampling, Test Specimens, and Test Appliances

10.1. Modifications to ASTM E 2515 requirements.

10.1.1. Liquid water should not be present anywhere in the sampling system for a valid sample. The presence of condensed water anywhere in the sampling system invalidates the test run. All data from all invalid test runs shall be included in the report. The reviewing authority shall make a final determination on invalidated runs. Data from any invalidated test run shall not be used to calculate results. If the testing agency believes a run has been invalidated, the test run shall be repeated.

10.1.2. Dilution tunnel temperature and relative humidity shall be measured and logged near the sample probe to calculate tunnel dewpoint.

10.1.3. Filter temperature shall be measured and logged using a measurement method with an accuracy of 1.0 ˚F (0.56 ˚C)) or better.

10.1.4. The following section details test conditions that shall be maintained for any valid test run. A valid test shall have no more than two individual deviations from any of the conditions below to remain a valid run. An example of an individual deviation is a single, five-minute rolling average where the dilution tunnel exceeded temperature thresholds. Another five-minute period exceeding the tunnel temperature requirement shall be considered a second deviation.

10.1.4.1. Tunnel temperature shall not exceed 104.0˚F. F (40.0˚C) based on ten-minute rolling averages derived from one-minute data, excluding periods when the appliance door is open.

10.1.4.2. Tunnel relative humidity shall not exceed 90% based on ten-minute rolling averages derived from one-minute data.

10.1.4.3. Tunnel dew point temperature shall not exceed 87.8˚F (31.0˚C).

10.1.4.4. A minimum tunnel flow of 600 CFM is required. Higher tunnel flows may be required to meet the parameters of Section 10.1.3.

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10.1.4.5. All exceedances must be reported in the test anomalies section, even if deviations are within the test method tolerances.

10.1.5. The following section details test conditions that shall be maintained for any valid test run. A valid test shall have no more than two individual deviations from any of the conditions below to remain a valid run. An example of an individual deviation is a single, five-minute rolling average where the dilution tunnel exceeded temperature thresholds. Another five-minute period exceeding the tunnel temperature requirement shall be considered a second deviation.

10.1.6. Particulate Matter Sampling for one-hour filter pull. PM emissions allow the use of two options to obtain integrated results and one-hour emissions data.

10.1.6.1. **Option 1** - three ASTM E2515 trains will be used for this testing.

10.1.6.2. Proportional Rate Variation shall meet the requirements of ASTM E2515 for all phases.

10.1.6.3. Train 1: Start-up Measurement. A measurement of the start-up phase will be reported using one ASTM E2515 train. This measurement will commence at the beginning of the test and ends sixty (60) minutes after commencing the test.

10.1.6.4. ASTM E2515 Trains 2 and 3: Integrated load measurement. Two, dual ASTM E2515 trains will measure particulate for the entire test run.

10.1.6.5. Option 1 use three ASTM E2515 trains, two are run through the entirety of the test and one obtains measurement for the first hour.

10.1.7. **Option 2** – 2 ASTM E2515 trains and TEOM.

10.1.7.1. Proportional Rate Variation shall meet the requirements of ASTM E2515 for all phases.

10.1.7.2. ASTM E2515 Trains 1 and 2: Integrated load measurement. Two, dual ASTM E2515 trains will measure particulate for the entire test run.

10.1.7.3. TEOM data will be collected at 10-second intervals and averaged up to 1-minute intervals for reporting. TEOM operation shall follow the procedures listed in the TEOM SOP found at [HYPERLINK "https://www.nescaum.org/topics/test-methods"]. TEOM data shall be recorded on an excel spreadsheet following the minimum data reporting

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requirements. Emissions from the ASTM E2515 trains shall serve as the primary PM emission measurement. The TEOM data will be used to report emissions for the first, one-hour period.

10.1.8. **Option 3** - two ASTM E2515 trains will be used for this testing.

10.1.8.1. Proportional Rate Variation shall meet the requirements of ASTM E2515 for all phases.

10.1.8.2. A measurement of the start-up phase will be reported using one ASTM E2515 train. This measurement will commence at the beginning of the test and ends sixty (60) minutes after commencing the test.

10.1.8.3.Start-up Measurement (one-hour filter pull) – Both trains will change filters at the one hour. Data from this filter pull will be reported separately as the one-hour measurement. PM from one-hour filters will be combined with other filter measurements for total filter run.

10.1.9.Weigh room conditions. The following conditions shall be met:

10.1.9.1. The facility shall use an active ionizing air blower (or 210Polonium alpha sources) to neutralize charge associated with the filter. 210Polonium alpha sources must be replaced annually or more often.

10.1.9.2. Temperature range of 68.0 to 78.0 ˚F (20.0 to 25.6 ˚C).

10.1.9.3. Relative humidity shall be no higher than 45%.

10.1.9.4.*Filter equilibration / conditioning post sample collection*. Use of desiccation is not allowed. Equilibrate filters at a relative humidity between 30 and 40% for at least 24 hours. A saturated salt solution of magnesium chloride (33% RH) can be used. PREPARATION OF SALT SOLUTIONSU: Use only pure distilled water to make up the solution. Put 200 g of the salt into a beaker. Gradually add distilled water. Stir well after each addition, until the salt can absorb no more water, as will be evidenced by some free liquid on the surface of the mixture. For best results keep the excess liquid to a minimum. The mixture should be slushy but must have a small amount of liquid water on the surface. Put this slushy mixture in the desiccant tray of the equilibration chamber. After equilibration, the chamber RH should measure 33% +/- 3%.

10.1.10. Filter weight measurements. Report the following filter measurements:

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10.1.10.1. Day zero – initial filter measurement before going into the equilibrium chamber.

10.1.10.2.*Blanks*. Test reports shall measure and report data on blanks as follows:

10.1.10.3. Lab blank, which is removed from each filter batch, stored in a protective environment, and weighed during each weighing session.

10.1.10.4. Room blank collected during every test run. The blank shall be placed within 10 feet of the intake for the dilution air

10.1.11. Probe Catch: Report sampling system catch as a separate number from filter catch.

10.2. Teflon coated glass fiber filters as supplied by the TEOM manufacturer for use with the TEOM model 1405-D. These are Pallflex Emfab (TX40) with an exposed diameter of 13 mm, without organic binder, exhibiting at least 99.95 percent efficiency.

10.3. Test Specimens. Appliance shall be supplied as a complete system, including all controls and accessories necessary for installation at the test facility including any special insulation. A full set of specifications, designs, and assembly drawings shall be provided when the product is placed under certification of a third-party agency. Examples of parts to be supplied by the manufacturer could be a thermostat or various sensors required for communicating duct outlet temperature to the appliance.

10.4.User Guide. The manufacturer must supply a one-page user guide that will direct certain portions of the test protocol. The User Guide must be provided to the lab and the consumer as a single sheet and documented in the test report. The user guide shall be the only directions provided and used by the testing facility for certification purposes; it shall address key user operations for simple residential duct heating, and it shall conform to the following requirements. Manufacturers are not allowed to direct or inform any portion of testing or deviate from operations specified in this test protocol. The User Guide that can be used to inform appliance operation during certification testing. User Guide Layout Requirements – the User Guide shall conform to the following design specifications:

10.4.1. Directions must be illustrated by text and colored pictures

10.4.1.1. Font size – minimum font size is 12.

10.4.1.2. Use of columns allowed

10.4.1.3. Margins – must have a minimum of ¾" inch margins

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10.4.1.4. A minimum of 40% of the user guide must use graphics or photos to support text directions.

10.4.1.5. Complete instructions but fit on a double sided of an 8 x11.5-inch sheet of paper

10.4.1.5.1.One side may be used to show tank setup and control settings

10.4.1.6. Must be provided in a laminated form to the consumer.

10.4.2. User Guide elements – The User Guide cannot contradict or deviate from user instructions provided in the appliance user manual. The User Guide shall include information on the following items.

10.4.2.1. Appliance preparation – what must be done to the appliance prior to starting a fire to include appliance setpoints and software settings.

10.4.2.2. Appliance settings – to include modulation setpoints, shut-off temperatures, and other operations that are part of normal operation (cleaning cycles, etc)

10.4.2.3. Reloading procedures – If applicable, guidelines for properly reloading fuel once a fire has been started in the appliance.

10.5.Preparation of Apparatus

10.5.1. Assemble the appliance and parts in conformance with the manufacturer's provided User Guide. These instructions must match all instruction materials developed by the manufacturer and/or their distributors. Manufacturer may assist or instruct during the install prior to the first test.

*10.5.2.*Place the appliance centrally on the platform scale meeting the requirements

10.5.3. Setup shall conform to the schematics provided below.

XXXXINCLUDE DIAGRAM

Commented [LR9]: Can reviewers look at this section carefully does this seem correct? Are we missing something? Tom does ASHRAE have something we can reference.?

Figure [SEQ Figure * ARABIC]. *Test Ducting Configuration*

10.5.4.Appliance Ducting

10.5.4.1.Insulation shall be minimum 0.6 in. (1.5 cm) of fiberglass insulation if specification is not provided by the manufacturing instructions;

10.5.4.2.Provide a flow velocity sufficient for measurement with an accuracy of +/- 5% at all fan operating speeds

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10.5.4.3. Be of adequate cross-sectional area to allow static pressure in the duct at or below specified in this method. Can be fitted with adjustable restrictors at the duct exits to allow a target static pressure when the circulating blower is at its highest setting and with the circulating air at room temperature.

10.5.4.4. Be of minimum length to provide at least eight duct diameters downstream of duct inlet or flow straighteners for flow velocity measuring and continuing at least 2 duct diameters past the measuring point to minimize impact of the outlet air on test enclosure temperatures.

10.5.4.5. Warm air duct shall have at least ten duct diameters or equivalent for non-circular ducts.

10.5.4.6. The reported heat output rate shall be based on measurements made on the load side of the heat exchanger.

10.5.4.7. Flow straighteners may be fitted in the beginning of the outlet air duct to improve air flow characteristics.

10.5.4.8. The outlet air duct may exit vertically from the furnace.

10.5.4.9. The inlet air duct shall be at least 1.6 ft (0.5 m) long shall be fitted. If appliance has various inlet plenum locations, the location for testing shall be specified in the User Guide.

10.6. Furnace Duct Velocity

10.6.1. Install a standard pitot tube and pressure differential gauge for measuring velocity shall be installed to measure a single point measurement near the centroid of the warm ducting at a minimum of eight duct diameters downstream of the inlet ducting and any flow disturbances.

10.6.1.1. A velocity traverse, meeting requirements of EPA Test Method 1, shall be conducted in the warm air duct to determine a correction factor for determining actual flow rate.

Commented [KO'B10]: EPA test method 1 does not work with small ducts. Need to find another procedure. We followed the rules for traverseing the tunnel in ASTM E2515.

10.7. Starting Weight. Prior to firing the appliance with, weigh and record the appliance mass.

10.8. Conditioning

10.8.1. Appliance Aging. Prior to testing, the appliance shall be operated for a minimum of 50 hours using a variety of heat demands. The conditioning may take place at the manufacturer's facility prior to testing or at the certification facility.

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10.8.2. If the appliance uses a catalytic combustor, it must be engaged according to manufacturer's instructions and operate for at least 50 hours during the break-in period. Report hourly catalyst exit temperature data and the hours of operation.

10.8.3. Appliance Aging Documentation. The aging procedure shall be conducted and documented by the manufacturer or the certified testing laboratory. All aging data must be reported and shall include the hours of operation and heat demands for aging, hourly flue gas temperature, amount of fuel burned, fuel parameters (species, heat demands, and fuel types), air and control settings used, and note the time spent in each phase.

11. Procedure

11.1.Test Facility Conditions. The test facility shall meet the following requirements during testing:

11.1.1. Shall conform to 9.7 of ASTM E2515-11

11.1.2. The test facility temperature shall be maintained between 55.0 and 90.0˚F (12.8 and 32.2 ˚C) during each test run

11.1.3. The flue shall discharge into the same space or into a space freely communicating with the test facility. Any hood or similar device used to vent combustion products shall not induce a draft greater than 0.005 in. H_2O (1.25 Pa) on the wood heater measured when the wood heater is not operating.

11.1.4. For test facilities with artificially induced barometric pressures (e.g., pressurized chambers), the barometric pressure in the test facility shall not exceed 30.5 in. Hg (775 mm Hg) during any test run.

11.1.5. Locate the test facility temperature monitor on the horizontal plane that includes the primary air intake opening for the wood heater. Locate the temperature monitor 3 to 6 ft. (1 to 2 m) from the front of the wood heater in the 90° sector in front of the wood heater.

11.1.6. Air velocities within 2 ft (0.6 m) of the test appliance and exhaust system shall be less than 50 ft/min (0.25 m/sec) without fire in the unit prior to startup and one immediately following the test run completion

11.2.Cordwood warm air furnaces

11.2.1. Wood Heater Firebox Volume.

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11.2.1.1.Determine the firebox volume using the definitions for height, width, and length in Section 3. Volume adjustments due to the presence of firebrick and other permanent fixtures may be necessary. Adjust width and length dimensions to extend to the metal wall of the wood heater above the firebrick or permanent obstruction if the firebrick or obstruction extending the length of the side(s) or back wall extends less than one-third of the usable firebox height. Use the width or length dimensions inside the firebrick if the firebrick extends more than one-third of the usable firebox height. If a log retainer or grate is a permanent fixture and the manufacturer recommends that no fuel be placed outside the retainer, the area outside of the retainer is excluded from the firebox volume calculations

11.2.1.2.In general, exclude the area above the ash lip if that area is less than 10 percent of the usable firebox volume. Otherwise, consider consumer loading practices. For instance, if fuel is to be loaded front-to-back, an ash lip may be considered usable firebox volume.

11.2.1.3. Include areas adjacent to and above a baffle (up to two inches above the fuel loading opening) if four inches or more horizontal space exist between the edge of the baffle and a vertical obstruction (e.g., sidewalls or air channels).

Commented [LR11]: This is the firebox volume definition from Method 28 is this sufficient?

*11.2.2.*Cordwood fuels shall conform to the following requirements.

11.2.2.1.Fuel Species. Untreated, air-dried, cordwood fuel.

11.2.2.1.1.Allowable species: maple (big leaf, red, silver), oak (white), fir (Douglas), or white birch.

11.2.2.1.2.Kiln-dried fuel is not permitted.

11.2.2.1.3.Fuel shall be free of decay, fungus, or other contaminants.

11.2.2.2. Fuel Moisture.

11.2.2.2.1.The test fuel shall have a moisture content range between 16 to 20 percent on a wet basis (19 to 25 percent dry basis).

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11.2.2.2.2.The addition of moisture to previously dried wood is not allowed.

11.2.2.2.3.Use of kiln-dried wood is not allowed

11.2.2.2.4. It is recommended that the test fuel be stored in a temperature and humidity-controlled room.

11.2.2.2.5.Fuel moisture shall be measured within 24 hours of using the fuel for the test and shall be stored in a humidity-controlled environment prior to testing.

11.2.2.2.6.No moisture requirements from kindling fuel.

11.2.2.3. Fuel Temperature. The test fuel shall be at the test facility temperature of 55.0 to 90.0°F (12.8˚C to 32.2˚C).

11.2.2.4.Fuel length:

11.2.2.4.1.The length of the piece will be determined by the fuel load calculator.

11.2.2.4.2.Measurements shall be taken, and the length of the test fuel will be determined by entering the firebox dimensions, which calculates the length for all the fuel pieces into a generally available commercial size (14, 16, 18, 20 or 22 inches in length).

11.2.2.4.3.Piece length specified by the fuel calculator shall be communicated and specified for use in the owner's manual and website.

11.2.2.5.Fuel Loading Direction

11.2.2.5.1.Fuel loading direction shall be determined by the firebox measurement.

11.2.2.5.1.1.Furnaces with a depth measurement greater than two inches from the length shall be tested with the fuel in a north-south configuration.

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11.2.2.5.1.2. Furnaces with a length measurement up to two inches shorter than the depth measurement shall be tested with the fuel loaded in an east-west configuration may not test with fuel in a north-south configuration and vice versa.

11.2.2.6. Cordwood load weight shall be determined by the fuel load calculator.

11.2.2.6.1. Kindling to be 1 lb./ft^3 of firebox volume in total weight with individual piece weight and size meeting specifications determined by the fuel load calculator.

11.2.2.6.2. Starter Fuel to be 3 lbs./ft^3 of firebox in total weight with individual piece weight and side meeting specifications determined by the fuel load calculator.

11.2.2.6.3. Cordwood Load 1 loading density consists of 10lbs./ft^3 of firebox volume. 6lbs/ft^3 of the load shall be made up of small pieces as defined in Section 3 and 4lbs/ft^3 of the load must be made up of large pieces as defined in Section 3.

11.2.2.6.4. Cordwood Load 2 loading density consists of 14 lbs./ft^3 of firebox volume. 80% of the load shall be made up of large pieces at a minimum.

11.2.2.7. Kindling –shall be:

11.2.2.7.1.1. pieces of wood less than 1" in diameter.

11.2.2.7.1.2. No bark requirements for kindling fuel

11.2.2.7.1.3. No moisture requirements.

11.2.2.7.1.4. Length of kindling shall be 50% to 100% of the fuel length specified by the fuel load calculator.

11.2.2.7.1.5. Kindling fuel shall conform to the rule that 7 to 12 pieces of kindling equal 1 lb. of kindling fuel (+/- 10%).

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11.2.2.8. Starter fuel: pieces of cordwood shall be used during the startup phase. Individual piece weight for starter fuel shall be determined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall be not be used in testing (see Figure 1). Pieces that have squared cross sections shall be split to represent the typical triangle nature of wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible and fuel load pieces shall be composed to include different shapes of wood if using any trapezoidal pieces. .

11.2.2.9. Small fuel pieces: smaller pieces of cordwood by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall not be used (see figure 1). Pieces that have square cross-sections shall be split to represent the typical triangle nature of wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible. No more than 2 small fuel pieces can be trapezoidal in shape (Figure 2) per fuel load.

11.2.2.10. Large fuel pieces: larger pieces of cordwood, by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall be not be used (see figure 1). Pieces that have square cross sections shall be split to represent the typical triangle nature of wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible. No more than 1 large fuel pieces can be trapezoidal in shape (Figure 2) per fuel load.

Figure 1. Schematic of unacceptable cross-sectional profiles

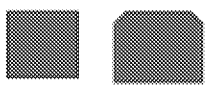

Figure 2. Limited Acceptance

Figure 3. Schematics of acceptable cross-sectional profiles

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11.2.2.11.

11.3.Automatically Feed Warm Air Furnaces

*11.3.1.*Pelletized fuels shall conform to the following requirements:

11.3.1.1. Fuel used must be PFI, CANplus, or ENPlus certified, or other equivalent fuel certification standard.

11.3.1.2. Test fuel must undergo and report ultimate/proximate analysis by an independent accredited lab.

11.3.1.3. All fuels used for testing must have a temperature no greater than 5 ˚F of laboratory temperature when loaded into the appliance within 60 minutes of starting the test.

11.3.2. Wood chip fuels shall conform to the following requirements:

11.3.2.1. Fuel used for testing must undergo ultimate/proximate analysis by an independent accredited lab.

11.3.2.2. Fuel used for testing must be characterized by ANSI/ASABE AD17225-4:2014 FEB2018 Solid biofuels — Fuel specifications and classes — Part 4: Graded wood chips

Commented [KO'B12]: All blue refers to be pellet or chip fuel and can be rem

11.4. Manufacturer participation in certification testing

*11.4.1.*A representative of the manufacturer may observe testing but may not provide instructions to the certification lab, in any form, with testing staff or equipment once the certification tests begin. The names of testing witnesses cannot be withheld as confidential business information (CBI).

11.4.2. During certification testing, the appliance cannot be connected for remote access. Nor can the appliance be operated remotely. For example, the appliance cannot be connected to the internet unless remote access is to allow for remote witnessing or recording of the test. Remote access may only be granted by the certification

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laboratory. If remote access is granted, witness list shall reflect those who have been granted remote witness capacity and provide recordings of remote activities as part of the test report.

11.5. Appliance Instructions and Program Configuration/Setting

11.5.1. For certification testing, all system control settings shall be tested with all controls and software set as-the manufacturer will ship or install, often referred to as default settings. These default settings shall be specified by the manufacturer and included in the test report. Settings for certification testing shall match those communicated in all manufacturer materials and installation instructions to the installer or end-user.

11.5.2. Appliance Operation and Adjustments. If appliance does not arrive with control settings preset, then follow user guide instructions for control setting. Adjustments to controls are not allowed once testing has begun. If adjustments to controls are required due to invalid test run, then it is documented, and the user guide must be revised prior to starting the new test series.

11.5.3. Manufacture representative may assist with control settings prior to the start of the test but must be consistent with the user guide and any deviations from the User Guide will require a revised User Guide prior to the start of the certification test series.

11.5.4. Control settings and the documentation of the control settings shall be included in the user guide and in the non-CBI portion of the test report.

11.6. Before each test series, the firebox shall be vacuumed. Testing shall begin without any ash or other materials in the appliance.

11.7. Before initiating the compliance test, clean the flue and dilution tunnel with an appropriately sized wire chimney brush before each certification test. Test documentation should include the date and time of flue cleaning.

11.8. All air temperatures, warm air duct flowrates, and appliance temperatures, and all other temperature sensors shall be recorded at intervals of 1 minute or less.

11.9. Scale weight shall be recorded at 1-minute intervals and documented at the start and end of each test phase.

11.10. Test Run Procedure. The table below summarizes the phases that encompass a complete test run. A complete test run requires completion of all six phases of the test protocol, as described below.

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IDC Furnace Test Procedure Summary DRAFT	
Phase 1-Start-up	Startup with kindling and starter fuel, then add Cordwood Load 1 when coal bed is 20% of Cordwood Load 1. Continue until Cordwood Load 1 is loaded into firebox and heat is delivered through ducting.
Phase 2 – Maximum Heat	Thermostat on for 60 minutes
Phase 3 – Cyclic Operation	Thermostat cycles 15 minutes off and 15 minutes on until 75% of fuel load is consumed.
Phase 4 -No demand	Thermostat is shut off for 45 minutes. Zero scale and then add Cordwood Load 2 when Cordwood load 1 is 90% consumed or after 45 minutes, whatever comes first.
Phase 5 – Low Heat Demand	Thermostat cycles 30 minutes off and 5 minutes on. until 50% of Cordwood Load 2 is consumed and a minimum of 1 30/5 cycle is completed.
Phase 6 - Recovery	Thermostat is on for 60 minutes or 100% consumption of Cordwood Load 2, whatever comes first.

11.10.1.Phase – Start-up

11.10.1.1.Tare the appliance scale before starting the test. Record appliance scale weights at the start of Phase 1.

11.10.1.2.Appliance Parameters

11.10.1.2.1.*Appliance temperature*. For the first run (Run #1) firebox temperature shall be recorded.

11.10.1.2.1.1.Appliance and firebox temperatures shall be measured within 60 minutes of starting the test run and shall be reported for all test runs.

11.10.1.3.Appliance Operation during Phase 1

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*11.10.1.3.1.*The thermostat shall be in the ON position or in a setting that is higher than the lab room temperature to ensure a constant call for heat.

11.10.1.3.2.Cordwood Furnace

*11.10.1.3.2.1.*Load and fire starter fuel and kindling per the User Guide. An option of up to six full sheets of traditional newspaper mat be used. All kindling, starter fuel, and newspaper must be in the firebox for light off.

*11.10.1.3.2.2.*Light a fire with a torch for a period of no more than 60 seconds. The firebox door may be cracked open no more than 1 inch up to 5 minutes from the time of lighting and then the firebox door is closed immediately.

11.10.1.3.2.3. Fuel Adjustments*:* Up to three fuel adjustments, no longer than 30 seconds, are allowed prior to loading Cordwood Load 1 and must be documented in the test report notes and summary.

*11.10.1.3.2.4.*Load Cordwood Load 1 within 60 seconds when scale indicates a coal bed that is 20% of Cordwood Load 1. The firebox door may be cracked open no more than 1 inch up to 5 minutes from the time of loading and then the firebox door is closed immediately.

11.10.1.3.3.Automatically Feed Furnace

11.10.1.3.3.1.Follow User Guide to startup appliance and begin fueling.

11.10.1.4.End of Phase 1: Phase 1 shall end when the appliance delivers heat through the warm air duct as observed through a detection of warm air flow and the operation of the warm air duct fan and Cordwood Load 1 has been loaded into the firebox. Both conditions must be met. If heat is delivered prior to loading Cordwood Load 1, then Phase 1 ends when upon loading Cordwood Load 1.

11.10.1.5.Photo Documentation – Pictures to show the following: kindling and starter fuel, Kindling and starter fuel in firebox, coal bed prior to adding Cordwood Load 1, firebox loaded with Cordwood Load 1, and of the firebox for any before and after fuel adjustments.

Commented [LR13]: Should we remove photo documentation requirement and add requirement for video? Unlike stoves, not much to see once the door is closed.

11.10.2. Phase 2 – Maximum Heat Demand. This phase commences immediately after Phase

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11.10.2.1.*Appliance Parameters Phase 2.* During Phase 2, the unit must produce an average heat output rate that is within 10% of the manufacturer's rated heat output capacity. If average heat output is not within these limits, the manufacturer's rated heat output capacity is considered not validated and must be changed.

11.10.2.2.Appliance Operation during Phase 2.

*11.10.2.2.1.*The appliance shall fire at its maximum firing rate for the entire period.

*11.10.2.2.2.*The thermostat shall remain in the ON position or in a setting that is higher than the lab room temperature to ensure a constant call for heat.

11.10.2.3.End of Phase 2: The end of Phase 2 is defined by a continuous period of 60 minutes of maximum heat demand delivered by the appliance.

11.10.3.Phase 3 – Cyclic Operation. This phase commences immediately after Phase 2.

11.10.3.1.Appliance Operation during Phase 3. The system heat demand is cycled at the thermostat by cycling OFF for 15 minutes, or at a setting that is below the lab room temperature to ensure there is no call for heat and then ON for 15 minutes, or at a setting that is higher than the lab temperature to ensure a constant call for heat. Record the timeframes of the start and end of each cycle.

*11.10.3.1.1.*The first cycle shall be with the thermostat in the OFF position.

11.10.3.2.End of Phase 3: Phase 3 end is completed when the scale indicates that 75% of the Cordwood Load 1 has been consumed for cordwood furnaces or XX minutes for automatically feed furnaces.

Commented [LR14]: Recommendations for timing?

11.10.4.Phase 4 – No Heat Demand Phase. This phase commences immediately after Phase 3.

11.10.4.1.*Appliance Operation during Phase 4.* Appliance heat demand is 0% by turning the thermostat is in the off position or at a setting that is higher than the lab room temperature to ensure there is no call for heat.

11.10.4.2.*Cordwood Furnace*

11.10.4.2.1.*Fuel Reload.* Cordwood Load 2 is loaded within 90 seconds immediately after the scale indicates 90% consumption of Cordwood Load 1 or after 45 minutes, whatever comes first.

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11.10.4.2.1.1.Prior to loading Cordwood 2, tare scale.

11.10.4.2.1.2.The firebox door may remain cracked open no more than 1 inch for up to 5 minutes from the time of loading and then the firebox door is closed immediately.

11.10.4.3.*Automatically Fed Furnace*

11.10.4.3.1.Turn off appliance to stop fueling for 45 minutes.

11.10.4.4.*End of Phase 4.* The end of Phase 4 occurs when the appliance spends 45 minutes at no heat demand or the scale indicates that 90% of Cordwood Load 1 has been consumed, whatever comes first.

11.10.4.4.1. Power on automatically fed appliances at end of Phase 4.

11.10.4.5.Photo Documentation – Pictures to show the following: Cordwood Load 2, coal bed prior to loading Cordwood Load 2, firebox loaded with Cordwood Load 2.

11.10.5.Phase 5 – Low Heat Demand

11.10.5.1.Appliance Operation during Phase 5. This phase emulates the operation of the appliance at a low heat demand. The system heat demand is cycled at the thermostat by cycling OFF for 30 minutes, or at a setting that is below the lab room temperature to ensure there is no call for heat and then ON for 5 minutes, or at a setting that is higher than the lab room temperature to ensure a constant call for heat. Record the timeframes of the start and end of each cycle.

11.10.5.1.1. The first cycle shall be with the thermostat in the OFF position for 30 minutes.

11.10.5.2.End of Phase 5: Phase 5 ends when the scale indicates 50% of the Cordwood Load 2 has been consumed and at least one 30/5 minute cycle for has been completed or after X cycles for automatically fed furnaces.

11.10.6.Phase 6 – Response to Setback Conditions.

11.10.6.1.*Appliance Operation during Phase 6.* The thermostat is set in an ON position, or at a setting that is higher than the lab room temperature to ensure there is a constant call for heat.

11.10.6.2.*End of Phase 6.* the end of Phase 6 occurs when after 60 minutes from the start of the phase or when the fuel has been consumed 100%, whatever comes

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first. 100% of fuel consumed is evident when the scale reaches 0 lbs. (0 kg.) for a minimum 30 seconds.

11.10.7. End of the Test Run. The test run ends when all six phases of the test run have been completed in sequence.

11.10.7.1. Test Run Completion. At the end of the Phase 6, stop the particulate sampling instruments and measurements required for the efficiency determination, and record the run time and all final measurement values.

11.10.7.2. At the end of the test run, set the thermostat in the ON position or a temperature higher than the lab room temperature to allow the remaining fuel to be safely be consumed if necessary. No measurements are required during this period.

11.11. Test run requirements. The following are the pre-testing appliance use requirements for each test run.

11.11.1. Consecutive Test Runs. Consecutive test runs may be conducted, provided that the following requirements are met:

11.11.1.1. Run 1 – appliance can only be run for a shake down test to verify proper installation. The unit cannot run for period greater than 8 hours within the 48-hour period proceeding commencement of official tests runs. Record average firebox temperature within 1 hour of the start of test by measuring the central point along all walls of the firebox.

11.11.1.2. Run 2 – shall not operate for a minimum of 8 hours from the conclusion of Run 1 before commencing Run 2. Appliance coals and ash can remain in the appliance until 1 hour before conducting Run 2. All coals and ash must be removed before commencing Run 2.

11.11.1.3. Run 3 – shall wait a minimum 8 hours from the conclusion of Run 2 before commencing Run 3. Appliance coals and ash can remain in the appliance until 1 hour before conducting Run 3. All coals and ash must be removed before commencing Run 3.

11.12. Failure to Operate at All Test Conditions.

11.12.1. If the appliance fails two runs due to incomplete or failed test runs, it shall be determined that the appliance has failed the certification test and requires a modification

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to appliance design. All data for incomplete runs shall be reported. Incomplete failed test runs are defined as the following:

11.12.1.1.If an appliance fails to complete all six phases of the test run, the run shall be considered an incomplete test run.

11.12.1.2.If there is no weight change for a consecutive period of 20 minutes at any point during the test, the appliance has failed the test run.

11.12.1.3.If the appliance fails to comply with test protocol parameters, the appliance has failed the test run.

11.12.1.4.If a test run violates the parameters of the test method, the run is invalid.

11.12.1.5.If during certification testing a critical component of the appliance is damaged or breaks, the certification test will be stopped and considered invalid.

11.12.1.6.If damage is noted during a test, repairs shall be made by the manufacturer (or by laboratory personnel with written direction from the manufacturer). If the repair involves components that require aging, the appliance shall then undergo another round of appliance aging. Components requiring aging shall include but are not limited to catalyst elements, gaskets, and refractory components. Manufacturers have the option of aging these elements in other prototypes. The aging process is intended not only to 'cure' the appliance but also to cycle parts that may fail with extended use. Alternate aging techniques may be approved by the administrator, depending on the nature of the failure, material, and critical nature.

11.13. Test Series completion. A complete test series is defined as the successful completion of three full test runs, as specified in Section 11.10 of this method.

11.14.Additional Test Runs. If there is an invalid run, may attempt two additional runs to complete the test series. If more than three test runs are conducted, the results from all valid test runs shall be used in calculating the average emission rate. The measurement data and results of all test runs shall be reported regardless of which values are used in calculating the emission rate. No test run data can be eliminated from the reporting requirements of this method.

11.15. Invalid Runs. When a test run fails to meet one of the QA/QC criteria stipulated in the test method, the data are invalid, and the run must be repeated. Data for the invalidated

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test run must be included in the test report but the data must not be used in calculation of average emission values.

11.16.Incomplete Runs. When an appliance cannot successfully complete all operational elements of the protocol specified in Section 11.10, it is an incomplete run.

[redacted]

12. *Calculation of Results – Calculation of Results*

Commented [KO'B15]: END OF IDC PROTOCOL

NOTE: If a TEOM is used for PM measurement, proportioning of emission factors and rates per phase according to Appendix A, variables will have subscript added to determine the relevancy of phase i.e. $E_{T(P1)}$ indicates Total particulate emissions for Phase 1 and $E_{g/hr(P2)}$ indicates emissions factor in grams per hour for Phase 2.

12.1. Emission Calculations. Particulate matter, carbon dioxide, and carbon monoxide shall be calculated using the following methodology and reported in grams per hour, grams per kilogram and pounds per million British Therma Unit (Btu) per hour based on heat output:

12.1.1. Two PM measurements shall be reported

12.1.1.1. 60-minute reporting. Emissions from the first sixty minutes shall be reported. The 60-minute periods begins at match light. 60-minute data shall be collected and reported as a separate ASTM 2515-11 train or the TEOM (if applicable) data calculated per the SOP.

12.1.1.2. Integrated Result. The results two, dual ASTM E2515-11 trains, shall integrate into a single result the appliance performance over the six phases of this test method's operational protocol.

12.2.Particulate Matter Emissions Rates. After the test is completed determine the particulate matter emissions rate E_r in accordance with ASTM E2515-11 for each test run. If using ASTM E2515-11 for one-hour data, prepare calculations for each first hour of operation.

12.3. Nomenclature

A – Duct cross-sectional area, ft^2 (m^2)
BR – Average dry fuel burn rate, lb./min
CA – Carbon
HY - Hydrogen

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OX - Oxygen
C_p – Pitot tube factor (0.99 for a standard pitot tube)
E_T – Total particulate emissions for the full test run as determined per ASTM E2515-11 in grams
$E_{g/MJ}$ – PM Emissions rate in grams per megajoule of heat output
$E_{lb/MMBtu\ output}$ – PM Emissions rate in pounds per million Btu of heat output
$E_{g/kg}$ – PM Emissions factor in grams per kilogram of dry fuel burned
$E_{g/hr}$ – PM Emissions factor in grams per hour
E_{Rco} – CO emission rate, g/hr.
EIi – Average CO emission index for interval i
E_{ICO} – CO emission index, g/kg dry fuel
EIco,avg – Average CO emission index for the run
F_p – Adjustment factor for center of duct pitot tube placement
HHV – Higher heating value of fuel = Use accredited test results
K_p – Pitot Tube Constant
LHV – Lower heating value of fuel = Use accredited test results
M – Mass flow rate of air in lb./hr. (kg/hr.)
MC – Fuel moisture content, % dry basis
MC_i – Average moisture content as determined by ultimate/proximate analysis
P_{bar} – Barometric pressure, in Hg (mm Hg)
P_s – Duct static pressure, in Hg. (mm Hg)
PCTCO2– average CO_2 in the dry flue gas (%)
PPMco -average CO in the dry flue gas (ppm)
Q_{out} – Total heat output in BTU's (megajoules)
$Q_{out(p2)}$ - Total heat output in BTU's (megajoules) in Phase 2
$Q_{out(p5)}$ - Total heat output in BTU's (megajoules) in Phase 5
$Q_{out(p6)}$ - Total heat output in BTU's (megajoules) in Phase 6
Q_{in} – Total heat input available in test fuel charge in BTU (megajoules)
$Q_{in(p2)}$ - Total heat input available in test fuel charge in BTU (megajoules) in Phase 2
$Q_{in(p5)}$ - Total heat input available in test fuel charge in BTU (megajoules) in Phase 5
$Q_{in(p6)}$ - Total heat input available in test fuel charge in BTU (megajoules) in Phase 6
SC – change in scale mass during measurement interval, lb.
$t_{(i)}$ – Data sampling interval in minutes
T – Temperature, K
T1 – Temperature of air at the inlet duct, ˚F (˚C).
T2 – Average Temperature of heat delivered in the outlet duct, ˚F (˚C).

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TI_{avg} – Average temperature of the appliance at start of the test, ˚F (˚C).
TF_{avg} – Average temperature of the appliance the end of the test, ˚F (˚C)
V = Air flow velocity, ft/sec (m/s)
W_{fuel} – Fuel charge weight in pounds (kg)
W_i – Weight of fuel in pounds (kg)
W_{app} – Weight of empty appliance in pounds (kg)
x – Humidity ratio, kg/kg
Δe – Rate of heat release into the circulating air (kj/h)
Δh – Change in enthalpy of the circulating air,(kj/kg)
ΔP – Velocity pressure, in. WC. (mm W.C.)
ΔT – Temperature difference between water the inlet and delivered heat, ˚C
η_{del} – Delivered heating efficiency in percent
$\eta_{del(p2)}$ Delivered Efficiency of Phase 2, percent
$\eta_{del(p5)}$ Delivered Efficiency of Phase 5, percent
$\eta_{del(p6)}$ Delivered Efficiency of Phase 6, percent
Θ – Total length of test run in hours
$\Theta_{(x)}$ – Total length of test run in hours per phase, X
ρ – Density of air at standard temperature and pressure (use 1.204 kg/m3)

12.4. Determine Heat Input.

12.4.1.Average Fuel Load Content. Determine average fuel load content using HHV and LHV results of the ultimate/proximate analysis per test run and Phases 2,6, and 6.

$Q_{in} = (W_{fuel}/(1+(MC/100))) \times HHV$, BTU
$Q_{in\ LHV} = (W_{fuel}/(1+(MC/100))) \times LHV$, BTU

12.5. Determine Heat Output per test run and Phases 2,5, and 6

$$Qout = \Sigma(\Delta e \times i)\ i = t1\ to\ t2$$
$$\Delta e = \Delta h \times m$$
$$m = 3600\ seconds\ per\ hour\ VA\rho$$
$$V = Fp \times Cp \times Kp \times \sqrt{\Delta P} \times \sqrt{(T} \div (28.56 \times (Pbar + Ps)))$$
$$\Delta h = \Delta t\ (1.006 + 1.84x)$$

*12.5.1.*Determine heat output rate as:

Heat Output Rate = Q_{out}/Θ, BTU/hr.

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12.5.2. Delivered Efficiency - delivered efficiency over the six phases is representative of annual efficiency. Determine delivered efficiency as:

$\eta_{del} = (Q_{out}/Q_{in}) \times 100, \%$

$\eta_{del\ LHV} = (Q_{out}/Q_{in}\ LHV) \times 100, \%$

12.5.3. Determine Steady Heat Demand Period Delivered Efficiency.
Determined For efficiency of high and low heat demands, determine the delivered efficiency of the individual steady heat demand phases, Phases 2,5, and 6.

$\eta_{del(p2)} = Q_{out(p2)}/ Q_{in(p2)} \times 100, \%$

$\eta_{del(p3)} = Q_{out(p5)}/ Q_{in(p5)} \times 100, \%$

$\eta_{del(p6)} = Q_{out(p6)}/ Q_{in(p6)} \times 100, \%$

12.5.4. Determine emission rates and emission factors as:

$E_{g/MJ} = E_T/(Q_{out} \times 0.001055)$, g/MJ

$E_{lb/MM\ BTU\ output} = (E_T/453.59)/(Q_{output} \times 10^{-6})$, lb./MMBtu Out

$E_{g/kg} = E_T/(W_{fuel}/(1+MC/100))$, g/dry kg

$E_{g/hr} = E_T/\Theta$, g/hr

12.6. Determination of CO Emissions Per Phase

In this section CO emission rate and CO emission index are calculated for each phase in 10-minute intervals. For each interval this is based on average burn rate, flue CO and CO_2 for the period.

12.6.1. Determination of Dry Fuel burn rate During each Interval

Density of water at the start and end of each 10-minute interval shall be calculated using the equation in section 12.5 based on average temperature of the appliance.

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$BR = (100/(100+MC))*(SC- V_{blr} * (\sigma F - \sigma I))/10$

If the burn rate for any interval is equal to or less than zero or if the burner is obviously not firing during that part of the test, the burn rate and CO emission rate during that interval shall be assigned a value of zero. For any 10-minute intervals where the burner is transitioning between on and off or off and on, include active burn data in the previous 10-minute interval if active period is less than 5 minutes or include as its own 10-minute interval if active period is greater than 5 minutes.

12.6.2. Intermediate Calculations

The following intermediate calculations and constants are defined in this section for convenience. These results are used in calculations in following section.

x= CA/12

y = HY

z = OX/16

The following parameters shall be calculated for each interval over which the burn rate is not zero.

gamma_n = x + y/4 -z/2

beta_n = ((100 * x * PPMco)/(1000000 * PCTCO2+100 * PPMco))

alpha_n = ((100 * (x-beta_n)/PCTCO2)-x-(beta_n/2)-gamma_n * 3.76)/(gamma_n * 4.76)

MFco_n = beta_n- kmoles of CO produced when 100 kg dry fuel is burned

MFCO2_n = x-beta_n - kmoles of CO_2 produced when 100 kg dry fuel is burned

MFO2x_n = (alpha_n * gamma_n+beta_n/2) - kmoles of O_2 produced when 100 kg dry fuel is burned

MFNI_n = (1+alpha_n) * gamma_n * 3.76 - kmoles of N_2 produced when 100 kg dry fuel is burned

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DryGas = MFco_n + MF_CO2_n + MF_O2_n + MFNI_n - total kmols of dry gas produced per 100 kg of dry fuel burned

DryGasRate = (BurnRate*60*0.454*DryGas)/100 - Kmol of dry gas produced per hour

Informative note – kmol used here refers to kilogram mols.

12.6.3. Calculation of CO Emission Rate and CO Emission Index

For each interval during which the burn rate is not zero, calculate the CO emission rate and emission index as follows:

ERco = (PPMco * DryGasRate * 28 * 454)/(1000000 * 0.454) - CO emission rate, g/hr

EIco = (DryGas * PPMco * 1000 * 28)/(100 * 1000000) - CO emission index, g/kg dry fuel

12.6.4. CO Emissions Test Run Calculations

For each run the average CO emission rate shall be calculated as the average of the CO emission rates during each of the active burn period 10-minute intervals, g/hr. Intervals for which the burn rate is zero shall not be included in this average.

For each run the average CO emission index shall be calculated as the burn rate weighted average of the emission indices during each of the active burn period 10-minute intervals, g/kg. This calculation can be expressed as:

[EMBED Equation.DSMT4]

13. Reporting Requirements. The report shall include the following:

13.1. Introduction - no portion of the introduction may be claimed as CBI.

13.1.1. Purpose of test: certification, audit, efficiency, research, and development

13.1.2. Name and location of the laboratory conducting the test.

13.1.3. Wood appliance identification – manufacturer, model number/name, design type, description of the appliance tested, appliance condition, and date of receipt.

13.1.4. Test information – location of testing, date of tests, sampling methods used, number

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of test runs, a statement detailing any previous testing completed on the wood appliance.

13.1.5. A list of participants, their roles, and any observers present for the tests. The list shall include the participant's name, title, company, contact information and the purpose of their participation.

13.1.6. A statement that the test results apply only to the specific appliance tested.

13.2. Summary and Discussion of Results - no portion of the introduction may be claimed as CBI.

13.2.1. Record summary results in tables 1A, 1B, and 1C. Table of results to include test run number, average burn rate for entire run, particulate emission rate for full run, particulate emission rate for start-up, carbon monoxide emission rate for a full run, carbon monoxide for startup, efficiency, burn time – total and by phase.

13.2.2. If the TEOM is used for the entire test, the report shall contain the following: For each test run use the TEOM to apportion filter PM data for the six individual phases. Calculated results for the emissions reported as total emissions in grams, grams per hour.

13.2.3. A statement of the estimated uncertainty of measurement of the emissions and efficiency test results.

13.2.4. If a TEOM is used, provide a plot of PM emission rate in grams/hour vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

13.2.5. Summary of other data – test facility conditions such as test facility temperature, air velocity and humidity, catalyst averages, pretest fuel weights, test fuel charge weights – total and by phase.

13.2.6. Two measurements shall be reported

13.2.6.1. Start-up. Emissions from match light until the end of the start-up phase shall be collected and reported as a separate element using two ASTM E2515-11 trains. One-hour data shall be reported by a third ASTM E2515-11 train or the TEOM data calculated per the SOP.

13.2.6.2. Integrated Result. The results two, dual ASTM E2515-11 trains shall integrate into a single result the appliance performance over the six phases of this test methods operational protocol.

13.3. Discussion. - no portion of the discussion may be claimed as CBI.

13.3.1. Discussion shall include detailed information describing each test conducted on the

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appliance:

13.3.1.1. How the test was run

13.3.1.2. Specific test run problems and solutions

13.3.1.3. Test run result

13.3.1.4. Deviations

13.4. Process description:

13.4.1. Data and drawings indicating the fire box size and location of the fuel charge.

13.4.2. Drawings and calculations used to determine firebox volume to include volume, height, width, and lengths, weight and volume adjustments. No portion of this section can be CBI.

13.4.3. Firebox configuration – At a minimum to include air supply locations and operation, air supply introduction location, refractory location and dimensions, catalyst location, baffle and by-pass location and operation (include line drawings or photographs)

13.4.4. Process operation during test – shall supply details on air supply settings and adjustments. No portion of this section can be CBI.

13.4.5. Test fuel properties – species, density, fuel moisture, fuel temperature, and load details. No portion of this section can be CBI. Also, a description of test fuel sourcing, handling and storage practices shall be included.

13.4.6. Sampling. No portion of this section can be CBI.

13.4.6.1. A description of the test procedures and test equipment including a schematic or other drawing showing the location of all required sampling equipment.

13.4.6.2. Describe sampling location relative to appliance, include drawing or photographs.

13.4.6.3. Provide data on sampling blanks.

13.4.6.4.Sampling and Analytical procedures. Detailed description of procedures followed by laboratory personnel in conducting the certification test.

13.5. Quality Control and Assurance Procedures. No portion of this section can be CBI.

13.5.1. Calibration procedures and results certification procedures, sample and analysis procedures.

13.5.2. Test method quality control procedures to include leak-checks, volume meter checks, stratification (velocity) checks, proportionality results.

13.6. Appendices – No data contained in the appendices can be claimed as CBI.

13.6.1. Results and Example Calculations. Complete summary tables and accompanying calculations.

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13.6.2. Raw data. Copies of all files or sheets for sampling measurement, temperatures records, and sample recovery data.

13.6.3. Test Equipment Calibration Results. Summary of all calibrations, check and audits pertinent to the certification.

13.6.4. Sampling and Operation Records. Copies of all uncorrected records of activities not included in raw data sheets (e.g. appliance door open, times and durations).

13.6.5. User Guide. Appliance instructions for operating the device during the test following the User Guide specifications detailed in Section 9.3.

13.6.6. Details of deviations from, additions to or exclusions from the test method, and their data quality implications on the test results (if any). An explanation of the deviations, additions, or exclusions shall be provided along with an analysis as to why these elements had no impact.

13.6.7. All required data and applicable blanks for each test run shall be provided in spreadsheet format both in the printed report and in a computer file such that the data can be easily analyzed and calculations easily verified. Formulas used for all calculations shall be accessible for review.

13.6.8. For each test run, if used: report TEOM flow and temperature and verification of all TEOM parameters presented in the TEOM 1405 SOP.

13.7. Raw data, calibration records, and other relevant documentation shall be retained by the laboratory for a minimum of 7 years.

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Table 1A – Must complete a table for each test run, minimum of three

Data Summary Part A - Run 1

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Phase	Target Load	Actual Load	Phase Duration	Wood Consumed	Total Heat Output	Total Heat Input	Delivered Efficiency	CO Rate
	Btu/hr.	Btu/hr.	hours	Lbs.	Btu	Btu	%	g/min.
2								
3								
6								
Total								

Data Summary Part A - Run 2

Phase	Target Load	Actual Load	Phase Duration	Wood Consumed	Total Heat Output	Total Heat Input	Delivered Efficiency	CO Rate
	Btu/hr.	Btu/hr.	hours	Lbs.	Btu	Btu	%	g/min.
2								
3								
6								
Total								

Data Summary Part A - Run 3

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Phase	Target Load	Actual Load	Phase Duration	Wood Consumed	Total Heat Output	Total Heat Input	Delivered Efficiency	CO Rate
	Btu/hr.	Btu/hr.	hours	Lbs.	Btu	Btu	%	g/min.
2								
3								
6								
Total								

DRAFT

Table 1B – Must complete a table for each test run, minimum of three

Data Summary Part B – 60-minute test results

		Q_{out}	E_T	E	E	E_{Rco}	E_{Ico}
Run No	Date	Heat Output	Total PM Emissions	PM Output Based	PM Output Based	PM Rate	PM Factor
		Btu	g	lb/MMBtu Out	g/MJ	g/hr.	g/kg
1							
2							
3							

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Table 1C Data Summary – Averages

Data Summary – Part 1

			Θ	W_{fuel}	MC_{ave}	Q_{in}	Q_{out}
Run No	Date	Fuel Gross Ca. Value	Test Duration	Wood Weight as-fired	Wood Moisture	Heat Input	Heat Output
-		Btu/lb.	Hrs.	Lbs.	%DB.	Btu.	Btu.
1							
2							
3							
Average							

Data Summary – Part 2

	E_T	E	E	$E_{PMg/hr}$	$E_{g/kg}$	$E_{CO\ g/hr}$	$E_{Cog/kg}$

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Run No	Date	Total PM Emissions	PM Output Based	PM Output Based	PM Rate	PM Factor	CO Rate	CO Factor
		g	Lb./MM Btu Out	g/MJ	g/hr.	g/kg fuel	g/hr.	g/kg fuel
1								
2								
3								
Average								

DRAFT

ED_005942D_00000076-00043

Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 5/27/2021 8:41:12 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
Subject: rounding narrative

Stef, is there specific rounding text that you would like in the test method?

NESCAUM

Lisa Rector, Policy and Program Director at **NESCAUM**
89 South Street, Suite 602, Boston, Massachusetts, 02111 | 802.899.5306| 617.259.2095 | Fax: 617.742.9162
| lrector@nescaum.org

Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 5/28/2021 12:06:00 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]; Burkhard, Ellen G (NYSERDA) [Ellen.Burkhard@nyserda.ny.gov]
Subject: protocol and calculator
Attachments: Fuel Calculator - Woodstoves-05-27-21.xlsm; NYSERDA IDC Stove Research Protocol 5 28 2021.pdf

Stef and Ellen, attached are the updated protocol and calculator for the IDC Stove test method. The password to unlock the calculator is **nescaum123456** which will allow you to review code from the calculator.

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Integrated Duty Cycle Fuel Calculator

Last updated of the tool: 3/8/2021

Link to download the latest version:

Start a New Calculation for a Stove

Go to the Last Saved Calculation

Start a New Calculation for a Boiler

Unlock The Spreadsheet

Instruction:

1- Color Codes and Cells Lock

In this tool, the user can only select and change the content of pre-determined cells. If a cell cannot be selected it means it is not designated to be changed by the user.

There are four main levels of color coding to help the user navigate through the tool easier:

(A) White cells with black font: these cells are either a parameter name, a parameter unit, a fixed formula, or some sort of information about the table. The user cannot change the content of these cells directly. For example, non of these three cells can be edited directly by the user:

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Firebox volume:	3.361	ft^3

(B) Green background cells with blue font: these cells are designed to accept necessary input data by the user. If the content of these cells are empty they will turn into yellow, meaning that data is required to be entered by the user. However, if the cell background is green but the font is black it means the data is NOT required and the cell can be left empty. For example, firebox width, depth and height are necessary data fields but the Volume adjustment is not necessary. Therefore, the firebox dimension cells are yellow and the volume adjustment cell is green when they are empty. After entering valid data into all cells, the font color in the three first cells turn blue:

1.2 Firebox Information		
Firebox width:		in.
Firebox depth:		in.
Firebox height:		in.
Volume adjustment:		ft^3
Firebox volume:		ft^3

1.2 Firebox Information		
Firebox width:	14.0	in.
Firebox depth:	16.5	in.
Firebox height:	18.0	in.
Volume adjustment:	0.200	ft^3
Firebox volume:	2.206	ft^3

(C) Yellow background cells: these cells are missing data that is required. Yellow background cells are two types: the first type are locked and cannot be directly edited, and the second type can be edited directly by the user. In the previous example the cell in front of the "Firebox volume" cell is the one that cannot be directly selected and edited. Rather, it gets updated automatically because there is a formula in it. To change the value in it, the user should enter data in other yellow cells. In this example when the user set the width, height, and depth of the firebox, the volume cell gets updated and it turns white.

(D) Red background cells with yellow font: The red color of these cells is a warning that the number is out of the allowable range and it should be modified either directly or indirectly (by changing the cells that participate in the formula). For example, in the following table for Load 3 the "Load total" weight is red because it is higher than the allowable limit. But user cannot directly change the total load value. Rather, she should change the value of each piece weight to make the "Load total" fall in the correct range:

set the # of logs	Weight (lb)
Piece 1:	5.00
Piece 2:	5.00
Piece 3:	6.00
Load total:	16.00

set the # of logs	Weight (lb)
Piece 1:	5.00
Piece 2:	5.00
Piece 3:	5.10
Load total:	15.10

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In addition to the above color coding, there are white background cells with gray front that show helpful information to user:

Load total:	14.20
	↑↑ Remove some fuel pieces or use lighter logs to reach the target weight :11.00–12.15 lb Allowed weight of each piece: 1.00–2.26 lb

2- Starting a new calculation

2.1 To start a fresh and new fuel calculation for a stove testing click on "Start a new Calculation for a Stove" in this tab. NOTE: by starting a new calculation all previous calculations and data will be DELETED WITHOUT UNDO. Therefore, before starting a new calculation make sure you have made a copy of the spreadsheet to save your previous data. Preparing the tool for a new calculation may take several minutes.

2.2 After the tool is re-started, it will proceed to the '1-Stove' tab. In this tab the user is required to fill in stove information, firebox dimensions, and test lb information. The firebox dimensions should be between 0-40 inches and the volume adjustment value cannot be more than 1 cubic feet. After entering data, click on "Next >>" button at the bottom-right corner of the tab to proceed to the "2- Fuel Load" tab.

2.3 In the Fuel Load tab there is only one parameter to enter: Wood Species. The user can select one of the four wood species from the drop-down list. With each selection the wood density and all load piece details will be updated automatically. After selecting the wood species, click on "Next >>" to show 4 new tabs for run details.

2.4 There are four identical and independent run details tab in this tool. Each tab contains 12 tables to enter details of the run. The first set of tables (Table 3.1 through 3.6) are designed to enter details of wood pieces in each load. To start entering information the first step is to enter the number of pieces for each load in the last column (Actual # of pieces) in Table 3.1:

Enter the number of fuel pieces first, then enter the weight and MC details in Tables 3.2 through 3.6 ↓↓

3.1 Fuel Load Data

	Target load (lb)	Actual weight (lb)	Allowed # of pieces	Actual # of pieces	
L1 - Kindling weight	2.75 – 3.04		20	20	Go to table
L1 - Starter	8.25 – 9.12		6	5	Go to table
L2 - Small pieces	19.24 – 21.27		6	6	Go to table
L3 - Large pieces	13.75 – 15.19		2	2	Go to table
L4 - Small pieces	11.00 – 12.15		4	3	Go to table
L4 - Large pieces	21.99 – 24.31		4	4	Go to table

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For each load a separate table is designed in the tab that can be reached either by scrolling down or by clicking on "Go to table" link.

Notice: In the load tables (Tables 3.2 through 3.6) the number of pieces cannot be changed. To add or remove pieces you should use the "Actual # of pieces" column in Table 3.1

By entering the actual number of pieces in Table 3.1, the tool will automatically make the correct number of rows available in the corresponding t

3.3 Load 2 - Small pieces

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)	pin 3 (%)	pin 4 (%)	Avg moisture
Piece 1:						
Piece 2:						
Piece 3:						
Piece 4:						
Piece 5:						
Piece 6:						
Piece 7:						
Piece 8:						
Piece 9:						
Piece 10:						
Load total:						

!! Add more fuel pieces or use heavier logs to reach the target weight. 19.24-21.27 lb

Allowed weight of each piece: 2.29-4.83 lb

In each row of the load detail table, the user should enter weight and four MC pin readings in the corresponding cells. The total weight, average moisture of each piece, and final weighted average moisture will update automatically (cannot be edited directly):

3.3 Load 2 - Small pieces

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)	pin 3 (%)	pin 4 (%)	Avg moisture
Piece 1:	2.30	22.0	21.0	22.0	21.0	21.5
Piece 2:	4.10	21.0	21.0	22.0	21.0	21.3
Piece 3:	4.00	23.0	24.0	22.0	20.0	22.3
Piece 4:	3.50	19.0	18.0	19.0	19.0	18.8
Piece 5:	3.00	21.0	21.0	22.0	22.0	21.5
Piece 6:	3.00	21.0	21.0	21.0	23.0	21.5
Piece 7:						
Piece 8:						
Piece 9:						
Piece 10:						
Load total:	19.90					21.12

✓ Load weight is in the range

If you click on "set the # of logs" link on the top-left corner of each load table, it will take you to Table 3.1, where you can set the number of pieces. Below each of the load table, there is an information cell with gray font that shows useful hints about data in the table.

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the table.

After finishing data entry in Tables 3.1 through 3.6, the user should provide information about run information and test lab condition in Tables 3.7 and 3.8.

Tables 3.9 through 3.11 are designed to be filled out as the test goes on. User should enter data about the weights and timing of the loads at the beginning and end of each load.

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Integrated Duty Cycle Fuel Calculator

1- Stove and Lab Information

1.1 Stove Information	
Appliance manufacturer:	
Appliance model:	

1.2 Firebox Information		
Firebox Shape:	■ Cubic	○ Cylindrical
Firebox width:		in.
Firebox depth:		in.
Firebox height:		in.
Volume adjustment:		ft^3
Firebox Net Volume:		ft^3

1.3 Test Lab Information	
Lab name:	
Test lab location:	
Primary testing staff name:	
Test lab phone:	
Test lab contact email:	
Third party certifier:	
Third party phone:	
Third party email:	
Other people present or participating either in person or remotely in the test:	

These timestamps cannot be edited

Calculation Started at:	4/12/2021 19:52
Saved and Finished at:	Still in progress

Next >>

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Integrated Duty Cycle Fuel Calculator

2- Fuel Load Information

2.1 Fuel Load General Information			
Wood species:	Oak		
Wood density:	0.7	10^3 kg/m^3	= 43.7 lb/ft3
Firebox Volume:		ft^3	Firebox volume is not correct. Fix it in the Stove sheet.
Loadind direction:	East-West		
Target log length:		±0.5 in.	

2.2 Load Piece Details				
Load	Total load weight (lb)	Min. piece weight (lb)	Max. piece weight (lb)	Target piece number per load
L1 - Kindling				
L1 - Starter				
L2 - Small pieces				
L3 - Large pieces				
L4 - Small pieces				
L4 - Large pieces				

<< Back

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Next >>

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Poly curve fitting paramaters for calculating log characteristics

	Firebox Volume, ft^3	Sm Pc. Low (in)	Sm pc Hi (in)	Lg Pc Low (in)	Lg Pc Hi (in)
"Small" Volume	0.80	2.2	3.1	3.1	4.5
"Medium" Volume	2.00	2.8	4	4	5.3
"Large" Volume	3.00	3	4.4	4.4	6.3
		x2	x	c	
Poly Small Low		-0.136363636	0.881818182	1.581818182	
Poly Small Hi		-0.159090909	1.195454545	2.245454545	
Poly Large Low		-0.159090909	1.195454545	2.245454545	
Poly Large Hi		0.151515152	0.242424242	4.209090909	

Range of the Log Diameters:

Min. Small Log Diamter Target (in):				
Max. Small Log Diamter Target (in):				
Min. Large Log Diamter Target:				
Max. Large Log Diamter Target:				

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Integra

3.1

	Target load (lb)	Actual weight (lb)	Target # of pieces
L1 - Kindling weight			
L1 - Starter			
L2 - Small pieces			
L3 - Large pieces			
L4 - Small pieces			
L4 - Large pieces			

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Kindling total:			
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Piece 7:			
Piece 8:			
Piece 9:			
Piece 10:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)

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ted Duty Cycle Fuel Calculator

3.1 Run #1 Details

Detailed Fuel Information

Enter the number of fuel pieces first, then enter the weight and MC details in Tables 3.2 through 3.6 ↓↓

Fuel Load Data	
Actual # of pieces	
	Go to table
	Go to table
	Go to table
	Go to table
	Go to table
	Go to table

3.2 Load 1 - Kindling and starter fuel		
pin 3 (%)	pin 4 (%)	Avg moisture
Not applicable		

3.3 Load 2 - Small pieces		
pin 3 (%)	pin 4 (%)	Avg moisture

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Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Piece 7:			
Piece 8:			
Piece 9:			
Piece 10:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Load total:			

Target load is not defined yet.

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3.4 Load 3 - Large pieces

pin 3 (%)	pin 4 (%)	Avg moisture

3.5 Load 4 - Small pieces

pin 3 (%)	pin 4 (%)	Avg moisture

3.6 Load 4 - Large pieces

pin 3 (%)	pin 4 (%)	Avg moisture

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3.7 Run Information	
Run date:	
Run number:	
Testing staff:	
Witnesses or others present for test:	
Start time:	
End time:	

Temperature:	
Barometric pressure:	
Relative humidity:	

3.9 Ru

Load	Actual weight at start of phase before loading (lb)	Actual weight at start of phase after loading (lb)	Target weight at end of phase (lb)
L1 (Fully Open)			
L2(A) (Fully Open)			
L2(B) (Fully Closed)		Not applicable	
L3 (Fully Closed)			
L4 (Fully Closed)			

3.10 Ru

Load	Start time	End time	Door open time
L1 (Fully Open)			
L2(A) (Fully Open)			
L2(B) (Fully Closed)			
L3 (Fully Closed)			
L4 (Fully Closed)			

Load	
L1 (Fully Open)	
L2(A) (Fully Open)	
L2(B) (Fully Closed)	
L3 (Fully Closed)	
L4 (Fully Closed)	

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Other Testing Information

3.8 Test Lab Condition		
pre-test	post-test	
		F
		in. Hg
		%

n Operation Data
Actual Weight at end of phase (lb)

ın Operation Data
Door closed time

3.11 Run Operation Data
Notes on fuel adjustments/time

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	3.12 Po
1) Any data points with filter temperatures outside the 80-90F?	
If yes, how many and for how long	
2) Did tunnel temperature exceed 40C during the test?	
If yes, how many and for how long	
3) Did tunnel humidity exceed 90%?	
If yes, how many and for how long	
4) Any tunnel dew point measurements within 2C of filter temp	
If yes, how many and for how long	
5) Tunnel flow for test? (dscf/min)	

<< Back

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st Run Data Check

Next >>

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Integra

3.1

	Target load (lb)	Actual weight (lb)	Target # of pieces
L1 - Kindling weight			
L1 - Starter			
L2 - Small pieces			
L3 - Large pieces			
L4 - Small pieces			
L4 - Large pieces			

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Kindling total:			
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Piece 7:			
Piece 8:			
Piece 9:			
Piece 10:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)

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ted Duty Cycle Fuel Calculator

3.2 Run #2 Details

Detailed Fuel Information

Enter the number of fuel pieces first, then enter the weight and MC details in Tables 3.2 through 3.6 ↓↓

Fuel Load Data	
Actual # of pieces	
	Go to table
	Go to table
	Go to table
	Go to table
	Go to table
	Go to table

3.2 Load 1 - Kindling and starter fuel		
pin 3 (%)	pin 4 (%)	Avg moisture
Not applicable		

3.3 Load 2 - Small pieces		
pin 3 (%)	pin 4 (%)	Avg moisture

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Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Piece 7:			
Piece 8:			
Piece 9:			
Piece 10:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Load total:			

Target load is not defined yet.

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3.4 Load 3 - Large pieces

pin 3 (%)	pin 4 (%)	Avg moisture

3.5 Load 4 - Small pieces

pin 3 (%)	pin 4 (%)	Avg moisture

3.6 Load 4 - Large pieces

pin 3 (%)	pin 4 (%)	Avg moisture

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3.7 Run Information	
Run date:	
Run number:	
Testing staff:	
Witnesses or others present for test:	
Start time:	
End time:	

Temperature:	
Barometric pressure:	
Relative humidity:	

3.9 Ru

Load	Actual weight at start of phase before loading (lb)	Actual weight at start of phase after loading (lb)	Target weight at end of phase (lb)
L1 (Fully Open)			
L2(A) (Fully Open)			
L2(B) (Fully Closed)		Not applicable	
L3 (Fully Closed)			
L4 (Fully Closed)			

3.10 Ru

Load	Start time	End time	Door open time
L1 (Fully Open)			
L2(A) (Fully Open)			
L2(B) (Fully Closed)			
L3 (Fully Closed)			
L4 (Fully Closed)			

Load	
L1 (Fully Open)	
L2(A) (Fully Open)	
L2(B) (Fully Closed)	
L3 (Fully Closed)	
L4 (Fully Closed)	

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Other Testing Information

3.8 Test Lab Condition		
pre-test	post-test	
		F
		in. Hg
		%

n Operation Data
Actual Weight at end of phase (lb)

ın Operation Data
Door closed time

3.11 Run Operation Data
Notes on fuel adjustments/time

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	3.12 Po
1) Any data points with filter temperatures outside the 80-90F?	
If yes, how many and for how long	
2) Did tunnel temperature exceed 40C during the test?	
If yes, how many and for how long	
3) Did tunnel humidity exceed 90%?	
If yes, how many and for how long	
4) Any tunnel dew point measurements within 2C of filter temp	
If yes, how many and for how long	
5) Tunnel flow for test? (dscf/min)	

<< Back

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st Run Data Check

Next >>

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Integra

3.1 I

	Target load (lb)	Actual weight (lb)	Target # of pieces
L1 - Kindling weight			
L1 - Starter			
L2 - Small pieces			
L3 - Large pieces			
L4 - Small pieces			
L4 - Large pieces			

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Kindling total:			
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Piece 7:			
Piece 8:			
Piece 9:			
Piece 10:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)

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ted Duty Cycle Fuel Calculator

3.3 Run #3 Details

Detailed Fuel Information

Enter the number of fuel pieces first, then enter the weight and MC details in Tables 3.2 through 3.6 ↓↓

Fuel Load Data	
Actual # of pieces	
	Go to table
	Go to table
	Go to table
	Go to table
	Go to table
	Go to table

3.2 Load 1 - Kindling and starter fuel		
pin 3 (%)	pin 4 (%)	Avg moisture
Not applicable		

3.3 Load 2 - Small pieces		
pin 3 (%)	pin 4 (%)	Avg moisture

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Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Piece 7:			
Piece 8:			
Piece 9:			
Piece 10:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Load total:			

Target load is not defined yet.

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3.4 Load 3 - Large pieces

pin 3 (%)	pin 4 (%)	Avg moisture

3.5 Load 4 - Small pieces

pin 3 (%)	pin 4 (%)	Avg moisture

3.6 Load 4 - Large pieces

pin 3 (%)	pin 4 (%)	Avg moisture

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3.7 Run Information	
Run date:	
Run number:	
Testing staff:	
Witnesses or others present for test:	
Start time:	
End time:	

Temperature:	
Barometric pressure:	
Relative humidity:	

3.9 Ru

Load	Actual weight at start of phase before loading (lb)	Actual weight at start of phase after loading (lb)	Target weight at end of phase (lb)
L1 (Fully Open)			
L2(A) (Fully Open)			
L2(B) (Fully Closed)		Not applicable	
L3 (Fully Closed)			
L4 (Fully Closed)			

3.10 Ru

Load	Start time	End time	Door open time
L1 (Fully Open)			
L2(A) (Fully Open)			
L2(B) (Fully Closed)			
L3 (Fully Closed)			
L4 (Fully Closed)			

Load	
L1 (Fully Open)	
L2(A) (Fully Open)	
L2(B) (Fully Closed)	
L3 (Fully Closed)	
L4 (Fully Closed)	

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Other Testing Information

3.8 Test Lab Condition		
pre-test	post-test	
		F
		in. Hg
		%

n Operation Data
Actual Weight at end of phase (lb)

ın Operation Data
Door closed time

3.11 Run Operation Data
Notes on fuel adjustments/time

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	3.12 Po
1) Any data points with filter temperatures outside the 80-90F?	
If yes, how many and for how long	
2) Did tunnel temperature exceed 40C during the test?	
If yes, how many and for how long	
3) Did tunnel humidity exceed 90%?	
If yes, how many and for how long	
4) Any tunnel dew point measurements within 2C of filter temp	
If yes, how many and for how long	
5) Tunnel flow for test? (dscf/min)	

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st Run Data Check

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Integra

3.1

	Target load (lb)	Actual weight (lb)	Target # of pieces
L1 - Kindling weight			
L1 - Starter			
L2 - Small pieces			
L3 - Large pieces			
L4 - Small pieces			
L4 - Large pieces			

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Kindling total:			
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Piece 7:			
Piece 8:			
Piece 9:			
Piece 10:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)

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ted Duty Cycle Fuel Calculator

3.4 Run #4 Details

Detailed Fuel Information

Enter the number of fuel pieces first, then enter the weight and MC details in Tables 3.2 through 3.6 ↓↓

Fuel Load Data	
Actual # of pieces	
	Go to table
	Go to table
	Go to table
	Go to table
	Go to table
	Go to table

3.2 Load 1 - Kindling and starter fuel		
pin 3 (%)	pin 4 (%)	Avg moisture
Not applicable		

3.3 Load 2 - Small pieces		
pin 3 (%)	pin 4 (%)	Avg moisture

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Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Piece 7:			
Piece 8:			
Piece 9:			
Piece 10:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Load total:			

Target load is not defined yet.

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3.4 Load 3 - Large pieces

pin 3 (%)	pin 4 (%)	Avg moisture

3.5 Load 4 - Small pieces

pin 3 (%)	pin 4 (%)	Avg moisture

3.6 Load 4 - Large pieces

pin 3 (%)	pin 4 (%)	Avg moisture

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3.7 Run Information	
Run date:	
Run number:	
Testing staff:	
Witnesses or others present for test:	
Start time:	
End time:	

Temperature:	
Barometric pressure:	
Relative humidity:	

3.9 Ru

Load	Actual weight at start of phase before loading (lb)	Actual weight at start of phase after loading (lb)	Target weight at end of phase (lb)
L1 (Fully Open)			
L2(A) (Fully Open)			
L2(B) (Fully Closed)		Not applicable	
L3 (Fully Closed)			
L4 (Fully Closed)			

3.10 Ru

Load	Start time	End time	Door open time
L1 (Fully Open)			
L2(A) (Fully Open)			
L2(B) (Fully Closed)			
L3 (Fully Closed)			
L4 (Fully Closed)			

Load	
L1 (Fully Open)	
L2(A) (Fully Open)	
L2(B) (Fully Closed)	
L3 (Fully Closed)	
L4 (Fully Closed)	

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Other Testing Information

3.8 Test Lab Condition		
pre-test	post-test	
		F
		in. Hg
		%

n Operation Data
Actual Weight at end of phase (lb)

ın Operation Data
Door closed time

3.11 Run Operation Data
Notes on fuel adjustments/time

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	3.12 Po
1) Any data points with filter temperatures outside the 80-90F?	
If yes, how many and for how long	
2) Did tunnel temperature exceed 40C during the test?	
If yes, how many and for how long	
3) Did tunnel humidity exceed 90%?	
If yes, how many and for how long	
4) Any tunnel dew point measurements within 2C of filter temp	
If yes, how many and for how long	
5) Tunnel flow for test? (dscf/min)	

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st Run Data Check

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Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 5/28/2021 3:38:25 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]; Burkhard, Ellen G (NYSERDA) [Ellen.Burkhard@nyserda.ny.gov]
Subject: Revised TEOM protocol
Attachments: NYSERDA IDC Stove protocol EPA Research 5 28 21 clean-GA-LR-GA secured with clean properties.pdf

Stef, attached is the revised TEOM protocol for dichot and single. You should have everything now.

THIS INTEGRATED-DUTY-CYCLE (IDC) PROTOCOL FOR WOOD STOVES IS THE PROPERTY OF THE NEW YORK STATE ENERGY RESEARCH AND DEVELOPMENT AUTHORITY (NYSERDA) AND CAN BE USED TO TEST TECHNOLOGIES IN A LABORATORY SETTING. ANY DEVIATIONS OR CHANGES TO THIS IDC PROTOCOL FOR WOOD STOVES ARE NOT APPROVED OR SANCTIONED BY NYSERDA. DO NOT CITE, COPY, or DISTRIBUTE THIS IDC PROTOCOL FOR WOOD STOVES WITHOUT THE WRITTEN PERMISSION OF NYSERDA

NYSERDA Integrated Duty Cycle Test Method for Certification of Wood-Fired Stoves Using Cordwood: Measurement of Particulate Matter (PM) and Carbon Monoxide (CO) Emissions and Heating Efficiency

Note: This method does not include all the specifications (e.g. equipment and supplies) and procedures (e.g., sample and analytical) essential to its performance. Some material is incorporated by reference from other methods. Therefore, to obtain reliable results, persons using this method shall have a thorough knowledge of at least the following EPA Tests:

- Method 1- Sample and Velocity Traverses for Stationary Sources
- Method 2- Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube)
- Method 3 – Gas Analysis for the Determination of Dry Molecular Weight
- Method 4 – Determination of Moisture Content in Stack Gases
- Method 5G – Determination of Particulate Matter from Wood Heaters (Dilution Tunnel Sampling Location)
- Method 10 - Carbon Monoxide - Instrumental Analyzer
- Method 28 – Certification and Auditing of Wood Heaters

1. Scope and Application

1.1. This test method specifies operation and fueling for certification and auditing of manually operated wood-fired stoves and heaters.

1.2. This test method measures particulate matter (PM) emissions, carbon monoxide, and efficiency.

1.3. Particulate emissions are measured in the dilution tunnel method as specified in ASTM E2515, Standard Test Method for Determination of Particulate Matter Emissions Collected in a Dilution Tunnel, using the Tapered Element Oscillating Microbalance (TEOM) continuous PM method as detailed in this test method.

1.4. Analyte. Particulate matter (PM). No CAS number assigned. Carbon monoxide (CO). No CAS number assigned.

1.5. Applicability. This method is applicable for the certification and auditing of wood space heaters, which burn cordwood fuel. The test quantifies PM and CO emissions and provides overall efficiency ratings, maximum burn time, and heat output.

1.6. Data Quality Objectives. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods.

1.7. Distinguishing features of appliances covered by this standard include:

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1.7.1. Cordwood fuel is hand-fed into firebox.

1.7.2. A chimney or vent that exhausts combustion products from the appliance.

1.8. The values stated are to be regarded as the standard, whether in I-P or SI units. The values given in parentheses are for information only.

1.9. Data Quality Objectives.

1.9.1. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods.

1.9.2. Measurement of emissions and heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

1.9.3. This is a laboratory method intended to capture operating periods that are representative of actual field use without excessive test burden.

2. Referenced Methods

2.1. NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel

2.2. ASTM 2515: Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel.

3. Definitions

3.1. Appliance – a wood heater capable of and intended for space heating defined in the applicable regulation. The appliance includes a combustion chamber, combustion air settings, operating controls, and a thermostat if specified, and any other accessory required for standard operation, such as a barometric damper,

3.2. Catch - any mass from the sample probe system on the filter.

3.3. Certification or audit test - a series of at least three test runs conducted for certification or audit purposes that meets the specifications detailed in this protocol.

3.4. Chop – using a poker or another piece of wood to strike a piece of the fuel charge to break it into smaller pieces.

3.5. Coal-bed Stirring – prior to adding a new fuel charge, using a poker or piece of wood to stir or level the coal bed of the appliance for the sole purpose of ensuring ease of loading of the fuel charge. No special formations can be made, such as creating coal bed formations or pushing coals to one side or creating slopes with the coals.

3.6. East-west stove – a stove where the firebox dimension parallel to the loading door is greater or equal to the stove depth measurement. Logs are loaded so that they are viewed on the long length of the stove.

3.7. Emission factor – the emission of a pollutant expressed in mass per unit of energy (typically) output from the appliance.

3.8. Firebox - the portion of the chamber in the wood heater in which the test fuel charge is placed and combusted.

3.9. Firebox depth - the horizontal length of the fire chamber dimension measured perpendicular to the loading door. If the manufacturer believes that a portion of the firebox depth is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.10. Firebox Height - the vertical distance extending above the top of the firebox to the floor of the firebox. Firebox height is not necessarily uniform. The measurement must account for variations caused by internal baffles, air channels, or other permanent obstructions. If the manufacturer believes that a portion of the firebox height is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.11. Firebox width - the horizontal fire chamber dimension that is parallel to the loading door. If the manufacturer believes that a portion of the firebox width is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.12. Fuel Adjustment – manipulations to the fuel charge to reflect typical owner practices that allow the cordwood fuel to burn appropriately during the test period. A fuel adjustment includes minor changes in fuel placement. It does not include chopping the wood, stirring the coal bed, or reorganizing fuel placement.

3.13. Fuel load calculator – The locked excel spreadsheet tool that determines the allowable test fuel load weights and required piece sizes for each individual load.

3.14. Fuel loading direction – For loads 2, 3, and 4 fuel shall be loaded based parallel to the dimension with the largest value. If the firebox length and width are within 2", fuel shall be loaded in an east/west fashion, parallel to the loading door. A crisscross configuration is allowed for L1 but cannot be used as a load configuration for loads 2, 3, or 4.

3.15. Kindling pieces – small pieces of wood less than 1" in diameter. No bark or moisture requirements for these pieces, however kindling pieces shall not be dried or stored anywhere but in laboratory ambient conditions. Kindling length shall be of the same wood species as the fuel charge length. Individually kindling pieces may weigh no less than 1.5 ounces.

3.16. Large fuel pieces – pieces that are larger for the appliance as defined by the fuel load calculator.

3.17. L1 – Start-up – period of the test when the unit has kindling and startup fuel under the conditions described in Section 11.6.7.

3.18. L2 – High-fire Phase – period of the test when the unit has a small coal bed and the stoves air settings are fully open. It is intended to replicate periods when homeowners are trying to quickly heat an area, shortly after starting or restarting the appliance.

3.19. L3 - Maintenance-fire phase– period of the test when a fire is maintained with a medium-sized coal bed, and a smaller batch of wood made up of two large pieces. This is intended to simulate a period when the operator is trying to maintain consistent heat output.

3.20. L4 - Low-burn Rate Phase – period of the test when the stove has a large coal bed, the stove is fully loaded, and the adjustable air settings are set to produce the lowest possible burn rate and have the lowest air settings. It is intended to simulate when the operator is trying to maintain heat over a long time, such as overnight or while away for significant periods of time.

3.21. North-south stove: a firebox that has its longest dimension measurement perpendicular to the loading door. In this stove type, logs are loaded so that the ends of the fuel are viewed when loaded.

3.22. Phase – A distinct period in the test run with its own operational procedures and conditions.

3.23. Primary air supply – air supply that introduces air to the wood heater in the combustion chamber and is adjusted to target a desired burn rate. The wood heater manufacturer or test facility can document this through design drawings.

3.24. Secondary air supply - air supply that introduces air to the wood heater such that the burn rate is not altered by more than 10 percent when the secondary air supply is adjusted during the test run. The wood heater manufacturer or test facility can document this through design drawings that show the secondary air is introduced only into a mixing chamber or secondary chamber outside the firebox.

3.25. Significant figure – is any digit that is necessary to define the specific value or quantity. Zeros may be used either to indicate a specific value, like any other digit, or to indicate the magnitude of a number.

3.26. Small fuel pieces - pieces that are small for the appliance as defined by the fuel load calculator.

3.27. Starter fuel – pieces of cordwood that can be smaller than small and large pieces but larger than kindling, as defined by the fuel load calculator.

3.28. Test data– means the data for all test runs conducted on the wood heater, including any data collected during failed and invalid runs and includes records of preparation of standards, identification of equipment used and personnel present, records of calibrations, raw data sheets for field sampling, raw data sheets for field and laboratory analyses, chain-of-custody documentation, and example calculations for reported results.

3.29. Test facility - the area in which the wood heater is installed, operated, and sampled for emissions.

3.30. Test fuel charge - the collection of test fuel pieces used in each of the four phases of the test run. L2, L3, and L4 recommend that at least 75% of the individual pieces with at least 80% bark on one side of the fuel piece. Bark shall not be removed for certification testing. Any fuel charge that suggests bark was purposely removed or shaped shall deem the certification test invalid. Examples of fuel piece manipulation are provided in Section 11. If 75% of the fuel load pieces for L2, L3, and L4 do not have bark, document in the test report.

3.31. Test fuel load – the group of test fuel pieces that are loaded, as specified by phase, throughout the test run.

3.32. Test fuel loading – the arrangement of the test fuel charge.

3.33. Total run fuel load – the amount of wood burned during the entire test run.

3.34. Test fuel loading density – the calculation that determines the weight of the as-fired test fuel load. The calculation is based on the usable volume of the firebox.

3.35. Test run – an individual emission test that includes the four operational phases required by the fueling protocol.

3.36. Usable firebox volume – the calculated volume of the firebox determined using its height, width, and depth as defined in this section. This calculation represents the area where wood is likely to be loaded. If the manufacturer claims that portions of the firebox may not be used in the calculation, a justification must be submitted with the test report. If the justification is not approved, the test results will be deemed unrepresentative for certification purposes. It is highly recommended that manufacturers obtain regulatory approval if making claims that portions of the firebox are not appropriate for inclusion in the calculation.

3.37. Wood heater – an enclosed, wood-burning appliance capable of and intended for space heating or domestic water heating, as defined in the applicable regulation.

4. Interferences

None.

5. Summary of Method

5.1. Particulate matter emissions are measured from a wood heater burning cordwood test fuel in a test facility maintained at a set of prescribed ambient conditions. Procedures for operating the appliance, measuring PM and CO emission rates, and methods for reducing data and calculating results are provided.

5.2. *Dilution Tunnel*. A dilution tunnel following the specifications detailed in ASTM E2515-11 shall be used for particulate measurements.

5.3. *Particulate Matter:* PM emissions are measured in a dilution tunnel with a Thermo model 1405-D 2-channel TEOM using NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel, with a dilution tunnel as specified in ASTM 2515 with modifications discussed in Section 10.

5.4. *Carbon Monoxide*. The CO is measured in the stack and is used to calculate efficiency determination.

5.5. *Operation*. Appliance operation is conducted on a cold-to-hot test cycle, meaning that the appliance starts the first test run at room temperature and ends with the appliance in a heated state. The second and third test runs may start at a slightly warmer temperature if the appliance is designed to retain the heat from the first run. The appliance is operated at operational phases

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representing start-up emissions, high heat demand, low heat demand, changing air conditions, and refueling. To complete the certification test, the appliance shall complete three valid test runs that are averaged to determine the test results.

5.6. *Repeatability.* A series of at least three test runs conducted for certification or audit purposes.

6. Significance and Use

6.1. The measurement of particulate matter emission rates is an important test method widely used in the practice of air pollution control.

6.1.1. These measurements, when approved by state or federal agencies, are often required for the purpose of determining compliance with regulations and statutes.

6.1.2. The measurements made before and after design modifications are necessary to demonstrate the effectiveness of design changes in reducing emissions and make this standard an important tool in manufacturers' research and development programs.

6.2. Measurement of heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

7. Safety

7.1. Disclaimer. This method may involve hazardous materials, operations, and equipment. This test method may not address all the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to performing this test method.

7.2. These tests involve combustion of wood, which releases substantial amounts of heat and combustion products. The heating system also produces large quantities of very hot water and the potential for steam production and system pressurization. Appropriate precautions must be taken to protect personnel from burn hazards and respiration of products of combustion. Exposure of personnel to unsafe levels of carbon monoxide must be avoided, and the use of continuous ambient carbon monoxide monitoring is strongly recommended.

8. ***Equipment and Supplies.*** The following items are required for sample collection:

8.1. Anemometer. A device capable of detecting air velocities less than 0.10 m/sec (20 ft/min), for measuring air velocities near the test appliance.

8.2. *Appliance Flue.*

8.2.1. Steel flue pipe extending to 8.5 ±0.5 ft. (2.6 ±0.15 m) above the top of the platform scale, and above this level, insulated solid pack type chimney extending to 15 ±1 ft (4.6 ±0.3 m) above the platform scale, and of the size specified by the appliance manufacturer. This applies to both freestanding and inserts type appliances.

8.2.2. Other chimney types (e.g., solid pack insulated pipe) may be used in place of the steel flue pipe if the appliance manufacturer's written appliance specifications require such chimney for home installation (e.g., zero clearance appliance inserts). Such alternative chimney or flue pipe must remain and be sealed with the appliance following the certification test. This applies only to appliances requiring a specialized chimney.

8.2.3. Solid pack insulated chimneys shall have a minimum of 2.5 cm (1 in.) solid-pack insulating material surrounding the entire flue and possess a label demonstrating conformance to U.L. 103 (incorporated by reference—see §60.17).

8.3. Appliance Platform Scale and Monitor. For monitoring of fuel load weight change. The scale shall be capable of measuring weight to within 0.01 kg (0.02 lb.) and calibrated to NIST traceable standards at least annually.

8.4. Barometer. Aneroid or another barometer capable of measuring atmospheric pressure to within 0.1 in. Hg (2.5 mm Hg) with an uncertainty of +/- 0.05 in. Hg (+/- 1.27 mm Hg).

8.5. Dilution Tunnel must meet the requirements of ASTM E2515, clauses 6.1.6 and 9.2.

8.6. Dilution Tunnel temperature and relative humidity measurement. A probe with analog or digital data outputs capable of measuring tunnel temperature to within 0.5 °C (1.0 °F) and tunnel RH to within 2% between 5 and 95% RH at maximum tunnel temperatures, such as the Omega HX85A or equivalent. The probe should also report calculated dewpoint.

8.7. Draft Gauge. Electromanometer or other devices for the determination of flue draft or static pressure readable to within 0.005 in. H2O (1.2 Pa)

8.8. Flue Gas Temperature Measurement. A type K thermocouple or equivalent located in the centroid of the stack located 8.0 +/- 0.5 ft (2.44 m +/- 150 mm) above the platform scale, capable of measuring with an accuracy of 4.0°F (2.2°C) or 0.75% of reading, whichever is greater.

8.9. Flue Gas Composition Measurement. A sample probe and continuous infrared analyzer or equivalent capable of measuring span of carbon monoxide (CO) and carbon dioxide (CO_2) in the flue gas produced by the appliance tested. Continuous analyzers (or equivalent) shall have maximum zero and span drift, over a 24 h period, of 1% of full scale.

8.10. Fuel Scale. Balance capable of weighing the test fuel charge to within 0.02 kg (0.05 lb.) and calibrated to NIST traceable standards at least annually.

8.11. Humidity Gauge. Psychrometer or hygrometer for measuring room humidity to within +/- 4% from 25 to 95% RH.

8.12. Moisture Meter. Calibrated electrical resistance meter for measuring test fuel moisture to within 2 percent moisture content.

8.13. Surface Temperatures. Capable of measuring temperature to within 1.5 percent of expected absolute temperatures with an accuracy of 4.0°F (2.2°C) or 0.75% of reading, whichever is greater.

8.14. Test Facility Temperature Monitor. A thermistor, RTD, Type T-Special thermocouple, or other equivalent device, located centrally in a vertically oriented 150 mm (6 in.) long, 50 mm (2 in.) diameter pipe shield that is open at both ends, capable of measuring temperature to within 1°F of expected temperatures.

8.15. TEOM – Thermo Fisher Scientific TEOM model 1405-D (Thermo part # 1405D-ANF, excluding models 1405, 1405-DF, or 1405-F) to measure and report continuous particulate matter (PM) measurements in an ASTM 2515 dilution tunnel or equivalent dilution method, and operated according to the NYSERDA Dichot TEOM Standard Operating Procedures. For lab air PM measurements, Thermo Fisher Scientific TEOM model 1405 (Thermo part # 1405-ANF, excluding model 1405-F), operated according to the NYSERDA Dichot TEOM Standard Operating Procedures.

9. Calibration and Standardizations

9.1. Anemometer. Calibrate the anemometer as specified by the manufacturer's instructions before the first certification test every six months thereafter.

9.2. Appliance Platform Scale. Perform a multipoint calibration (at least five points spanning the operational range) of the platform scale before its initial use. The scale manufacturer's calibration results are sufficient for this purpose. Before each certification test, audit the scale with the wood heater in place by weighing at least one calibration weight (Class F) that corresponds to between 20 percent and 80 percent of the expected test fuel charge weight. If the scale cannot reproduce the value of the calibration weight within 0.0045 kg (0.01 lb.) or 1 percent of the expected test fuel charge weight, whichever is greater, recalibrate the scale before use with at least five calibration weights spanning the operational range of the scale.

9.3. Barometer. Calibrate using a reference pressure monitor calibrator before the first certification test and semiannually after.

9.4. Draft Gauge. Calibrate as per the manufacturer's instructions; a liquid manometer does not require calibration (but must be properly leveled, zeroed, and the system leak checked).

9.5. Humidity Gauge. Calibrate as per the manufacturer's instructions before the first certification test and annually thereafter.

9.6. Fuel Scale. Calibrate as described in 9.2.

9.7. Moisture Meter. Calibrate as per the manufacturer's instructions before the first certification test and semiannually thereafter.

9.8. Temperature Sensors. Calibrate using at least five points within operating range within specification and in compliance with NIST Monograph 175. To be calibrated before the first certification test and semiannually thereafter.

10. Sampling, Test Specimens, and Test Appliances

10.1. Modifications to ASTM 2515 requirements.

10.1.1. Liquid water should not be present anywhere in the sampling system for a valid sample. The presence of condensed water anywhere in the sampling system invalidates the test run. All data from all invalid test runs shall be included in the report. The reviewing authority shall make a final determination on invalidated runs. Data from any invalidated test run shall not be used to calculate results. If the testing agency believes a run has been invalidated, the test run shall be repeated.

10.1.2. Dilution tunnel temperature and relative humidity shall be measured electronically and logged at one-minute intervals near the sample probe to calculate dewpoint.

10.1.3. The following section details test conditions that shall be maintained for a valid test run. A valid test shall have no more than two individual deviations from any of the conditions below to remain a valid run. An example of an individual deviation is a single, ten-minute rolling average where the dilution tunnel exceeded temperature thresholds. Another ten-minute period exceeding the tunnel temperature requirement shall be considered a second deviation.

10.1.3.1. Tunnel temperature shall not exceed 104 deg. F (40 deg. C) based on ten-minute rolling averages derived from one-minute data, excluding periods when the appliance door is open.

10.1.3.2. Tunnel relative humidity shall not exceed 90% based on ten-minute rolling averages derived from one-minute data excluding periods when the appliance door is open.

10.1.3.3. A minimum tunnel flow of 600 CFM is required. Higher tunnel flows may be required to meet the parameters of Section 10.1.3.

10.1.3.4. All exceedances must be reported in the test anomalies section, even if deviations are within the test method tolerances.

10.2. Sample Collection. The following are required for sample collection:

10.2.1. Teflon coated glass fiber filters as supplied by the TEOM manufacturer for use with the TEOM model 1405-D. These are Pallflex Emfab (TX40) with an exposed diameter of 13 mm, without organic binder, exhibiting at least 99.95 percent efficiency.

10.2.2. *Test Specimens.* Appliances shall be supplied as complete systems, including all controls and accessories necessary for installation at the test facility. A full set of specifications, designs, and

assembly drawings shall be provided when the product is placed under certification of a third-party agency.

10.3. Preparation of Apparatus

10.3.1. Wood Heater Installation for Certification Testing. Assemble the wood heater appliance and parts in conformance with the manufacturer's provided User Guide. These instructions must match all instructions materials developed by the manufacturer and/or their distributors. Place the wood heater on the platform scale and connect the chimney to the appliance. Clean the flue with an appropriately sized, wire chimney brush before initiating Run 1 of the certification test. Test documentation should include the date and time of flue cleaning.

10.3.2. Wood Heater Temperature Monitors.

10.3.2.1. For catalyst-equipped wood heaters, locate a temperature monitor (optional) about 25 mm (1 in.) upstream of the catalyst at the centroid of the catalyst face area, and locate a temperature monitor (mandatory) that will indicate the catalyst exhaust temperature. This temperature monitor is centrally located within 25 mm (1 in.) downstream at the centroid of the catalyst face area. Record these locations.

10.3.2.2. Locate wood heater surface temperature monitors at five locations on the wood heater firebox exterior surface. Position the temperature monitors centrally on the top surface, centrally on two sidewall surfaces, and centrally on the bottom and back surfaces. Position the monitor sensing tip on the exterior of the firebox surface inside of any heat shield, room air circulation walls, or other wall or shield separated from the firebox exterior surface. Surface temperature locations for unusual design shapes (e.g., spherical, etc.) shall be positioned so that there are four surface temperature monitors positioned to average stove temperature across various points on the appliance.

10.4. Conditioning

10.4.1. Wood Heater Aging Prior to Certification Testing. A wood heater of any type shall be aged at least 50 hours before initiating a certification test. The aging procedure shall be conducted by the manufacturer or a manufacturer's agent prior to sending the appliance to the testing laboratory. The certification lab cannot be involved with wood heater aging in any manner.

During aging, the appliance shall be operated at a variety of burn rates. Documentation for wood heating aging must be included in the test report to include data on individual hourly burn rates. The testing laboratory shall not conduct any firing of the appliance prior to conducting the certification test.

10.4.1.1. The manufacturer shall supply wood heater aging information for the final test reports. Aging data that shall be reported include all fuel parameters (species, moisture content, load weights,

piece amounts, and size), air settings used, time spent in each air setting phase, amount of fuel burned, and appliance burn rates.

10.4.1.2. If an appliance uses a catalytic combustor, it must be engaged according to the manufacturer's instructions and operate with the catalyst engaged for at least 50 hours during the break-in period. In addition to the reporting requirements listed in 8.1.1, catalytic appliances shall also report hourly catalyst exit temperature data to include the dates and hours of operation.

11. Procedure

11.1. Test Facility Conditions. The test facility shall meet the following requirements during testing.

11.1.1. The test facility temperature shall be maintained between 55 and 87 °F (13 and 30.6 °C) during each test run.

11.1.2. The flue shall discharge into the same space or into a space freely communicating with the test facility. Any hood or similar device used to vent combustion products shall not induce a draft greater than 0.005 in. H_2O (1.25 Pa) on the wood heater measured when the wood heater is not operating.

11.1.3. For test facilities with artificially induced barometric pressures (e.g., pressurized chambers), the barometric pressure in the test facility shall not exceed 30.5 in. Hg (775 mm Hg) during any test run.

11.1.4. Locate the test facility temperature monitor on the horizontal plane that includes the primary air intake opening for the wood heater. Locate the temperature monitor 3 to 6 ft. (0.9 to 1.8 m) from the front of the wood heater in the 90° sector in front of the wood heater.

11.1.5. Use an anemometer, or equivalent device, to measure the air velocity. Measure and record the room air velocity before the ignition period in L1 Startup and once immediately following the test run completion. Air velocities within 0.6 m (2 ft) of the test appliance and exhaust system shall be less than 0.25 m/sec (50 ft/min) without fire in the unit.

11.1.6. Measure and record the test facility's ambient relative humidity, barometric pressure, and temperature before and after each test run using equipment as specified in Section 6.

11.2. Wood Heater Firebox Volume.

11.2.1. Determine the firebox volume using the definitions for height, width, and length. Volume adjustments due to the presence of firebrick and other permanent fixtures may be necessary. All adjustments shall be detailed in the test report and shall conform to the definition of usable firebox volume contained in this test method. Measurements shall include areas adjacent to and above a baffle.

11.2.2. If a manufacturer deems certain areas of the firebox as unusable for fuel load calculations, written documentation stating the basis for that claim and supporting photographic image(s) must

be provided and approved by the regulatory authority prior to conducting the certification test. If approval is not granted prior to the test, then the test may be invalidated if the reviewing agency determines the firebox volume is inaccurate.

11.3. Test Fuel. The test fuel shall conform to the following requirements and meet specifications as required by the fuel loading calculator:

11.3.1. Fuel Species. Untreated, air-dried, cordwood fuel.

11.3.1.1.For EPA research purposes, allowable species: maple (big leaf, red, silver), or birch (black, white, yellow, paper).

11.3.1.2.Kiln-dried fuel is not permitted. Kiln-dried fuel includes elevating air temperature settings.

11.3.1.3.Fuel shall be free of decay, fungus, or other contaminants.

11.3.2. Fuel Moisture.

11.3.2.1.Determine fuel moisture for each fuel piece by averaging four moisture meter readings, one from each of three sides, measured parallel to the wood grain.

11.3.2.2.The test fuel load shall have an average moisture content from 19% to 25%, dry basis.

11.3.2.3.Average individual piece moisture content shall have an average moisture content 18% to 27% dry basis.

11.3.2.4.The addition of moisture to previously dried wood is not allowed.

11.3.2.5.It is recommended that the test fuel be stored in a temperature and humidity-controlled room.

11.3.2.6. Fuel moisture shall be measured within 24 hours of using the fuel for the test and shall be bagged or stored in a humidity-controlled environment until 2 hours prior to testing. A humidity-controlled environment is one where fuel is not subject to conditions that would remove moisture from the fuel, such as fans or a heating source, and maintain relative humidity levels greater than 75%.

11.3.3.Fuel Temperature. The test fuel shall be at the test facility temperature of 55 to 87 °F (13 to 30.6 °C) +/-2 °F.

11.3.4. Fuel Dimensions. The dimensions of each test fuel piece shall conform to definitions specified by the protocols using the fuel load calculator.

11.3.4.1.Fuel length:

11.3.4.1.1.The length of the fuel pieces will be determined by the fuel load calculator.

11.3.4.1.2.Measurements shall be taken, and the length of the test fuel will be determined by entering the firebox dimensions, which calculates the length for all the fuel pieces into a generally available commercial size (14, 16, 18, 20, or 22 inches in length).

11.3.4.1.3.Piece length specified by the fuel calculator shall be communicated and specified for use in the owner's manual and website. Piece size shall be within 0.5" of the log length determined by the calculator, as measured on the shortest length measurement.

11.3.5.Fuel Loading Direction

11.3.5.1.Fuel loading direction shall be determined by the firebox measurement.

11.3.5.1.1.Stoves with a depth measurement greater than two inches from the width measurement shall be tested with the fuel in a north-south configuration and may not test with fuel in an east/west or crisscross configuration in any load other than Load 1 and Load 2.

11.3.5.1.2.Stoves with a width measurement greater than the depth measurement or a width measurement within two inches of the depth measurement shall be tested with the fuel loaded in an east-west configuration and may not test with fuel in a north/south configuration or crisscross configuration in any load other than Load 1 and Load 2.

11.3.6.Fuel piece weight for each phase of the protocol shall be determined by the fuel load calculator.

11.3.6.1.Kindling – shall be:

11.3.6.1.1.Pieces of wood less than or equal to 1" in diameter.

11.3.6.1.2.No bark requirements for kindling fuel.

11.3.6.1.3.Fuel species may be any species allowed in 7.2.1.1.

11.3.6.1.4.No moisture requirements.

11.3.6.1.5.Length of kindling shall be the fuel length specified by the fuel load calculator.

11.3.6.1.6.Kindling fuel shall conform to the rule that 7 to 10 pieces of kindling equal 1 pound of kindling fuel (+/- 5%).

11.3.6.2. Starter fuel: pieces of cordwood shall be used during the startup phase. Individual piece weight for starter fuel shall be determined by the fuel load calculator. Each piece shall be

triangular, irregular, or circular in cross-section. Square pieces shall be not be used in testing (see Figure 1). Pieces that have squared cross sections shall be split to represent the typical triangle nature of wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible and fuel load pieces shall be composed to include different shapes of wood if using any trapezoidal pieces. .

11.3.6.3.Small fuel pieces: smaller pieces of cordwood by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall not be used (see figure 1). Pieces that have square cross-sections shall be split to represent the typical triangle nature of wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible. No more than two (2) small fuel pieces can be trapezoidal in shape (Figure 2) per fuel load.

11.3.6.4.Large fuel pieces: larger pieces of cordwood, by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall be not be used (see figure 1). Pieces that have square cross-sections shall be split to represent the typical triangle nature of wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible. No more than one (1) large fuel piece can be trapezoidal in shape (Figure 2) per fuel load.

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Figure 1. Schematic of unacceptable cross-sectional profiles

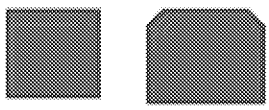


Figure 2. Schematic of undesirable and limited use shapes

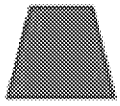
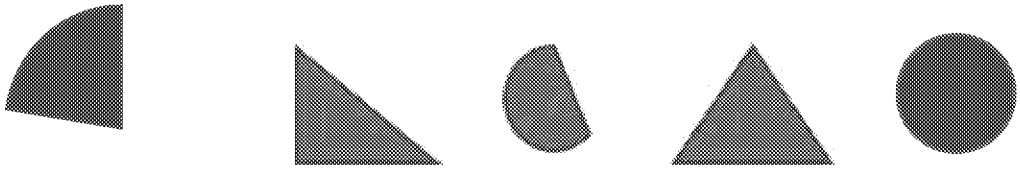


Figure 3. Schematics of acceptable cross-sectional profiles



11.4. Sampling Equipment.

11.4.1. Prepare the tunnel and lab air PM sampling equipment as defined by the TEOM Protocol.

11.4.2. Prepare all other equipment as defined by method EPA Method 1, 2, 3, 4, and ASTM 2515 (dilution tunnel specifications only).

11.5. Manufacturer participation in certification testing.

11.5.1. A representative of the manufacturer may observe testing but may not provide instructions to the certification lab, in any form, with testing staff or equipment once the certification tests begin. The names of testing witnesses cannot be withheld as confidential business information (CBI).

11.6. Test Run Procedure.

11.6.1. Before each test series, the firebox shall be vacuumed. Testing shall begin without any ash or other materials in the appliance.

11.6.2. Before initiating the compliance test series, clean the flue and dilution tunnel with an appropriately sized wire chimney brush before each certification test. Test documentation should include the date and time of flue cleaning.

11.6.3. Record fuel weight data, temperature measurements, and gas concentrations at 1-minute intervals.

11.6.4. Wood Heater Operation and Adjustments. Record all adjustments made to the air supply controls, adjustments to and additions or subtractions of fuel, and any other changes to wood heater operations that occur during the test period.

11.6.5. Appliance operation -bypass operation for catalytic and hybrid models shall follow operational instructions contained in the appliances owner's manual.

11.6.6. The weight of fuel remaining at the end of the test run is determined as the difference between the weight of the wood heater with the remaining coals and fuel and the weight after loading the fuel charge. The starting weight is the tare weight of the cleaned, dry wood heater.

11.6.7. All runs shall be video-recorded in their entirety. Video shall be of sufficient quality to determine fuel characteristics, fuel loading procedures, and firebox conditions during any testing or aging conducted by the test lab. The testing lab shall have the capacity to allow appropriate agencies the opportunity to remotely witness the test.

11.6.8.L1: Start-up Phase.

11.6.8.1.L1 Appliance requirements.

11.6.8.1.1.Stove temperature: internal and external stove temperature must not be greater than the ambient temperature +/- 2˚F (1.1˚C) for Run 1. There is no stove starting temperature requirement for Runs 2 and 3 except in the case of a failed first run. In this case, if Run 1 is invalid or incomplete, the stove must meet Run 1 conditions for at least one valid run. Temperature measurements for the external and internal temperatures shall be taken within 15 minutes before starting the test and shall be reported in the test report.

11.6.8.1.2.Tare the appliance scale before starting the test. Record appliance scale weights at the start and end of L1 phase.

11.6.8.2.L1 Fuel requirements.

11.6.8.2.1.L1 Fuel type – during the startup phase newspaper (optional up to six full sheets traditional newspaper size), kindling, and starter fuel pieces are used. No other additions are allowed.

11.6.8.2.2.L1 loading density

11.6.8.2.2.1.Kindling loading density: 1 lb. per cubic foot for dry kindling, +/- 5%. The fuel load calculator determines the amount of kindling that can be used.

11.6.8.2.2.2.Starter Fuel loading density: 3 lb. per cubic foot, +/- 5%. The fuel load calculator will determine the minimum piece weight that can be used as starter fuel.

11.6.8.2.3.L1 fuel loading structure: The loading structure of the fire shall be a bottom-up configuration with newspaper on the bottom, kindling on top of the paper, and starter fuel on top of the kindling. Kindling and starter fuel shall be loaded in a crisscross configuration.

11.6.8.3.L1 Operational parameters.

11.6.8.3.1.All kindling, starter fuel, and newspaper must be in the firebox for light off.

11.6.8.3.2.Air settings are fully open.

11.6.8.3.3.Light the fire with a torch for a period of no more than 30 seconds.

11.6.8.3.4. Immediately after lighting the fire and completing the photo requirement, the appliance door shall be moved to a cracked open position. Cracked open position is defined as opening no more than one inch. The appliance door shall be closed 5 minutes after ignition.

11.6.8.4.L1 Fuel Adjustments: up to three fuel adjustments are allowed in the startup phase. The door may be open for 30 seconds during each fuel adjustment.

11.6.8.5.L1 End of Phase – the end of the startup phase is defined by the weight specified by the fuel load calculator.

11.6.8.6. L1 Documentation – Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed, and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge.

11.6.9. *L2: High-fire Phase* – the high-fire phase commences immediately after the startup phase ends.

11.6.9.1.L2 Appliance requirements.

11.6.9.1.1.Record the weight of the stove prior to loading the L2 fuel charge, the weight of the fuel charge prior to loading, and the scale weight after loading the L2 fuel charge.

11.6.9.2. L2 Fuel requirements.

11.6.9.2.1. L2 piece size – during the high-fire phase, small cordwood pieces by weight, as defined by the fuel load calculator, are used.

11.6.9.2.2. L2 loading density: 7 lb. per cubic foot, +/- 5%. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.9.3.L2 Operational parameters: Open the door upon completion of the startup phase and load the L2 fuel load within 60 seconds. Once the fuel has been loaded, the appliance doors shall be closed immediately. Air settings shall be left fully open. When 50% of the L2 fuel load mass has been consumed, the air settings shall be moved to the lowest settings.

11.6.9.4.L2 Fuel Adjustments.

11.6.9.4.1.One fuel adjustment shall be made during the high-fire phase prior to moving the primary air control(s) to their lowest setting. The fuel adjustment shall optimize fuel placement for burn conditions. The door shall remain open for 30 seconds for fuel adjustments.

11.6.9.4.2.Additional fuel adjustments shall be made if there is a five-minute period without a weight change of 0.1 pounds at any point during the high-fire phase.

11.6.9.4.3.if there is a five-minute period without a weight change at any point during the high-fire phase. The door may only be open for 30 seconds for fuel adjustments.

11.6.9.4.4.All fuel adjustments must be documented in the test report notes and summary.

11.6.9.5.End of L2 Phase –The high-fire phase ends when the scale indicates that 90% of the high-fire fuel mass has been consumed.

11.6.9.6. L2 Documentation – Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed, and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge prior to loading.

11.6.10. *L3: Maintenance-fire Phase* – the L3 maintenance-fire phase commences immediately after the L2 high-fire phase ends.

11.6.10.1.L3 Appliance Requirements.

11.6.10.1.1. Record the weight of the stove prior to loading the maintenance-fire fuel charge, the weight of the fuel charge prior to loading, and the scale weight after loading the maintenance-fire fuel charge.

11.6.10.2.L3 Fuel Requirements.

11.6.10.2.1.Fuel type – during the L3 phase, large cordwood pieces are used. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.10.2.2.L3 Fuel loading structure: fuel shall be loaded in the direction specified by the fueling calculator.

11.6.10.2.3. L3 loading density: 5 lb. per cubic foot, +/- 5%. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.10.3. L3 Operational Parameters:

11.6.10.3.1.Open door upon completion of the L2 phase and load the maintenance-fire fuel charge.

11.6.10.3.2.Air controls shall be placed in the fully open position for the first five minutes of the phase, and then returned to the low air setting.

11.6.10.3.3.L3 Load - L3 fuel loaded within 30 seconds of the door opening. Close the loading door immediately.

11.6.10.4. L3 Fuel Adjustments: Fuel Adjustments: If there is a ten-minute period without weight change (0.10 lb.) at any point during the L3-fire phase, a fuel adjustment shall be made to increase the burn rate. The door may be open for up to 30 seconds for fuel adjustments. Only two

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fuel adjustments may be made during this phase. If after the second fuel adjustment, another ten-minute period of no weight change (0.10 lb.) occurs, the run ends, and it is a failed test run.

11.6.10.5.L3 End of Phase – The L3-fire phase ends when the scale indicates that 90% of the maintenance-fire fuel mass has been consumed.

11.6.10.6.L3 Documentation – Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed, and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge prior to loading.

11.6.11.*L4: Low burn rate phase* – L4 phase commences immediately after the L3-fire ends.

11.6.11.1.L4 Appliance Requirements.

11.6.11.1.1.Record the weight of the stove prior to loading the L4-fire fuel charge, the load of the fuel charge prior to loading, and the scale weight after loading the overnight-fire fuel charge. Alternatively, if the scale was zeroed prior to starting the test, record the scale weight before and after loading the overnight-fire fuel charge.

11.6.11.2.L4 Fuel requirements

11.6.11.2.1. L4 fuel type –a mix of small and large cordwood pieces are used. At least 50% of the fuel charge load, by the number of pieces, must be large pieces.

11.6.11.2.2.L4 Loading structure: fuel will be loaded in one direction.

11.6.11.2.3.L4 loading density: The fuel load calculator specifies a load volume of 12 lb/ft^3 +/-5%. Fuel shall be loaded in a manner to maximize the number of pieces that will fit in the stove without using force.

11.6.11.3. L4 Operational Parameters:

11.6.11.3.1. Open the loading door upon completion of the L3 maintenance-fire phase.

11.6.11.3.2.Load the L4 fuel charge within two minutes (120 seconds).

11.6.11.3.3.Keep the door in the 1" cracked position for five minutes from the beginning of the L4 phase.

11.6.11.3.4.Air controls shall be placed in the fully open position for the first ten minutes of the phase, and then returned to the low air setting.

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11.6.11.4.L4 Fuel Adjustments.

11.6.11.4.1.Unlimited fuel adjustments are allowed within the first five minutes of the phase. After ten minutes, air control(s) shall be moved to their lowest position. A picture of the air setting used must be included in the test report. The door may be open for up to 30 seconds for fuel adjustments.

11.6.11.4.2.If there is a ten-minute period without weight change (0.10 lb.) during the first hour of the L4- phase, a fuel adjustment shall be made. The door may be open for up to 30 seconds for fuel adjustments.

11.6.11.4.3.Only two fuel adjustments may be made during the first hour. If after the second fuel adjustment, another period of no weight change (0.10 lb.) is observed, the run ends, and it is a failed test run.

11.6.11.4.4.No fuel adjustments are allowed after the first hour of the phase.

11.6.11.4.5.If there is no weight change for a consecutive period of 20 minutes at any point after the first hour of the phase, the unit has failed the test run.

11.6.11.5.L4 End of Phase – The L4 phase shall end when the scale indicates that 90% of the total L4 fuel mass has been consumed. If the fuel load does not burn to 90%, it is a failed test run.

11.6.11.6. L4 Documentation - Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed, and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge prior to loading.

11.7. Test Run. A complete test run requires the completion of all four burn phases and loads. For any appliance that will not accommodate the loading arrangement specified in this test method, the test facility personnel shall contact the Agency Administrator to obtain written approval for an alternative loading arrangement.

11.8. Test Run Requirements. The following describes the required parameters for each test run. Each emission test run shall include all phases of the operational and fueling protocol run in order as described.

11.8.1.Consecutive Test Runs. Consecutive test runs may be conducted, provided that the following requirements are met:

11.8.1.1.Run 1 – The appliance shall have an internal and external starting temperature within +/- 2 °F (1.1°C) of ambient laboratory temperature at the beginning of Run 1.

11.8.1.2. Run 2 – The second test run may commence 24 hours after the start of Run 1. Stove coals and ash can remain in the stove until 1 hour before conducting Run 2. All coals and ash shall be removed at least one hour prior to commencing Run 2.

11.8.1.3. Run 3 – The third test run may commence 24 hours after the start of Run 2. Stove coals and ash may remain in the stove until 1 hour before conducting Run 3. All coals and ash shall be removed at least one hour prior to commencing Run 2.

11.9. *Failure to Operate at All Test Conditions*

11.9.1. If the appliance fails two runs due to incomplete or invalid test runs, it shall be determined that the appliance has failed the certification test and requires a modification to appliance design. All data for incomplete runs shall be reported. Incomplete failed test runs are defined as the following:

11.9.1.1. If a wood heater fails to complete all four phases of the test run, the run shall be considered a failed test run.

11.9.1.2. If there is no weight change, defined as 0.10 lb., for a consecutive period of 20 minutes at any point during the test, the unit has failed the test run.

11.9.2. If a test run violates the test method parameters, the run is invalid.

11.9.3. If during certification testing a critical component of the stove is damaged or breaks, the certification test will be stopped and considered invalid.

11.9.3.1. If damage is noted during a test, repairs shall be made by the manufacturer (or by laboratory personnel with written direction from the manufacturer). If the repair involves components that would need aging, the appliance shall then undergo another round of wood heater aging as specified in section 10.6. These components may include but are not limited to catalyst elements, gaskets, and refractory components. The aging process is intended not only to 'cure' the stove but also to cycle parts that may fail with extended use. Alternate aging techniques may be approved by the administrator, depending on the nature of the failure, material, and critical nature.

11.10. Test Run Completion. Once three valid runs have been completed, the testing is complete. No additional runs may be completed.

11.10.1. *Additional Test Runs*. If there is an invalid run, two additional runs may be attempted to complete the test series. If more than three test runs are conducted, the results from all valid test runs shall be used in calculating the average emission rate. The measurement data and results of all test runs shall be reported regardless of which values are used in calculating the emission rate. No test run data can be eliminated from the reporting requirements of this method.

11.10.2. *Invalid Runs.* When a test run fails to meet one of the QA/QC criteria stipulated in the test method, the data are invalid, and the run must be repeated. Data for the invalidated test run must be included in the test report, but the data must not be used in the calculation of average emission values.

11.10.3. *Incomplete Runs:* When an appliance cannot successfully complete all operational elements of the protocol specified in Section 11.6.7 through 11.6.10, it is an incomplete run

11.11. Auxiliary Wood Heater Equipment Operation. If optional heat exchange blowers are sold for use with the wood heater, three runs with the fan and an additional run without the fan shall be completed. If emissions are more than 1 gram per higher with the fan on, an additional two runs must be completed with the fan on. Heat exchange blowers shall operate in the highest airflow setting. (Automatically operated blowers shall be operated as designed) during the entire test.

11.12. PM Data Recording.

11.12.1. All data shall be collected and recorded at intervals of no more than 1 minute. TEOM operation shall follow the procedures listed in NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

11.12.2. Data shall be reported in an Excel or compatible spreadsheet following the minimum data reporting requirements. All electronic files, including raw instrument data, shall be submitted as part of the test report. Spreadsheet files shall be supplied as part of the publicly available test report.

11.12.3. Room PM measurement – TEOM. A single channel TEOM shall be used to measure ambient lab air PM during the test, as configured in NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel. The sample flow shall be 3 LPM.

12. Quality Control Measures

12.1. Dilution tunnel - Conduct sampling equipment leak check and calibration pre- and post-test.

12.2. TEOM – Flow and Leak checks are done before and after every test run per NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel. Additional quality control measures are included in the TEOM Operating Procedure.

13. Data Analysis and Calculations.

Proportioning of emission factors and rates per phase according to Appendix A, variables shall have subscript added to determine the relevancy of phase, i.e. $E_{T(P1)}$ indicates Total particulate emissions for Phase 1 and $E_{g/hr(P2)}$ indicates emissions factor in grams per hour for Phase 2.

13.1. Emission Calculations. Particulate matter, carbon dioxide, and carbon monoxide shall be calculated using the following methodology and reported in grams per hour, grams per kilogram and pounds per million British Thermal Unit (BTU) heat output.

13.2. Rounding

13.2.1. All calculations shall be conducted using all decimal values provided by the instrumentation or recorded by the operator.

13.2.2. No truncation of data is acceptable until the final result has been calculated.

13.2.3. Only the final calculation of the PM emissions rate shall be rounded to three significant figures.

13.2.4. When rounding off a figure, the following procedure should be used. If the first digit to be discarded is less than five, the last digit retained should not be changed. When the first digit discarded is greater than five, or if it is a five followed by at least one digit other than zero, the last figure retained should be increased by one unit. When the first digit discarded is exactly five, followed only by zeros, the last digit retained should be rounded upward if it is an odd number, but no adjustment made if it is an even number.

13.3. TEOM data shall be reported as follows.

13.3.1. Emissions from each of the 4 phases of the test shall be reported as individual results in grams per hour, grams per kilogram, and lb/MMBtu (heat output). Calculations shall use Section 7 of the NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM NYSERDA TEOM protocol.

Emissions from the entire test run in grams per hour, grams per kilogram, and lb/MMBtu (heat output).

Nomenclature

BR – average dry fuel burn rate, lb/hour
$BR_{(x)}$ – Burn rate for specific phase, BR_{L1}, BR_{L2}, BR_{L3}, BR_{L4}
CO – Carbon Monoxide
CO_2 – Carbon Dioxide
BT = time of 90% of overnight load consumed – time of overnight loading
C_{steel} – Specific heat of steel (0.1 Btu/ lb., ˚F)1
E_T – Total particulate emissions for the full test run in grams
$E_{g/MJ}$ – PM Emissions rate in grams per megajoule of heat output
$E_{g/kg}$ – PM Emissions factor in grams per kilogram of dry fuel burned

1 The value of 0.1 for the specific heat of steel is taken from EPA M28WHH.

$E_{g/hr}$ – PM Emissions factor in grams per hour
HHV – Higher heating value of dry fuel (Btu/lb), measured ASTM E711.
$\%M_d$ = Fuel moisture content, dry basis, percent.
$\%M_w$ = Average moisture in test fuel charge, wet basis, percent
PCTCO2– average CO_2 in the dry flue gas (%)
PPMco -average CO in the dry flue gas (ppm)
Q_{out} – Total heat output in BTU's (megajoules)
SC_i – Scale weight at specific time interval, lb.
T1 – Surface Temperature 1 °F (°C)
T2 – Surface Temperature 2 °F (°C)
T3 – Surface Temperature 3 °F (°C)
T4 – Surface Temperature 4 °F (°C)
T5 – Surface Temperature 5 °F (°C)
T6 - Flue Gas Temperature °F (°C)
T7 – Room Temperature °F (°C)
$TS_{avg(i)}$ – Initial Average Surface Temperature °F (°C)
$TS_{avg(f)}$ – Final Average Surface Temperature °F (°C)
W_{fuel} – Fuel charge weight in pounds (kg)
Θ – Total length of test run, hours
$\Theta_{(x)}$ – Total length of test run in hours per phase, X
$\%M_w = 100(\%M_d)/100+\%M_d$

13.4. Average Wood Heater Surface Temperatures. Calculate the average of the wood heater surface temperatures at the start of the phase (L4) and end at the end of the test (L4) of the test run.
L4 $TS_{avg(i)}$ – (T1 + T2 + T3 + T4 + T5) / 5
L4 $TS_{avg(f)}$ – (T1 + T2 + T3 + T4 + T5) / 5
Average surface temperatures at the start and end of any phase can be determined by averaging all five sensors at the beginning and end of each phase.
L_x $TS_{avg(i)}$ – (T1 + T2 + T3 + T4 + T5) / 5
L_x $TS_{avg(f)}$ – (T1 + T2 + T3 + T4 + T5) / 5

13.5. Burn Time Rating– A standardized burn time rating shall be determined by rounding the duration of the overnight-fire phase of the test up to the nearest 1 hour. Burn time shall be calculated as the time L4 is loaded into the stove until 90% of the fuel has been consumed. This provides an important rating for consumers and is not intended for any calculation purposes and shall be reported by all manufacturers materials that provide specifications on appliance performance. Language such as "this stove has demonstrated a low setting burn time of x hours in official testing."

13.6. Determine Burn Rates

BR_{L1} = not applicable
BR_{L2} = (L2 Initial SC_i – L2 Final SC_i) / $\Theta_{(L2)}$, lbs./hr

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BR_{L3} = (L3 Initial SC_i – L3 Final SC_i) / $\Theta_{(L3)}$, lbs./hr
BR_{L4} = (L4 Initial SC_i – L4 Final SC_i) / $\Theta_{(L4)}$, lbs./hr

13.7. Emissions

13.7.1. Determine emission rates and emission factors as:

$E_{g/MJ} = E_T/(Q_{out} \times 0.001055)$, g/MJ
$E_{g/kg} = E_T/(W_{fuel}/(1+M\%M_d/100))$, g/dry kg
$E_{g/hr} = E_T/\Theta$, g/hr

13.8. Efficiency calculation.

The following nomenclature is defined specifically for the efficiency calculation in this section.
Ultimate Analysis of dry fuel (% by weight, ASTM D5373)
Carbon – CA
Hydrogen – HY
Oxygen – OX
Moisture Content – mass of water per mass of dry fuel – Mcdb
Ambient Humidity Ratio[1] – mass of water per unit mass of dry air – ω
Flue gas temperature (F) – Ts
Room temperature (F)-Tr
CO in the dry flue gas (ppm) – PPMco
CO2 in the dry flue gas (%) – PCTCO2
Higher heating value of the dry fuel (lb/MMBtu, ASTM E711) – HHV

1. Humidity ratio is a commonly used term to express the moisture content in air. It can be determined from ambient temperature and relative humidity using, for example, a Psychrometric Chart. [ASHRAE Handbook of Fundamentals, Chapter 1, p. 1.15, American Society of Heating, Refrigeration, and Air Conditioning Engineers (2017)] For example, air at 65°F and 70% relative humidity has a humidity ratio of .0092 lb of water vapor per pound of dry air.

<u>Combustion Balance Equation:</u>

$$C_xH_yO_z + (1+\alpha)*\gamma(O_2 + 3.76N_2) + \left[\omega * \left(\frac{(1+\alpha)\bullet\gamma\bullet(32 + 3.76\bullet 28)}{18}\right) + \frac{Mcdb}{18}\right] H_2O$$

$$\rightarrow (x-\beta)\,CO_2 + \beta CO + (\alpha\bullet\gamma + \frac{\beta}{2})\,O_2 + (1+\alpha)\bullet\gamma \bullet 3.76N_2 + \left[\frac{y}{2} + \omega\bullet\left(\frac{(1+\alpha)\bullet\gamma\bullet(32 + 3.76\bullet 28)}{18}\right) + \frac{Mcdb}{18}\right] H_2O$$

Where:

$x = CA/12$

$y = HY$

$z = OX/16$

$\gamma = (x + \frac{y}{4} - \frac{z}{2})$

α = excess air parameter, e.g. if $\alpha = 0.5$, there is 50 % excess air

From this:

$$PPMco = \frac{1E6 * \beta}{x + \left(\alpha * \gamma + \frac{\beta}{2}\right) + (1 + \alpha) * \gamma * 3.76}$$

$$PCTCO2 = \frac{100 * (x - \beta)}{x + \left(\alpha * \gamma + \frac{\beta}{2}\right) + (1 + \alpha) * \gamma * 3.76}$$

With flue gas CO and CO_2 measured, these two equations can be solved simultaneously for β and α.

$$\frac{100 * x * PPMco}{1E6 * PCTCO2 + 100 * PPMco}$$

$$\alpha = \frac{\frac{100 * (x - \beta)}{PCTCO2} - x - \frac{\beta}{2} - 3.76 * \gamma}{4.76 * \gamma}$$

<u>Calculation of the Molar Coefficient for Each of the Products</u>

For the assumption of 100 kg of dry fuel, this is the number of moles of each product for the input conditions

$MFCO = \beta$ Molar Coefficient for CO

$MFCO2 = x - \beta$ Molar Coefficient for CO_2

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$MFH2O = \frac{\gamma}{2} + \frac{Mcdb}{18} + \frac{\omega * (1+\alpha) * \gamma * (32+3.76*28)}{18}$ Molar Coefficient for H_2O

$MFO2 = \alpha * \gamma + \frac{\beta}{2}$ Molar Coefficient for O_2

$MFN2 = (1+\alpha) * \gamma * 3.76$ Molar Coefficient for N_2

Conversion of Molar Coefficients to Mass of Products per Unit Mass of Dry Fuel

$MCO = MFCO * 28/100$ kg CO in flue products per kg dry fuel fired

$MCO2 = MFCO2 * 44/100$ kg CO_2 in flue products per kg dry fuel fired

$MH2O = MFH2O * 18/100$ kg H_2O in flue products per kg dry fuel fired

$MO2 = MFO2 * 32/100$ kg O_2 in flue products per kg dry fuel fired

$MN2 = MFN2 * 28/100$ kg N_2 in flue products per kg dry fuel fired

Heat Capacity of Exhaust Products

The general equation for representing how the heat capacity of the exhaust products varies with temperature is:

$C = A * Tk + B$

Where:

C = heat capacity J/mol K or kJ/kgmol K

A and B are constants

Tk = Temperature in °K

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The values for A and B for the exhaust components are provided in the table below

Component	A	B
CO	.0056	27.162
CO2	.029	29.54
H2O	.0057	32.859
O2	.009	26.782
N2	.0062	26.626

For each component, heat capacity is calculated at the stack temperature and at room temperature. The average of these is used to calculate sensible heat loss.

<u>Calculation of Heat Losses for Efficiency Determination</u>

$HHVJ = HHV * 2.326$ Higher heating value in kJ/kg (conversion from Btu/lb)

$LHWV = 43969$ Latent heat of water vapor in kJ/kgmol

$Llat = MFH2O * LHWV/HHVJ$ Heat loss in latent heat of water vapor, % of input energy

$Lco = MFCO * 282993/HHVJ$ Heat loss in chemical energy in CO, % of input energy

$Lsens = (MFCO * C_{COm} + MFCO2 * C_{CO2m} + MFH2O * C_{H2Om} + MFO2 * C\_O2m$

$+MFN2 * C\_N2)/HHVJ$ Heat loss in sensible heat in flue gas, % of input energy

<u>Note – T6 and T7 in this expression must be expressed in °C or K.</u>

$Efficiency = 100 - Llat - Lco - Lsens$ Stack loss efficiency, %

14. ***Reporting Requirements.*** The report shall include the following:

14.1.1. Introduction

14.1.2. Purpose of test: certification, audit, efficiency,

14.1.3. Name and location of the laboratory conducting the test.

14.1.4. Wood appliance identification – manufacturer, model number/name, design type, description of the appliance tested, stove condition, and date of receipt.

14.1.5. Test information – location of testing, date of tests, sampling methods used, number of test runs, a statement detailing any previous certification testing completed on the wood appliance.

14.1.6. A list of people who conducted research on the appliance, participated in testing preparation, or witnessed the certification testing. This list shall clearly specify their roles in the testing program for the appliance. The list shall include the participant's name, title, company, contact information and the purpose of their participation.

14.1.7. A statement that the test results apply only to the specific appliance tested.

14.2. Summary and Discussion of Results

14.2.1. Table of results to include test run number, average burn rate for entire run and each phase, carbon monoxide and particulate emission rate for full run, particulate and carbon monoxide emission rate for each load phase (L1, L2, L3, L4), efficiency for the full run and each phase, burn time for total run and each phase.

14.2.2. For each test run and pollutant with real-time data to include: Θ_1,Θ_2, Θ_3, CO, CO_2, PM, and efficiency for (1) L1 - the startup phase and (2) L2 - high-, (3) L3-maintenance-, and (4) L4 low burn rate fire phases. Calculated results for the emissions shall be reported as total emissions in grams, pounds per million Btu output, grams per MJ, grams per kilogram of dry fuel and grams per hour, and pounds per hour.

14.2.3. A narrative discussion detailing any issues or anomalies that arose during each test run and how those were handled, including comments about the fuel, and loading of the appliance.

14.2.4. PM Plots

14.2.4.1. A plot of PM emission rate in grams/hour vs. time at 1-minute intervals, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.5. Summary of other data – test facility conditions, surface temperature averages, catalyst temperature averages, pretest fuel weights, test fuel charge weights – total and by phase.

14.3. Discussion. Test run result, specific test run problems, and solutions. Comments on fuel, loading, analysis, and anything that may impact the reported result(s).

14.3.1. Details of deviations from, additions to or exclusions from the test method, and their data quality implications on the test results (if any), as well as information on specific test conditions, such as environmental conditions. An explanation of the deviations, additions, or exclusions shall be provided along with an analysis as to why these elements had no impact.

14.4. Process description:

14.4.1. Data and drawings indicating the firebox size and location of the fuel charge.

14.4.2. Drawings and calculations used to determine firebox volume to include volume, height, width, and lengths, weight, and volume adjustments.

14.4.3. Firebox configuration – At a minimum to include air supply locations and operation, air supply introduction location, refractory location and dimensions, catalyst location, baffle and by-pass location and operation (include line drawings or photographs)

14.4.4. Appliance operation during the test – shall supply details on air supply settings and adjustments.

14.5. Test fuel properties – the report shall provide information on the species, density, fuel moisture, fuel temperature, and load details from the fuel load calculator to include all measurements including the number of pieces, individual piece weights, piece length, moisture content and weight.

14.6. Sampling

14.6.1. A description of the test procedures and test equipment, including a schematic or other drawing showing the location of all required test equipment. Also, a description of test fuel sourcing, handling and storage practices shall be included.

14.6.2. Describe the sampling location relative to the wood heater, include drawing or photographs.

14.6.3. Provide data on sampling blanks.

14.7. Quality Control and Assurance Procedures

14.7.1. Calibration procedures and results certification procedures, sample and analysis procedures.

14.7.2. Test method quality control procedures to include TEOM leak and flow checks, stratification (velocity) checks, tunnel flow range results, filter temperature range verification and dilution tunnel RH verification.

14.8. Appendices

14.8.1. Results and Example Calculations. Raw data and complete calculations for data included in summary tables.

14.8.2. Raw data. Copies of all files or sheets for sampling measurement, temperature records, and other materials used by lab related to testing.

14.8.3. Calibration Results. Summary of all calibrations, check, and audits pertinent to the certification.

14.8.4. Sampling and Operation Records. Copies of all uncorrected records of activities not included in raw data sheets (e.g., wood heater door open, times and durations) as well as photographs of fuel loading and air flow settings.

14.8.5. Correspondence. Any correspondence to include written, electronic or verbal communications regarding appliance testing. Items shall include:

14.8.5.1. Request to conduct testing

14.8.5.2. Scheduling of testing

14.8.5.3. Notice to EPA to conduct test, and any modifications to that request.

14.8.6. Test Facility Information. Report test facility temperature, air velocity, and humidity information.

14.8.7. Test Equipment Calibration and Audit Information. Report calibration and audit results for the platform scale, test fuel balance, test fuel moisture meter, and sampling equipment including volume metering systems and gaseous analyzers.

14.8.8. Pretest procedures. Report all pretest procedures conducted at the lab on the appliance to burns, rates, and amounts.

14.8.9. All required data for each test run shall be provided in spreadsheet format both in the printed report and in a computer file such that the data can be easily analyzed and calculations easily verified. Formulas used for all calculations shall be accessible for review.

14.8.10. For each test run: report TEOM flow and temperature and verification of all TEOM data validation parameters as required in NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

14.8.11. Raw data, calibration records, and other relevant documentation shall be retained by the laboratory for a minimum of 7 years.

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Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 7/28/2021 4:14:15 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
Subject: RE: scale for boiler question
Attachments: IDC protocol.pdf

We don't have a final IDC for cordwood boilers yet, close but not there yet, but PFS could review the pellet boiler protocol, which will be very similar. I have attached the latest draft of the pellet boiler protocol to this email.

From: Johnson, Steffan <johnson.steffan@epa.gov>
Sent: Wednesday, July 28, 2021 11:55 AM
To: Lisa Rector <lrector@nescaum.org>
Subject: RE: scale for boiler question

Lisa,

Thank you, this will be helpful to PFS who needs to understand what scale resolution will be necessary for the OWB work.

Much appreciated!

Stef

From: Lisa Rector <lrector@nescaum.org>
Sent: Wednesday, July 28, 2021 11:22 AM
To: Johnson, Steffan <johnson.steffan@epa.gov>
Subject: FW: scale for boiler question

Stef, attached is information on the CS scale.

Integrated Duty Cycle (IDC) Test Method for Certification of Thermostatically Controlled Automatic-Feed Hydronic Heating Appliances with External Thermal Storage: Measurement of Particulate Matter (PM), Carbon Monoxide (CO) Emissions and Heating Efficiency

Note: This method does not include all the specifications (e.g. equipment and supplies) and procedures (e.g., sample and analytical) essential to its performance. Some material is incorporated by reference from other methods. Therefore, to obtain reliable results, persons using this method shall have a thorough knowledge of at least the following EPA Tests

- Method 1- Sample and Velocity Traverses for Stationary Sources
- Method 2- Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube)
- Method 3 – Gas Analysis for the Determination of Dry Molecular Weight
- Method 4 – Determination of Moisture Content in Stack Gases
- Method 5G – Determination of Particulate Matter from Appliances (Dilution Tunnel Sampling Location)
- Method 10 - Carbon Monoxide - Instrumental Analyzer
- Method 28 WHH – Measurement of Particulate Emissions and Heating Efficiency of Wood-Fired Hydronic Heating Appliances

1. *Scope and Application*

1.1. This test method applies to automatic feed, wood-fired hydronic heating appliances that utilizes an external buffer tank(s) (sometimes called thermal storage) as integral to the appliance operation. The units typically transfer heat through the circulation of a liquid heat exchange media such as water or a water-antifreeze mixture. Throughout this document, the term "water" will be used to denote any of the heat transfer liquids approved for use by the manufacturer.

1.2. This test method measures particulate matter (PM) emissions, carbon monoxide, and delivered heating efficiency at specified heat loads based on the appliances rated heat capacity.

1.3. Particulate emissions are measured by the dilution tunnel method as specified in ASTM E2515 *Standard Test Method for Determination of Particulate Matter Emissions Collected in a Dilution Tunnel* using only Emfab Pallflex filters. Additional particulate matter emissions measurements may also use the Tapered Element Oscillating Microbalance (TEOM) continuous PM method, as detailed in this test method.

1.4. Steady Heat Load efficiency, which is reflective of efficiency measurements in current EPA Federal reference methods is determined by calculating the delivered efficiency at

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the high and low load steady heat load periods of the test run (Phase 2 and 3). Delivered annual fuel use efficiency is determined by measurement of the usable heat output (determined through measurement of the flow rate and temperature change of water circulated through a heat exchanger external to the appliance) and the heat input (determined from the mass of dry fuel burned and its higher heating value) over the entire test run. Changes in the temperature of the appliance and thermal storage system from the start to the end of the run are considered in the heat output determination. Delivered efficiency does not attempt to account for energy loss in the piping between the system and the building heat distribution system. Energy loss from the connected piping and buffer tank to the surrounding test lab are included in the efficiency determination.

1.5. Products covered by this test method include both pressurized and non-pressurized hydronic heating appliances intended to be fired with wood and for which the manufacturer specifies for indoor or outdoor installation. The system is commonly connected to a heat exchanger by insulated pipes and normally includes a pump to circulate heated liquid. These systems are used to heat structures such as homes, barns, schools, and greenhouses. They also provide heat for domestic hot water, spas, and swimming pools.

1.6. Distinguishing features of products covered by this standard include:

1.6.1. The manufacturer specifies installation either inside a building or outside.

1.6.2. Products that automatically feed fuels, such as pelletized wood or wood chips.

1.6.3. An aquastat or similar device that controls the feed rate and combustion air supply to maintain the liquid in the appliance within a predetermined temperature range.

1.6.4. A chimney or vent that exhausts combustion products from the appliance.

1.7. The values stated are to be regarded as the standard, whether in I-P or SI units. The values given in parentheses are for information only.

1.8. Analyte. Particulate matter (PM). No CAS number assigned. Carbon monoxide (CO). No CAS number assigned.

1.9. Data Quality Objectives.

1.9.1. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods.

1.9.2. Measurement of emissions and heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

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1.9.3. This is a laboratory method intended to capture operating periods that are representative of actual field use without excessive test burden.

2. *Referenced Methods*

2.1. CAN/CSA-B415.1: Performance Testing of Solid-Fuel-Burning or latest approved EPA version.

2.2. ASTM E2515: Standard Test Method for Determination of Particulate matter Emissions Collected in a Dilution Tunnel or latest approved EPA version.

2.3. NESCAUM Standard Operating Practices for Thermo 1405 TEOM

2.4. NIST Monograph 175, Standard Limits of Error

3. *Definitions*

3.1. Aquastat – A control device that opens or closes a circuit to control the status of the burner in response to the temperature of the heating media in the heating appliance.

3.2. Appliance – a woodburning hydronic heater capable of and intended for central heating or domestic water heating, as defined in the applicable regulation. Appliance includes combustion chamber, fuel hopper size sufficient for testing, operating controls, and recirculation loop, if specified, and any other accessory required for standard operation, such as a barometric damper, an aquastat, pump, etc.

3.3. Buffer - storage tank or tanks including pressure relief valve and internal temperature measurement points required for operation of the system as specified in the manufacturer's instructions shipped with the hydronic heater. The size of the buffer shall be the minimum specified in the manufacturer's instructions shipped with the hydronic heater.

3.4. Catch - any mass from the sample probe system including PM on the front filter, back filter, and front half sample probe.

3.5. Cooling Water - cold water from an external source ("city water") used to extract the heat load.

3.6. Cycle – A cycle includes a shutdown initiated by a charged buffer tank and a startup initiated by a call for heat from the appliance to restart of the burner due to depletion of energy in the buffer tank.

3.7. Delivered Efficiency – The percentage of heat available in the fuel burned that the system delivers to a simulated heating load as specified in this test method.

3.8. Emission Factor – the emission of a pollutant expressed in mass per unit of energy (typically) output from the appliance.

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3.9. Emission index – the emission of a pollutant expressed in mass per unit mass of fuel used.

3.10. Emission Rate – the emission of a pollutant expressed in mass per unit time.

3.11. Failed Test Run – any complete or partial test that does not meet the specifications detailed in this test method at the fault of the system operation or does not meet the emission standard at the fault of the system operation.

3.12. Firebox - the chamber in the appliance in which the test fuel charge is fed into and combusted.

3.13. Heat Load: Rate of transfer of heat from the system to the cooling water through the cooling heat exchanger, Btu/hr (MJ/hr)

3.14. Heat Output rate, Total – Rate of total energy including the change in energy of the appliance, change in energy of the buffer tank or tanks and the sum of the energy transfer from the system to the cooling water through the cooling heat exchanger (MJ/hr).

3.15. Hydronic Heater– Same as appliance.

3.16. Idle – A control state where the hydronic heater is not feeding into the firebox chamber, the burner is inactive, and there is "no call for heat". This includes the hydronic heater's transition to idle, which may include purging of the feed tube or auger and burnout of remaining fuel in the firebox chamber. Idle ends when there is an active call for heat and signals the hydronic heater to activate burner. This may be visually indicated by a LED signal, an alert, or change in control status on the hydronic heater.

3.17. Manufacturer's Rated Heat Output Capacity –The value in Btu/hr (MJ/hr) that the manufacturer specifies that a particular model of an appliance and buffer is capable of supplying in steady state at its design capacity as verified by testing during Phase 1 and Phase 6 of the test protocol.

3.18. On-cycle – the burner is activated and fuel is being fed to the combustion chamber. This includes the cycling on period of restarting the burner and any control sequences related to igniting the fuel.

3.19. Off-cycle – the appliance cycles off and burner is not active and fuel is no longer fed into combustion chamber, but may include purging of feed tube or auger during initial shutdown

3.20. Phase – A distinct period in the test run with its own operational procedures and conditions.

3.21. Phase X Delivered Efficiency – The delivered efficiency of individual phases (X), specifically for Phase 2, Phase 3, and Phase 6 per test run.

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3.22. Phase X Delivered Efficiency Average – Average delivered efficiency of individual phases (X) per test series specifically Phase 2, Phase 3, and Phase 6

3.23. NIST – National Institute of Standards and Technology

3.24. Series Delivered Efficiency – The overall average delivered efficiency of each valid test run completed.

3.25. System - combination of the appliance and buffer and required interconnections and controls.

3.26. Temperature, Average Hydronic Heater - simple average of the hydronic heater supply and the return Water entering the hydronic heater.

3.27. Temperature, Average Buffer- average of all six of the test temperature sensors internal to the tank. If more than one buffer tank is required, then average all sensors. This does not include temperature sensors which may be added by the manufacturer for control purposes.

3.28. Temperature, Return water entering the hydronic heater - temperature of the water downstream of the mixing valve, as it enters the return connection on the hydronic heater.

3.29. Temperature, Hydronic Heater Minimum Operating - the lowest temperature of the return water entering the hydronic heater as specified in the manufacturer's instructions shipped with the system. The minimum operating temperature shall be 140 ˚F (60 ˚C) or higher if specified by the manufacture for all phases except Phase 1.

3.30. Temperature, Hydronic Heater Modulation - on rising hydronic heater temperature, the temperature measured at the control sensor point at which the control acts to reduce the burner input from the full fire level.

3.31. Temperature, Hydronic Heater Operating Limit - on rising hydronic heater temperature, the temperature at the control sensor point at which the control initiates a shutdown of the burner.

3.32. Temperature, Hydronic Heater Setpoint – The temperature the hydronic heater aims to maintain while operating at maximum burn rate.

3.33. Temperature, System Operating Limit - on rising buffer temperature, the temperature at the control sensor point or points at which the control initiates a shutdown of the burner. This typically will be below the hydronic heater operating limit temperature.

3.34. Temperature, System Restart - on falling buffer temperature, the tank temperature at the control sensor point at which the control initiates a restart of the burner.

3.35. Temperature, Safety High Limit - on rising appliance temperature, the hydronic heater temperature at the control sensor point at which the control forces a burner shut down and requires a manual restart.

3.36. Temperature Range, Hydronic Heater Modulation - temperature range between the hydronic heater setpoint temperature and the operating limit.

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3.37. Temperature Range, System - the temperature range between the system restart and the system operating limit.

3.38. Test Data– means the data for all test runs conducted on the system, including any data collected during failed and invalid runs and includes records of preparation of standards, identification of equipment used and personnel present, records of calibrations, raw data sheets for field sampling, raw data sheets for field and laboratory analyses, chain-of-custody documentation, and example calculations for reported results.

3.39. Test Series– means the data for all test runs conducted on the system.

3.40. Test Facility - the area in which the heating system is installed, operated, and sampled for emissions.

3.41. Test Run - An individual emission test, which encompasses the time required to complete all specified phases of the test profile.

3.42. Test Tun Delivered Efficiency –The delivered efficiency of a test run.

3.43. Thermopile - A device consisting of a number of thermocouples connected in series, used for measuring temperature differential.

3.44. Valid Test Run – a complete test run that complies with all requirements detailed in this test method. A failed completed test run that does not meet emission standards may still be considered a valid test run if all requirements detailed in the method are met.

4. *Summary of Test Method*

4.1. Dilution Tunnel. Emissions are determined using the "dilution tunnel" method specified in ASTM E2515-11 *Standard Test Method for Determination of Particulate Matter Emissions Collected in a Dilution Tunnel.* The flow rate in the dilution tunnel is maintained at a constant level throughout the test cycle and accurately measured. Samples of the dilution tunnel flow stream are extracted at a constant flow rate and drawn through high-efficiency filters. The filters are equilibrated and weighed before and after each test to determine the emissions catch, and this value is multiplied by the ratio of tunnel flow to filter flow to determine the total particulate emissions produced in the test cycle. The method also includes optional use of a real-time particulate matter measurement that allows for providing one-minute data, which can be used to provide one hour and test phase emissions information.

4.2. Particulate Matter. PM emissions are determined using a dilution tunnel method specified in ASTM 2515-11 *Standard Test Method for Determination of Particulate matter Emissions Collected in a Dilution Tunnel* with exceptions as defined in Section 9.1. The flow rate in the dilution tunnel is maintained at a constant rate throughout the

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test cycle and accurately measured. Three different particulate sampling methods are used in this test method.

4.2.1. Filter-based method. Samples of the dilution tunnel flow stream are extracted at a constant flow rate and drawn through high-efficiency filters as defined in ASTM E2515-11 using Teflon coated filters such as Pallflex Emfab (TX40) with a maximum diameter of 47 mm, without organic binder, exhibiting at least 99.95 percent efficiency. The filters are equilibrated and weighed before and after the test to determine the emissions collected and this value is multiplied by the ratio of tunnel flow to filter flow to determine the total particulate emissions produced in the test cycle.

4.2.2. Real-time PM Measurements (Optional). The second method is a real-time particulate measurement method based on a Tapered Element Oscillating Microbalance (TEOM) instrument, Thermo model 1405 TEOM or its equivalent, operated using the specifications detailed in the document titled, "*NESCAUM Standard Operating Procedures for Using TEOM 1405 in a Dilution Tunnel*" available at: https://www.nescaum.org/topics/test-methods.

4.3. Carbon Monoxide. The CO measured in the dilution tunnel and used to calculate efficiency determination.

4.4. Delivered Efficiency. Efficiency is measured by determining the fuel energy input and appliance output.

4.5. Operation. Appliance operation is conducted on a cold-to-hot test cycle, meaning that the appliance starts the first test run at room temperature and ends with the appliance in fully heated state. The second and third test runs are started a slightly warmer temperature. The appliance is operated at a variety of heat load loads representing start-up emissions, high heat load, low heat load, cycling, idling, and recovery from nighttime set back. The appliance is operated through six heating phases during the test run. To complete the certification test, a minimum of three full test runs are averaged to determine the test results. For automatic feed systems, fuel is fed as determined by appliance delivery systems.

4.6. Repeatability. A series of at least three test runs comprised of six different heat loads or phases are conducted for certification or audit purposes

5. *Significance and Use*

5.1. The measurement of particulate matter emission rates is an important test method widely used in the practice of air pollution control.

5.1.1. These measurements, when approved by state or federal agencies, are often required for the purpose of determining compliance with regulations and statutes.

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5.1.2. The measurements made before and after design modifications are necessary to demonstrate the effectiveness of design changes in reducing emissions and make this standard an important tool in manufacturers' research and development programs.

5.2. Measurement of heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

6. ***Test Equipment and Supplies***. The following items are required for sample collection:

6.1. Anemometer. A device capable of detecting air velocities less than 0.10 m/sec (20 ft/min), for measuring air velocities near the test appliance.

6.2. Appliance Flue.

6.2.1. Steel flue pipe extending to 8.5 ±0.5 ft. (2.6 ±0.15 m) above the top of the platform scale, and above this level, insulated solid pack type chimney extending to 15 ±1 ft (4.6 ±0.3 m) above the platform scale, and of the size specified by the appliance manufacturer.

6.2.2. Other chimney types (e.g., solid pack insulated pipe) may be used in place of the steel flue pipe if the appliance manufacturer's written appliance specifications require such chimney for home installation. Such alternative chimney or flue pipe must remain and be sealed with the appliance following the certification test.

6.3. Appliance Side Water Flow Meter (optional). A water flow meter with an accuracy of ± 1% of the flow rate is recommended to monitor the supply-side water flow rate.

6.4. Barometer. Aneroid or other barometer capable of measuring atmospheric pressure to within 0.1 in. Hg (2.5 mm Hg).

6.5. Buffer Temperature Sensors. To determine the average temperature of the buffer, in real time, six temperature sensors shall be located internally per buffer tank. The tank volume shall be divided into six equal volumes and a sensor shall be located at the vertical center of each volume. The sensors shall be located as close to the vertical centerline of the tank as practical and not be in contact with tank walls or any internal obstruction such as piping or internal heating coils. It may be necessary to modify top connections on the tank to enable the insertion of a 6-point probe for this purpose. The sensors shall not be attached to the surface of the tank.

6.6. Dilution Tunnel must meet the requirements of ASTM E2515, clauses 6.1.6 and 9.2.

6.7. Dilution Tunnel temperature and relative humidity measurement. A probe capable of measuring tunnel temperature to within 0.9 ˚F (0.5 ˚C)) and tunnel RH to within 2%, such as the Omega HX85-A or equivalent.

6.8. Flue Gas Temperature Measurement. Must meet the requirements of CSA B415.1-2010, Clause 6.2.2.

6.9. Flue Gas Composition Measurement. Must meet the requirements of CSA B415.1-2010, Clauses 6.3.1 through 6.3.3.

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6.10. Heat Exchanger. A water-to-water heat exchanger capable of dissipating the expected heat output from the system under test.

6.11. Humidity Gauge. Psychrometer or hygrometer for measuring Relative humidity measurement in lab with accuracy of 2% RH between 5 and 95% RH.

6.12. Insulated Solid Pack Chimney. For installation of appliances. Solid pack insulated chimneys shall have a minimum of 2.5 cm (1 in.) solid-pack insulating material surrounding the entire flue and possess a label demonstrating conformance to U.L. 103 (incorporated by reference—see §60.17).

6.13. Ionizing air blower (or 210Polonium alpha sources). For reducing static charge build up on beakers and/or filter media.

6.14. Platform Scale and Monitor. A platform scale capable of weighing the appliance under test and associated parts and accessories when completely filled with water to an accuracy of ± 1 pound (± 0.45 kg) and a readout resolution of ± 0.2 pound (± 0.1 kg).

6.15. Test Facility Temperature Monitor. A thermistor, RTD, or other equivalent device, located centrally in a vertically oriented 150 mm (6 in.) long, 50 mm (2 in.) diameter pipe shield that is open at both ends, capable of measuring temperature to within 1˚F of expected temperatures.

6.16. Water Temperature Difference Measurement. A Type –T 'special limits' thermopile with a minimum of 5 pairs of junctions shall be used to measure the temperature difference in cooling water entering and leaving the heat exchanger. The temperature difference measurement uncertainty of this type of thermopile is equal to or less than ± 1.0 ºF (± 0.5 ºC). Other temperature measurement methods may be used if the temperature difference measurement uncertainty is equal to or less than ± 1.0 ºF (± 0.50 ºC). This measurement uncertainty shall include the temperature sensor, sensor well arrangement, piping arrangements, lead wire, and measurement / recording system. The response time of the temperature measurement system shall be less than half of the time interval at which temperature measurements are recorded.

6.17. Water Flow Meter. A water flow meter shall be installed in the inlet to the load side of the heat exchanger. The flow meter shall have an accuracy of ± 1% of the measured flow.

6.18. Water Temperature Measurement. Thermocouples or other temperature sensors to measure the water temperature at the inlet and outlet of the load side of the heat exchanger must meet the calibration requirements specified in Section 8 of this method.

7. *Safety*

7.1. Disclaimer. This method may involve hazardous materials, operations, and equipment. This test method may not address all the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to performing this test method.

7.2. These tests involve combustion of wood, which releases substantial amounts of heat and combustion products. The heating system also produces large quantities of very hot water and the potential for steam production and system pressurization. Appropriate precautions must be taken to protect personnel from burn hazards and respiration of products of combustion. Exposure of personnel to unsafe levels of carbon monoxide must be avoided, and the use of continuous ambient carbon monoxide monitoring is strongly recommended.

8. Calibration, Standardization and Quality Control

8.1. ASTM E2515-11. Perform all calibrations required by ASTM E2515-11

8.2. Water Temperature Sensors. Temperature measuring equipment shall be calibrated before initial use and at least semi-annually thereafter. Calibrations shall follow NIST Monograph 175, Standard Limits of Error.

8.3. Heat Exchanger Load Side Water Flow Meter. The heat exchanger load side water flow meter shall be calibrated within the flow range used for the test run using NIST-traceable methods.

8.4. Scales. Perform a multipoint calibration using NIST-traceable methods (at least five points spanning the operational range) of the platform scale before its initial use and semiannually, thereafter. Calibration results from an accredited laboratory are sufficient for this purpose. Before each certification test, audit the scale with the appliance in place by weighing at least one calibration weight (Class F) that corresponds to between 20 percent and 80 percent of the expected change in fuel mass during a run. If the scale cannot reproduce the value of the calibration weight within 0.09 kg (0.2 lb.) or 1 percent of the expected test fuel charge weight, whichever is greater, then recalibrate or service scale.

8.5. Anemometer. Calibrate the anemometer as specified by the manufacturer's instructions before the first certification test and semiannually thereafter.

8.6. Humidity Gauge. Calibrate as per the manufacturer's instructions before the first certification test and semiannually thereafter

8.7. Flue Gas Analyzers. In accordance with CSA B415.1-2010, Clause 6.8.

9. Sampling, Test Specimens, and Test Appliances

9.1. Modifications to ASTM 2515 requirements.

9.1.1. Liquid water should not be present anywhere in the sampling system for a valid sample.

9.1.2. Dilution tunnel temperature and relative humidity shall be measured and logged near the sample probe to calculate tunnel dewpoint.

9.1.3. Filter temperature shall be measured and logged using a measurement method with an accuracy of 1 ˚F (0.5 ˚C)) or better.

9.1.4. For a valid test run the following conditions shall not exceed any of the following conditions for a period of more than five minutes in total:

9.1.4.1. Filter temperature shall remain between 80 and 90 ˚F (26.7 to 32.2 ˚C)

9.1.4.2. The dilution tunnel should be adjusted to a flow rate that is high enough for the dilution tunnel temperature, at the particulate measurement point, to be no more than 110 ˚F (43.3 ˚C) for any rolling 10-minute average.

9.1.4.3. Tunnel relative humidity shall not exceed 95%.

9.1.4.4. Tunnel dew point temperature shall be at least 3.6 ˚F (2 ˚C) less than filter temperature.

9.1.4.5. If any parameter is exceeded, the test report should explicitly report results from the run and note where exceedances occurred. The test run shall be invalid unless supporting evidence proves any exceedances do not affect test results and has been approved by regulating authorities.

9.1.5. Particulate Matter Sampling for one-hour filter pull. PM emissions allow the use of two options to obtain integrated results and one-hour emissions data.

9.1.5.1. **Option 1** - three ASTM E2515 trains will be used for this testing.

9.1.5.2. Proportional Rate Variation shall meet the requirements of ASTM E2515 for all phases.

9.1.5.3. Train 1: Start-up Measurement. A measurement of the start-up phase will be reported using one ASTM E2515 train. This measurement will commence at the beginning of the test and ends sixty (60) minutes after commencing the test.

9.1.5.4. ASTM E2515 Trains 2 and 3: Integrated load measurement. Two, dual ASTM E2515 trains will measure particulate for the entire test run.

9.1.5.5. Option 1 use three ASTM E2515 trains, two are run through the entirety of the test and one obtains measurement for startup and the first hour of Phase 2.

9.1.6. **Option 2** – 2 ASTM E2515 trains and TEOM.

9.1.6.1. Proportional Rate Variation shall meet the requirements of ASTM E2515 for all phases individually and for each run.

9.1.6.2. ASTM E2515 Trains 1 and 2: Integrated load measurement. Two, dual ASTM E2515 trains will measure particulate for the entire test run.

9.1.6.3. TEOM data will be collected at 10-second intervals and averaged up to 1-minute intervals for reporting. TEOM operation shall follow the procedures

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listed in the TEOM SOP found at https://www.nescaum.org/topics/test-methods. TEOM data shall be recorded on an excel spreadsheet following the minimum data reporting requirements. Emissions from the ASTM E2515 trains shall serve as the primary PM emission measurement. The TEOM data will be used to report emissions for the first, one-hour period.

9.1.7. **Option 3** - two ASTM E2515 trains will be used for this testing.

9.1.7.1. Proportional Rate Variation shall meet the requirements of ASTM E2515 for all phases individually and for each run.

9.1.7.2. A measurement of the start-up phase will be reported using one ASTM E2515 train. This measurement will commence at the beginning of the test and ends sixty (60) minutes after commencing the test.

9.1.7.3. Start-up Measurement (one-hour filter pull) – Both trains will change filters at the one hour. Data from this filter pull will be reported separately as the one-hour measurement. PM from one-hour filters will be combined with other filter measurements for total filter run.

9.1.8. Weigh room conditions. The following conditions shall be met:

9.1.8.1. The facility shall use an active ionizing air blower (or 210Polonium alpha sources) to neutralize charge associated with the filter. 210Polonium alpha sources must be replaced annually or more often.

9.1.8.2. Temperature range of 68 to 78 ˚F (20 to 25.6 ˚C).

9.1.8.3. Relative humidity shall be no higher than 45%.

9.1.8.4. *Filter equilibration / conditioning post sample collection*. Use of desiccation is not allowed. Equilibrate filters at a relative humidity between 30 and 40% for at least 24 hours. A saturated salt solution of magnesium chloride (33% RH) can be used. PREPARATION OF SALT SOLUTIONS: Use only pure distilled water to make up the solution. Put 200 g of the salt into a beaker. Gradually add distilled water. Stir well after each addition, until the salt can absorb no more water, as will be evidenced by some free liquid on the surface of the mixture. For best results keep the excess liquid to a minimum. The mixture should be slushy but must have a small amount of liquid water on the surface. Put this slushy mixture in the desiccant tray of the equilibration chamber. After equilibration, the chamber RH should measure 33% +/- 3%.

9.1.9. Filter weight measurements. Report the following filter measurements:

9.1.9.1. Day zero – initial filter measurement before going into the equilibrium chamber.

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9.1.9.2. Final filter measurement or day seven measurement, whichever measurement comes first.

9.1.9.3. *Blanks*. Test reports shall measure and report data on blanks as follows:

9.1.9.4. Lab blank, which is removed from each filter batch, stored in a protective environment, and weighed during each weighing session.

9.1.9.5. Room blank collected during every test run. The blank shall be placed within 10 feet of the intake for the dilution air

9.1.10. Probe Catch: Report sampling system catch as a separate number from back filter catch.

9.2. Test Specimens. Systems (appliance and buffer tank) shall be supplied as complete systems, including all controls and accessories necessary for installation at the test facility including thermal buffer tank description and volume. A full set of specifications, designs, and assembly drawings shall be provided when the product is placed under certification of a third-party agency. The manufacturer shall provide a tank with the minimum volume needed for operation and any parts that are specific for operation. Examples of parts to be supplied by the manufacturer would be a thermostat or various sensors required for communicating buffer tank temperature to the appliance, recirculation loops (if needed), specific pump (if needed), all fittings for coming off the buffer tank, etc.

9.3. User Guide. The manufacturer must supply a one-page user guide that will direct certain portions of the test protocol. The User Guide must be provided to the lab and the consumer as a single sheet and documented in the test report. The user guide shall be the only directions provided and used by the testing facility for certification purposes; it shall address key user operations for simple baseboard heating, and it shall conform to the following requirements. Manufacturers are not allowed to direct or inform any portion of testing or deviate from operations specified in the User Guide, as the User Guide is the only information that can be used to inform appliance operation during certification testing. User Guide Layout Requirements – the User Guide shall conform to the following design specifications:

9.3.1. Directions must be illustrated by text and colored pictures

9.3.1.1. Font size – minimum font size is 12.

9.3.1.2. Use of columns allowed

9.3.1.3. Margins – must have a minimum of ¾" inch margins

9.3.1.4. A minimum of 40% of the user guide must use graphics or photos to support text directions.

9.3.1.5. Complete instructions but fit on a double sided of an 8 x11.5-inch sheet of paper

9.3.1.5.1. One side may be used to show tank setup and control settings

9.3.1.6. Must be provided in a laminated form to the consumer.

9.3.2. User Guide elements – The User Guide cannot contradict or deviate from user instructions provided in the appliance user manual. The User Guide shall include information on the following items.

9.3.2.1. Appliance preparation – what must be done to the appliance prior to starting a fire to include appliance setpoints and software settings. Settings must reflect use in high-temperature heating systems.

9.3.2.2. Appliance and buffer (system) settings – to include modulation, setpoint, and restart, operating limits, and safety high limit temperatures, and other operations that are part of normal operation (cleaning cycles, etc).

9.3.2.3. Fuel properties – what types of fuel and fuel moisture requirements are allowed for use in the appliance. The fuel properties detailed in the User Guide are for homeowner use, for certification testing, fuel requirements shall follow the protocols detailed in this method.

9.3.2.4. Start-up procedures – general guidelines for properly starting the appliance to include starting procedures and appliance settings to include software configurations.

9.3.2.5. Reloading procedures – If applicable, guidelines for properly reloading fuel once a fire has been started in the appliance.

9.4. Preparation of Apparatus

9.4.1. Place the appliance centrally on the platform scale meeting the requirements

9.4.2. Setup shall conform to the schematics provided below.

9.4.2.1. Manufacturer may assist or instruct during install prior to the first test.

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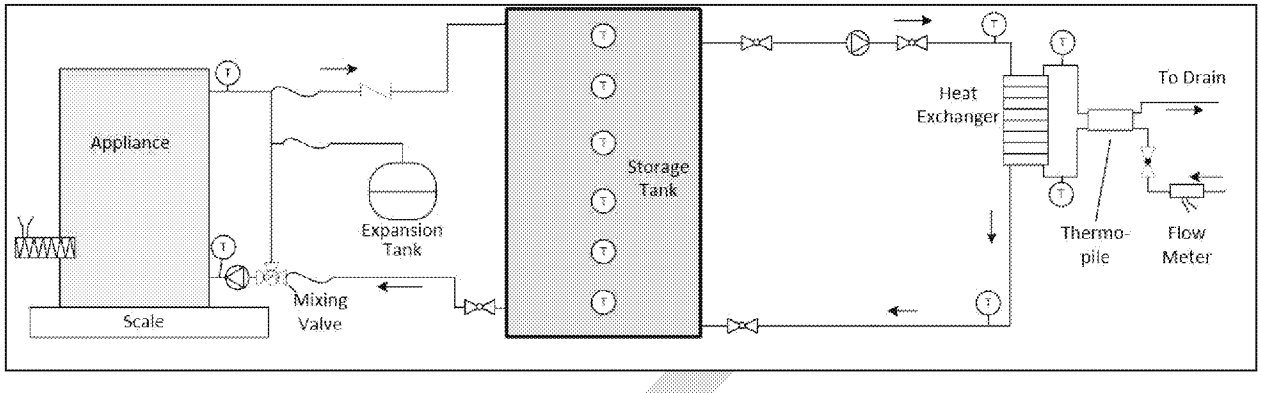

Figure 1. *Test Plumbing with 1 buffer*

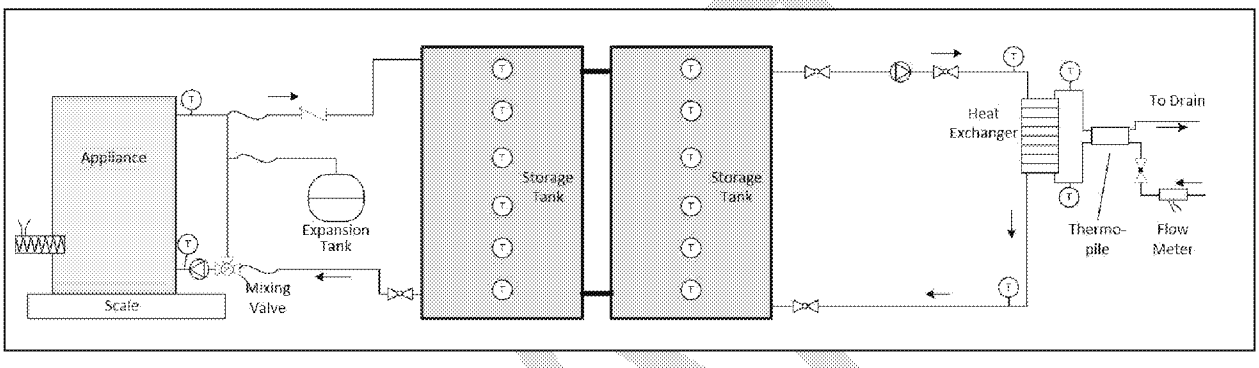

Figure 2 Test plumbing with multiple buffers

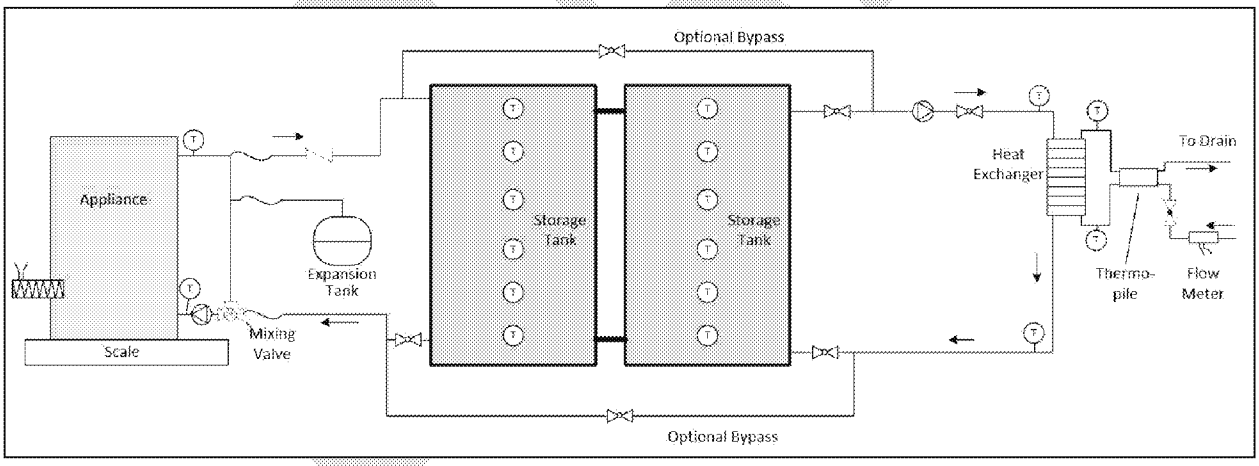

Figure 3 Optional buffer bypass loop for safety

9.4.3. A recirculation pump may be installed between connections at the top and bottom of the appliance to minimize thermal stratification if specified by the manufacturer's instructions shipped with the unit. If specified by the manufacturer, the manufacturer shall provide all piping, pumps, and controls necessary for the recirculation system. The

pump shall not be installed in such a way as to change or affect the flow rate between the appliance and the heat exchanger.

9.4.4. If the manufacturer's instructions shipped with the unit specify that a thermal control valve or other device be installed and set to control the return water temperature to a specific set point, the valve or other device shall be installed and set per the manufacturer's written instructions to reflect a high-temperature installation, unless the manufacturer specifies that the appliance is for use only in low-temperature installations.

Starting Weight. Prior to filling the appliance with water, weigh and record the appliance mass.

9.4.5.Heat Exchanger

9.4.5.1. Plumb the system to a water-to-water heat exchanger with sufficient capacity to draw off heat at the maximum rate anticipated. Route hoses and electrical cables and instrument wires in a manner that does not influence the weighing accuracy of the scale as indicated by placing dead weights on the platform and verifying the scale's accuracy.

9.4.5.2. Locate temperature sensors to measure the water temperature at the inlet and outlet of the supply side of the heat exchanger.

9.4.5.3. Install a thermopile (or equivalent instrumentation) meeting the requirements of Section 6.16 to measure the water temperature difference between the inlet and outlet of the load side of the heat exchanger.

9.4.5.4. Place the heat exchanger in a box with 2 in. (50 mm) of expanded polystyrene (EPS) foam insulation surrounding it to minimize heat losses from the heat exchanger.

9.4.5.5. The reported heat load output rate shall be based on measurements made on the load side of the heat exchanger.

9.4.6. Install a calibrated water flow meter in the heat exchanger load side cold water line. The water flow meter is to be installed on the cooling water inlet side of the heat exchanger so that it will operate at the temperature at which it is calibrated.

9.4.7. Temperature instrumentation shall be installed in the appliance outlet and return lines and appliance recirculation loop (if needed). The average of the outlet and return water temperature on the supply side of the system shall be considered the average appliance temperature. Installation of a water flow meter in the supply side of the system is optional.

9.4.8. Fill the system with water. Determine the total weight of the water in the appliance when the water is circulating. Verify that the scale indicates a stable weight under operating conditions. Make sure air is purged properly.

10. Conditioning

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10.1. Appliance Aging. Prior to testing, the appliance shall be operated for a minimum of 50 hours using a variety of heat loads. The conditioning may take place at the manufacturer's facility prior to testing or at the certification facility.

10.1.1. If the appliance uses a catalytic combustor, it must be engaged according to manufacturer's instructions and operate for at least 50 hours during the break-in period. Report hourly catalyst exit temperature data and the hours of operation.

10.2. *Appliance Aging Documentation.* The aging procedure shall be conducted and documented by the manufacturer or the certified testing laboratory. All aging data must be reported and shall include the hours of operation and heat loads for aging, hourly flue gas temperature, amount of fuel burned, fuel parameters (species, heat loads, and fuel types), air and control settings used, and note the time spent in each air setting phase.

11. Procedure

11.1. Test Facility Conditions. The test facility shall meet the following requirements during testing:

11.1.1. Shall conform to 9.7 of ASTM E2515-11

11.1.2. The test facility temperature shall be maintained between 65 and 90˚F (18 and 32 ˚C) during each test run

11.1.3. Air velocities within 2 ft(0.6 m) of the test appliance and exhaust system shall be less than 50 ft/min (0.25 m/sec) without fire in the unit.

11.1.4. For test facilities with artificially induced barometric pressures (e.g., pressurized chambers), the barometric pressure in the test facility shall not exceed 30.5 in. Hg (775 mm Hg) during any test run and shall be recorded before and after the test run.

11.2. Test Fuel. This method can be used with wood pellet fuels and fuel chips.

11.2.1. Pelletized fuels shall conform to the following requirements:

11.2.1.1. Fuel used must be PFI, CANplus, or ENPlus certified, or other equivalent fuel certification standard.

11.2.1.2. Test fuel must undergo and report ultimate/proximate analysis by an independent accredited lab.

11.2.1.3. All fuels used for testing must have a temperature no greater than 5 ˚F of laboratory temperature when loaded into the appliance within 60 minutes of starting the test.

11.2.2. Wood chip fuels shall conform to the following requirements:

11.2.2.1. Fuel used for testing must undergo ultimate/proximate analysis by an independent accredited lab.

11.2.2.2. Fuel used for testing must be characterized by ANSI/ASABE AD17225-4:2014 FEB2018 Solid biofuels — Fuel specifications and classes — Part 4: Graded wood chips

11.3. Manufacturer participation in certification testing

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11.3.1. A representative of the manufacturer may observe testing but may not provide instructions to the certification lab, in any form, with testing staff or equipment once the certification tests begin. The names of testing witnesses cannot be withheld as confidential business information (CBI).

11.3.2. During certification testing, the appliance cannot be connected for remote access. Nor can the appliance be operated remotely. For example, the appliance cannot be connected to the internet unless remote access is to allow for remote witnessing or recording of the test. Remote access may only be granted by the certification laboratory. If remote access is granted, witness list shall reflect those who have been granted remote witness capacity and provide recordings of remote activities as part of the test report.

11.4. Appliance Instructions and Program Configuration/Setting

11.4.1. For certification testing, all system control settings shall be tested with all controls and software set as-the manufacturer will ship or install, often referred to as default settings. These default settings shall be specified by the manufacturer and included in the test report. Settings for certification testing shall match those communicated in all manufacturer materials and installation instructions to the installer or end-user.

11.4.2. Appliance Operation and Adjustments. If appliance does not arrive with control settings preset, then follow user guide instructions for control setting. Adjustments to controls are not allowed once testing has begun. If adjustments to controls are required due to invalid test run, then it is documented, and the user guide must be revised prior to starting the new test series.

11.4.3. Manufacture representative may assist with control settings prior to the start of the test, but must be consistent with the user guide and any deviations from the User Guide will require a revised User Guide prior to the start of the certification test series.

11.4.4. Control settings and the documentation of the control settings shall be included in the user guide and in the non-CBI portion of the test report.

11.5. Before each test series, the firebox shall be vacuumed. Testing shall begin without any ash or other materials in the appliance. Record fuel weight data and appliance temperature measurements at 1-minute intervals.

11.6. Before initiating the compliance test, clean the flue and dilution tunnel with an appropriately sized wire chimney brush before each certification test. Test documentation should include the date and time of flue cleaning.

11.7. The flow rate of water between the buffer and the load heat exchanger shall be set to achieve a return temperature from the heat exchanger back to the system of 140˚F (60 ˚C) or greater.

11.8. *Low Appliance Temperature*. If at any time, average water temperature falls below the appliance minimum operating temperature, as specified by the User Guide, then cooling will be stopped until the appliance water temperature average reaches the target temperature. All interruptions in heat load will be documented and reported.

11.9. All water temperatures, water flowrates, and appliance temperatures, and all other temperature sensors shall be recorded at intervals of 1 minute or less.

11.10. The hydronic heater return water temperature may not drop be below 140˚F (60 ˚C) for all phases except phase 1.

11.11. Scale weight shall be recorded at 1-minute intervals and documented at the start and end of each test phase.

11.12. Test Run Procedure. The table below summarizes the phases that encompass a complete test run. Addition of cooling water during the testing is not allowed. A complete test run requires completion of all six phases of the test protocol, as described below.

IDC Pellet Hydronic Heater Test Procedure Summary	
Phase 1-Start-up	Startup per manufacturer's instructions. Pull off heat as needed when approaching operating temperature limit and ramp up to 100%
Phase 2 – Max Heat	100% heat load for 60 minutes at the load heat exchanger
Phase 3 – Low Heat	13% heat load at the load heat exchanger (+/-2%) for 120 minutes or after one cycle, whichever comes first. If unit begins to cycle off within 0-30 minutes of the start of Phase 3, 6 cycles must be completed in Phase 5. If the unit begins to cycle off within 31-60 minutes of the start of Phase 3, 4 cycles must be completed in Phase 5. If the unit begins to cycle off within 61-90 minutes of the start of Phase 3, 3 cycles must be completed in Phase 5. If the unit begins to cycle off within 91-120 minutes of the start of Phase 3, 2 cycles must be completed in Phase 5. If the unit does not cycle off during Phase 3, only 1 cycle must be completed in Phase 5.
Phase 4 -No load	No heat load for 45 minutes
Phase 5 – Cyclic operations	Forced cycling - Must complete 1-6 cycles, as determined by cycling time in Phase 2. • During on-cycle - cooling water is stopped, the system heats to the system operating limit temperature. • Off-cycle - Wait 30 minutes, then set cooling water at 100% heat load at the load heat exchanger until system reaches the system restart temperature. • Phase 4 ends after number of required cycles has been completed, and concludes the second 30 minute off period
Phase 6 - Recovery	• 100% heat load for 60 minutes

11.12.1. Phase – Start-up

11.12.1.1. Appliance Parameters

11.12.1.1.1. *Appliance temperature.* For the first run (Run #1) appliance temperature and firebox temperature shall be recorded.

11.12.1.1.1.1. Appliance and firebox temperatures shall be measured within 60 minutes of starting the test run and shall be reported for all test runs.

11.12.1.1.2. Water temperature requirements. Buffer tank and/or thermal storage shall not exceed 120 ˚F (48.9 ˚C) at the start of any test run. Average water temperature in the buffer tank and appliance at the start of testing shall be reported in the test report.

11.12.1.2. Appliance Operation during Phase 1

11.12.1.2.1. Following the start-up of the appliance, cooling water will be slowly adjusted to achieve high load operations. If the return water temperature appliance drops minimum operating temperatures during this phase then this is an invalid test run.

11.12.1.2.2. After the burner has stabilized at maximum burn rate and the average buffer tank temperature has reached 160 ˚F (71.1 ˚C), the cooling water flow shall be adjusted a necessary to achieve the nominal output rate.

11.12.1.3. End of Phase 1: Phase 1 shall end when the appliance is within appliance modulation temperature range and maximum heat load can be maintained for a period of at least five minutes without a change +/- 10˚F (5.6 ˚C) in average buffer tank and stack temperature.

11.12.2. Phase 2 – Maximum Heat Load. This phase commences immediately after Phase

11.12.2.1. *Appliance Parameters Phase 2.* During Phase 2, the unit must produce an average heat load output rate that is within ±10% of the manufacturer's rated heat output capacity. If average heat load output is not within these limits, the manufacturer's rated heat load output capacity is considered not validated and must be changed.

11.12.2.2. Appliance Operation during Phase 2.

11.12.2.2.1. The appliance shall fire at its maximum firing rate for the entire period. The average buffer temperature may not fluctuate more than 5˚F (2.8˚C) during this time period.

11.12.2.2.1.1. If at any time, the appliance temperature is rising and approaching the operating limit, the heat load shall be increased to prevent the appliance from cycling off or from modulating to a lower firing rate.

11.12.2.2.1.2. If at any time, the appliance temperature falls to less than 5˚F (2.78˚C) below the setpoint, the heat load rate shall be decreased until the appliance is within 5˚F (2.78˚C) of the appliance setpoint.

11.12.2.3. End of Phase 2: The end of Phase 2 is defined by a continuous period of 60 minutes of maximum heat load placed on the appliance.

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11.12.2.3.1.Complete 60-minute average calculation from Phase 2 to confirm maximum heat load output as this will impact Phase 3 setting.

11.12.3. Phase 3 – Low Heat Load Phase. This phase commences immediately after Phase 2.

11.12.3.1.Appliance Operation during Phase 3. The system heat load at the load heat exchanger is reduced to 13% +/- 2% of the appliance's maximum rated heat load output. The appliance stays at this heat load for a period of 120 minutes or one complete cycle, whichever comes first. Ramp down to this heat load must be made in a period of fewer than 10 minutes. The test report shall indicate the time period used for ramp down.

*11.12.3.1.1.*Heat load on the system at the load heat exchanger is placed at 13% +/- 2% of maximum heat load output.

11.12.3.2.End of Phase 3: the end of Phase 3 is defined by a period of 120 minutes at 13% +/-2% heat load placed on the appliance or after one cycle, whichever comes first.

11.12.3.2.1.Determine the number of cycles that must be completed in Phase 5, using the following process:

11.12.3.2.1.1.If unit begins to cycle off within 0-30 minutes of Phase 2, 6 cycles must be completed in Phase 4.

11.12.3.2.1.2.If the unit begins to cycle off within 31-60 minutes of Phase 2, 4 cycles must be completed in Phase 4.

11.12.3.2.1.3.If the unit cycles off within 61-90 minutes of Phase 2, 3 cycles must be completed in Phase 4.

11.12.3.2.1.4.If the unit cycles off within 91-120 minutes of Phase 2, 2 cycles must be completed in Phase 4. If the unit does not cycle during Phase 2, only 1 cycle must be completed in Phase 4.

11.12.4. Phase 4 – No Heat Load Phase. This phase commences immediately after Phase 3.

11.12.4.1.Appliance Operation during Phase 4. Appliance heat load is 0%, and the appliance is turned off. The appliance stays at this 0% heat load for a period of 45 minutes. Ramp down to this heat load must be made in a period of fewer than 5 minutes. The test report shall indicate the time period used for ramp down.

11.12.4.2.*End of Phase 4.* The end of Phase 4 occurs when the appliance spends a minimum of 45 minutes at no heat load and the appliance cools to a setpoint where the appliance will cycle on at the beginning of Phase 5. This may be completed by manually setting a cooling load. Cooling load shall be completed prior to turning the appliance on for Phase 5. The cooling load should not exceed 120% of the maximum heat load output of the appliance.

11.12.5. Phase 5 – Cyclic Operations

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11.12.5.1.*Appliance Operation during Phase 5.* This phase emulates the operation of the appliance, responding to a thermostat call at the start of this phase, power the appliance back on. This will be indicated by the appliance cycling on and restarting the burner, which can be indicated through control status, or starting of the combustion air/ induced draft fan. One cycle will start with a call for heat and then end once the appliance and buffer indicate a shutdown, cycles off, and has gone through one 30-minute idle period. A shutdown caused by reaching the system safety high limit temperature is not considered cycling off.

11.12.5.2. During Phase 5 the unit shall complete the number of cycles as determined in Phase 2, as defined in 11.11.3.2.1

11.12.5.2.1.The appliance must complete the required number of on/off cycles. During on-cycle - cooling water is stopped, the system heats to the system operating limit temperature. During the off-cycle – the system remains in idle for a period of 30 minutes with no heat load. After the 30-minute period, set cooling water for 100% heat load until the system minimum operating temperature is reached, and the appliance's controls acts to restart the burner.

*11.12.5.2.2.*If, during this test, the appliance shuts down on the high-temperature safety control, requiring a manual reset, the test is a failed run.

11.12.5.3.End of Phase 5: the end of Phase 5 occurs when the 30-minute period after the final cycling event is completed, and the appliance is in an off-cycle.

11.12.6. Phase 6 – Response to Setback Conditions.

11.12.6.1.*Appliance Operation during Phase 6.* For 60 minutes, the cooling water shall be adjusted for a heat load of 100% of the nominal full-load output. If the return water temperature in the system (heater and buffer tank) drops below the 120 ˚F (48.9 ˚C), cooling will stop temporarily until the heater returns to within 10 ˚F (5.6 ˚C) of its modulation temperature per the User Guide. Cooling water will then be adjusted to continue at 100% heat load, or nominal load. The time at which cooling is stopped and continued shall be recorded.

11.12.6.2.*End of Phase 6.* the end of Phase 6 occurs when after 60 minutes from the start of the phase

11.12.7. End of the Test Run. The test runs end when all six phases of the test run have been completed in sequence.

11.12.7.1. Test Run Completion. At the end of the Phase 6, stop the particulate sampling instruments and measurements required for the efficiency determination, and record the run time and all final measurement values.

11.12.7.2. At the end of the test run, continue to apply a thermal load to the heater to allow the remaining fuel to safely be consumed if necessary. No measurements are required during this period.

11.13. Test run requirements. The following are the pre-testing appliance use requirements for each test run.

11.13.1. Consecutive Test Runs. Consecutive test runs may be conducted, provided that the following requirements are met:

11.13.1.1. Run 1 – appliance can only be run for a shake down test to verify proper installation. The unit cannot run for period greater than 8 hours within the 48-hour period proceeding commencement of official tests runs. Record average firebox temperature within 1 hour of the start of test by measuring the central point along all walls of the firebox.

11.13.1.2. Run 2 – shall not operate for a minimum of 8 hours from the conclusion of Run 1 before commencing Run 2. Appliance coals and ash can remain in the appliance until 1 hour before conducting Run 2. All coals and ash must be removed before commencing Run 2.

11.13.1.3. Run 3 – shall wait a minimum 8 hours from the conclusion of Run 2 before commencing Run 3. Appliance coals and ash can remain in the appliance until 1 hour before conducting Run 3. All coals and ash must be removed before commencing Run 3.

11.14. Failure to Operate at All Test Conditions. If an appliance cannot operate in all of the test Phases without achieving an appliance temperature that causes the safety high limit to be activated, requiring a manual reset, the test is a failed run. After two failed test runs, the unit is deemed to have failed the test, and the unit cannot be certified with this test method.

11.15. Test Series completion. A complete test series is defined as the successful completion of three full test runs, as specified in Section 11.11 of this method.

11.15.1. If the appliance fails more than the two test runs, the appliance has failed the certification test and cannot be certified for compliance without modification to the appliance design.

11.16. Additional Test Runs. The testing laboratory may conduct more than three test runs but no more than five runs. If more than three test runs are conducted, the results from all valid test runs shall be used in calculating the average emission rate. The measurement data and results of all test runs shall be reported regardless of which values are used in calculating the emission rate. No test run data can be eliminated from the reporting requirements of this method.

12. Calculation of Results – Calculation of Results

NOTE: If a TEOM is used for PM measurement, proportioning of emission factors and rates per phase according to Appendix A, variables will have subscript added to determine the relevancy of phase i.e. $E_{T(P1)}$ indicates Total particulate emissions for Phase 1 and $E_{g/hr(P2)}$ indicates emissions factor in grams per hour for Phase 2.

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12.1. Emission Calculations. Particulate matter, carbon dioxide, and carbon monoxide shall be calculated using the following methodology and reported in grams per hour, grams per kilogram and pounds per million British Therma Unit (Btu) per hour based on heat output:

12.1.1. Two PM measurements shall be reported

12.1.1.1. 60-minute reporting. Emissions from the first sixty minutes shall be reported. The 60-minute periods begins at match light. 60-minute data shall be collected and reported as a separate ASTM 2515-11 train or the TEOM (if applicable) data calculated per the SOP.

12.1.1.2. Integrated Result. The results two, dual ASTM E2515-11 trains, shall integrate into a single result the appliance performance over the six phases of this test method's operational protocol.

12.2. Particulate Matter Emissions Rates. After the test is completed determine the particulate matter emissions rate E_r in accordance with ASTM E2515-11 for each test run. If using ASTM E2515-11 for one-hour data, prepare calculations for each first hour of operation.

12.3. Nomenclature

BR – average dry fuel burn rate, lb./min

CA – Carbon

HY - Hydrogen

OX - Oxygen

C_p – Specific heat of water in Btu /lb., ˚F

C_{steel} – Specific heat of steel (0.1 Btu/ lb., ˚F)

E_T – Total particulate emissions for the full test run as determined per ASTM E2515-11 in grams

$E_{g/MJ}$ – PM Emissions rate in grams per megajoule of heat output

$E_{lb/MMBtu\ output}$ – PM Emissions rate in pounds per million Btu of heat output

$E_{g/kg}$ – PM Emissions factor in grams per kilogram of dry fuel burned

$E_{g/hr}$ – PM Emissions factor in grams per hour

E_{Rco} – CO emission rate, g/hr.

EIi – Average CO emission index for interval i

E_{ICO} – CO emission index, g/kg dry fuel

EIco,avg – Average CO emission index for the run

HHV – Higher heating value of fuel = Use accredited test results

LHV – Lower heating value of fuel = Use accredited test results

M – Mass flow rate of water in lb./min (kg/min)

MC – Fuel moisture content, % dry basis

MC_i – Average moisture content as determined by ultimate/proximate analysis

PCTCO2– average CO_2 in the dry flue gas (%)

PPMco -average CO in the dry flue gas (ppm)

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Q_{out} – Total heat output in BTU's (megajoules)
$Q_{out(p2)}$ - Total heat output in BTU's (megajoules) in Phase 2
$Q_{out(p3)}$ - Total heat output in BTU's (megajoules) in Phase 3
$Q_{out(p6)}$ - Total heat output in BTU's (megajoules) in Phase 6
Q_{in} – Total heat input available in test fuel charge in BTU (megajoules)
$Q_{in(p2)}$ - Total heat input available in test fuel charge in BTU (megajoules) in Phase 2
$Q_{in(p3)}$ - Total heat input available in test fuel charge in BTU (megajoules) in Phase 3
$Q_{in(p6)}$ - Total heat input available in test fuel charge in BTU (megajoules) in Phase 6
SC – change in scale mass during measurement interval, lb.
$t_{(i)}$ – Data sampling interval in minutes
T1 – Temperature of water at the inlet on the supply side of the heat exchanger, ˚F (˚C).
T2 – Temperature of the water at the outlet on the supply side of the heat exchanger, ˚F (˚C).
T3 – Temperature of cooling water at the inlet to the load side of the heat exchanger, ˚F (˚C).
T4 – Temperature of cooling water at the outlet of the load side of the heat exchanger, ˚F (˚C).
T5 – Temperature of the hot water supply as it leaves the appliance, ˚F (˚C).
T6 – Temperature of return water as it enters the appliance, ˚F (˚C).
TI_{avg} – Average temperature of the appliance and water at start of the test, ˚F (˚C).
TF_{avg} – Average temperature of the appliance and water at the end of the test, ˚F (˚C)
TIS1 – Temperature measurement 1 in buffer tank positioned at the top 1/6th volume portion of the tank, ˚F (˚C).
TIS2 – Temperature measurement 2 in buffer tank positioned at the second 1/6th volume portion of tank, below TIS1 and above TIS3, ˚F (˚C).
TIS3 – Temperature measurement 3 in buffer tank positioned at the third 1/6th volume portion of the tank, below TIS2 and above TIS4, ˚F (˚C).
TIS4 – Temperature measurement 4 in buffer tank positioned at the fourth 1/6th volume portion of the tank, below TIS3 and above TIS5, ˚F (˚C).
TIS5 – Temperature measurement 5 in buffer tank positioned at the fifth 1/6th volume portion of the tank, below TIS4 and above TIS6, ˚F (˚C).
TIS6 – Temperature measurement 6 in buffer tank positioned at the bottom 1/6th volume portion of the tank below TIS5, ˚F (˚C).
TISavg – Average temperature of the 6 sensor buffer tank at the start of the test, ˚F (˚C).
TFSavg – Average temperature of the 6 sensor buffer tank at the end of the test, ˚F (˚C).
V_{blr} – appliance water capacity, gallons
V_i – Volume of water indicated by a totalizing flow meter at the ith reading in gallons (liters)
V_f – Volumetric flow rate of water in heat exchange system in gallons per minute (liters/min)

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σ – Density of water in pounds per gallon
σI – Density of water at average temperature of the appliance and water at start of measurement interval, pounds per gallon
σF – Density of water at average temperature of the appliance and water at end of measurement interval, pounds per gallon
W_{fuel} – Fuel charge weight in pounds (kg)
W_i – Weight of fuel in pounds (kg)
W_{app} – Weight of empty appliance in pounds (kg)
W_{wa} – Weight of water in the supply side of the system in pounds (kg)
WStorageTank – Weight of the buffer tank empty in pounds (kg)
WWaterStorage – Weight of the water in the buffer tank at TISavg in pounds (kg).
ΔT – Temperature difference between water entering and exiting the heat exchanger
η_{del} – Delivered heating efficiency in percent
$\eta_{del(p2)}$ Delivered Efficiency of Phase 2, percent
$\eta_{del(p3)}$ Delivered Efficiency of Phase 3, percent
$\eta_{del(p6)}$ Delivered Efficiency of Phase 6, percent
Θ – Total length of test run in hours
$\Theta_{(x)}$ – Total length of test run in hours per phase, X

12.4. Determine Heat Input.

12.4.1. Average Fuel Load Content. Determine average fuel load content using HHV and LHV results of the fuel energy density analysis (ultimate/proximate analysis) per test run and Phases 2,3, and 6.

$Q_{in} = (W_{fuel}/(1+(MC/100))) \times HHV$, BTU
$Q_{in\ LHV} = (W_{fuel}/(1+(MC/100))) \times LHV$, BTU
$Q_{inPhaseX} = (W_{fuelPhaseX}/(1+(MC/100))) \times HHV$, BTU
$Q_{in\ LHVPhaseX} = (W_{fuelPhaseX}/(1+(MC/100))) \times LHV$, BTU

12.5. Determine Heat Output per test run and Phases 2,3, and 6

$Q_{out} = \Sigma$ [Heat output determined for each sampling time interval] + Change in heat stored in the appliance over the entire phase + Change in heat in storage tank over the entire phase.

Note: The subscript (i) indicates the parameter value for sampling time interval ti. This sampling time interval is typically 1 minute.

$Q_{out} = \Sigma[Cpi \cdot \Delta Ti \cdot Mi \cdot ti] + (Wapp \cdot Csteel + Wwater \cdot Cpa) \cdot (TFavg - TIavg) + (WStorageTank \cdot Csteel + WWaterStorage \cdot Cpa) \cdot (TFSavg - TISavg)$ Btu (MJ)

Mi = Mass flow rate = gal/min x density of water (lb./gal) = lb./min
Mi =Vfi · σi, lb./min

Note: the above calculation assumes that the cooling water flow is measured on a volumetric basis.
σi = (62.56 + (-.0003413 x T3i) + (-.00006225 x T3i 2)) 0.1337, lbs./gal
Cp = 1.0014 + (-.000003485 x T3i) Btu/lb, °F
Csteel = 0.1 Btu/lb, °F
Cpa = 1.0014 + (-.000003485 X (TIavg +TFavg)/2), Btu/lb-°F

12.5.1. Determine total heat output rate as:

Total Heat Output Rate = Q_{out}/Θ, BTU/hr.

12.5.2. Determine heat load rate as:
Heat load rate = $\Sigma[Cpi \cdot \Delta Ti \cdot Mi \cdot ti]/\Theta$
Phase X Heat load rate: $\Sigma_{(PhaseX)}[Cpi \cdot \Delta Ti \cdot Mi \cdot ti]/\Theta_{(x)}$

12.5.3. Delivered Efficiency - delivered efficiency over the six phases is representative of annual efficiency. Determine delivered efficiency as:

$\eta_{del} = (Q_{out}/Q_{in}) \times 100, \%$
$\eta_{del\ LHV} = (Q_{out}/Q_{in}\ LHV) \times 100, \%$

12.5.4. Determine Steady Heat Load Period Delivered Efficiency.
Determined For efficiency of high and low heat loads, determine the delivered efficiency of the individual steady heat load phases, Phases 2,3, and 6.
$\eta_{del(p2)} = Q_{out(p2)}/Q_{in(p2)} \times 100, \%$
$\eta_{del(p3)} = Q_{out(p3)}/Q_{in(p3)} \times 100, \%$
$\eta_{del(p6)} = Q_{out(p6)}/Q_{in(p6)} \times 100, \%$
Note: If the system is able to satisfy a 100% heat load for phase 6 without cycling on the appliance, then assumed delivered efficiency for phase 6 is 98%.

If no fuel is used in Phase 6, as in the hydronic heater did not cycle on and fire up, and heat load is met, delivered efficiency for phase 6 ($\eta_{del(p6)}$) is considered to be 100%, not including losses through pipe or water jacket. It must be clearly documented that a reported 100% delivered efficiency for phase 6 ($\eta_{del(p6)}$) is because the hydronic heater met the full heat load for Phase 6 without cycling on and firing up.

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12.5.5. Determine emission rates and emission factors as:

$E_{g/MJ} = E_T/(Q_{out} \times 0.001055)$, g/MJ

$E_{lb/MM\ BTU\ output} = (E_T/453.59)/(Q_{output} \times 10^{-6})$, lb./MMBtu Out

$E_{g/kg} = E_T/(W_{fuel}/(1+MC/100))$, g/dry kg

$E_{g/hr} = E_T/\Theta$, g/hr

12.6. Determination of CO Emissions Per Phase

In this section CO emission rate and CO emission index are calculated for each phase in 10-minute intervals. For each interval this is based on average burn rate, flue CO and CO_2 for the period.

12.6.1. Determination of Dry Fuel burn rate During each Interval

Density of water at the start and end of each 10-minute interval shall be calculated using the equation in section 12.5 based on average temperature of the appliance.

$BR = (100/(100+MC))*(SC- V_{blr} * (\sigma F - \sigma I))/10$

If the burn rate for any interval is equal to or less than zero or if the burner is obviously not firing during that part of the test, the burn rate and CO emission rate during that interval shall be assigned a value of zero. For any 10-minute intervals where the burner is transitioning between on and off or off and on, include active burn data in the previous 10-minute interval if active period is less than 5 minutes or include as its own 10-minute interval if active period is greater than 5 minutes.

12.6.2. Intermediate Calculations

The following intermediate calculations and constants are defined in this section for convenience. These results are used in calculations in following section.

x= CA/12
y = HY
z = OX/16

The following parameters shall be calculated for each interval over which the burn rate is not zero.

gamma_n = x + y/4 -z/2
beta_n = ((100 * x * PPMco)/(1000000 * PCTCO2+100 * PPMco))
alpha_n = ((100 * (x-beta_n)/PCTCO2)-x-(beta_n/2)-gamma_n * 3.76)/(gamma_n * 4.76)

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MFco_n = beta_n- kmoles of CO produced when 100 kg dry fuel is burned
MFCO2_n = x-beta_n - kmoles of CO_2 produced when 100 kg dry fuel is burned
MFO2x_n = (alpha_n * gamma_n+beta_n/2) - kmoles of O_2 produced when 100 kg dry fuel is burned
MFNI_n = (1+alpha_n) * gamma_n * 3.76 - kmoles of N_2 produced when 100 kg dry fuel is burned
DryGas = MFco_n + MF_CO2_n + MF_O2_n + MFNI_n - total kmols of dry gas produced per 100 kg of dry fuel burned

DryGasRate = (BurnRate*60*0.454*DryGas)/100 - Kmol of dry gas produced per hour

Informative note – kmol used here refers to kilogram mols.

12.6.3. Calculation of CO Emission Rate and CO Emission Index
For each interval during which the burn rate is not zero, calculate the CO emission rate and emission index as follows:
ERco = (PPMco * DryGasRate * 28 * 454)/(1000000 * 0.454) - CO emission rate, g/hr
EIco = (DryGas * PPMco * 1000 * 28)/(100 * 1000000) - CO emission index, g/kg dry fuel

12.6.4. CO Emissions Test Run Calculations
For each run the average CO emission rate shall be calculated as the average of the CO emission rates during each of the active burn period 10-minute intervals, g/hr. Intervals for which the burn rate is zero shall not be included in this average.
For each run the average CO emission index shall be calculated as the burn rate weighted average of the emission indices during each of the active burn period 10-minute intervals, g/kg. This calculation can be expressed as:

$$EIco, avg = \frac{\sum_i EI_i \square BR_i}{\sum_i BR_i}$$

13. Reporting Requirements. The report shall include the following:

13.1. Introduction - no portion of the introduction may be claimed as CBI.

13.1.1. Purpose of test: certification, audit, efficiency, research, and development

13.1.2. Name and location of the laboratory conducting the test.

13.1.3. Wood appliance identification – manufacturer, model number/name, design type, description of the appliance tested, appliance condition, and date of receipt.

13.1.4. Test information – location of testing, date of tests, sampling methods used, number of test runs, a statement detailing any previous testing completed on the wood appliance.

13.1.5. A list of participants, their roles, and any observers present for the tests. The list shall include the participant's name, title, company, contact information and the purpose of their participation.

13.1.6. A statement that the test results apply only to the specific appliance tested.

13.2. Summary and Discussion of Results - no portion of the introduction may be claimed as CBI.

13.2.1. Record summary results in tables 1A, 1B, and 1C. Table of results to include test run number, average burn rate for entire run, particulate emission rate for full run, particulate emission rate for start-up, carbon monoxide emission rate for a full run, carbon monoxide for startup, efficiency, burn time – total and by phase.

13.2.2. If the TEOM is used for the entire test, the report shall contain the following: For each test run use the TEOM to apportion filter PM data for the six individual phases. Calculated results for the emissions reported as total emissions in grams, grams per hour.

13.2.3. If a TEOM is used, provide a plot of PM emission rate in grams/hour vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

13.2.4. Summary of other data – test facility conditions such as test facility temperature, air velocity and humidity, catalyst averages, pretest fuel weights, test fuel charge weights – total and by phase.

13.2.5. Two measurements shall be reported

13.2.5.1. Start-up. Emissions from powering on the appliance until the end of the start-up phase shall be collected and reported as a separate element using two ASTM E2515-11 trains. One-hour data shall be reported by a third ASTM E2515-11 train or the TEOM data calculated per the SOP.

13.2.5.2. Integrated Result. The results two, dual ASTM E2515-11 trains shall integrate into a single result the appliance performance over the six phases of this test methods operational protocol.

13.3. Discussion. - no portion of the discussion may be claimed as CBI.

13.3.1. Discussion shall include detailed information describing each test conducted on the appliance:

13.3.1.1. How the test was run

13.3.1.2. Specific test run problems and solutions

13.3.1.3. Test run result

13.3.1.4. Deviations

13.4. Process description:

13.4.1. Data and drawings indicating the fire box size and location of the fuel charge.

13.4.2. Drawings and calculations used to determine firebox volume to include volume, height, width, and lengths, weight and volume adjustments. No portion of this section can be CBI.

13.4.3. Firebox configuration – At a minimum to include air supply locations and operation, air supply introduction location, refractory location and dimensions, catalyst location,

baffle and by-pass location and operation (include line drawings or photographs)

13.4.4. Process operation during test – shall supply details on air supply settings and adjustments. No portion of this section can be CBI.

13.4.5. Test fuel properties – species, density, fuel moisture, fuel temperature, and load details. No portion of this section can be CBI. Also, a description of test fuel sourcing, handling and storage practices shall be included.

13.4.6. Sampling. No portion of this section can be CBI.

13.4.6.1. A description of the test procedures and test equipment including a schematic or other drawing showing the location of all required sampling equipment.

13.4.6.2. Describe sampling location relative to appliance, include drawing or photographs.

13.4.6.3. Provide data on sampling blanks.

13.4.6.4. Sampling and Analytical procedures. Detailed description of procedures followed by laboratory personnel in conducting the certification test.

13.5. Quality Control and Assurance Procedures. No portion of this section can be CBI.

13.5.1. Calibration procedures and results certification procedures, sample and analysis procedures.

13.5.2. Test method quality control procedures to include leak-checks, volume meter checks, stratification (velocity) checks, proportionality results.

13.6. Appendices – No data contained in the appendices can be claimed as CBI.

13.6.1. Results and Example Calculations. Complete summary tables and accompanying calculations.

13.6.2. Raw data. Copies of all files or sheets for sampling measurement, temperatures records, and sample recovery data.

13.6.3. Test Equipment Calibration Results. Summary of all calibrations, check and audits pertinent to the certification.

13.6.4. Sampling and Operation Records. Copies of all uncorrected records of activities not included in raw data sheets (e.g. appliance door open, times and durations).

13.6.5. User Guide. Appliance instructions for operating the device during the test following the User Guide specifications detailed in Section 9.3.

13.6.6. Details of deviations from, additions to or exclusions from the test method, and their data quality implications on the test results (if any). An explanation of the deviations, additions, or exclusions shall be provided along with an analysis as to why these elements had no impact.

13.6.7. All required data and applicable blanks for each test run shall be provided in spreadsheet format both in the printed report and in a computer file such that the data can be easily analyzed and calculations easily verified. Formulas used for all calculations shall be accessible for review.

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13.6.8. For each test run, if used: report TEOM flow and temperature and verification of all TEOM parameters presented in the TEOM 1405 SOP.

13.7. Raw data, calibration records, and other relevant documentation shall be retained by the laboratory for a minimum of 7 years.

Table 1A – Must complete a table for each test run, minimum of three

Data Summary Part A - Run 1

Phase	Target Load	Actual Load	Phase Duration	Wood Consumed	Total Heat Output	Total Heat Input	Delivered Efficiency	CO Rate
	Btu/hr.	Btu/hr.	hours	Lbs.	Btu	Btu	%	g/min.
2								
3								
6								
Total								

Data Summary Part A - Run 2

Phase	Target Load	Actual Load	Phase Duration	Wood Consumed	Total Heat Output	Total Heat Input	Delivered Efficiency	CO Rate
	Btu/hr.	Btu/hr.	hours	Lbs.	Btu	Btu	%	g/min.
2								
3								
6								
Total								

Data Summary Part A - Run 3

Phase	Target Load	Actual Load	Phase Duration	Wood Consumed	Total Heat Output	Total Heat Input	Delivered Efficiency	CO Rate
	Btu/hr.	Btu/hr.	hours	Lbs.	Btu	Btu	%	g/min.
2								
3								
6								

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Total								

Table 1B – Must complete a table for each test run, minimum of three

Data Summary Part B – 60-minute test results

		Q_{out}	E_T	E	E	E_{Rco}	E_{Ico}
Run No	Date	Heat Output	Total PM Emissions	PM Output Based	PM Output Based	PM Rate	PM Factor
		Btu	g	lb/MMBtu Out	g/MJ	g/hr.	g/kg
1							
2							
3							

Table 1C Data Summary – Averages

Data Summary – Part 1

			Θ	W_{fuel}	MC_{ave}	Q_{in}	Q_{out}
Run No	Date	Fuel Gross Ca. Value	Test Duration	Wood Weight as-fired	Wood Moisture	Heat Input	Heat Output
-		Btu/lb.	Hrs.	Lbs.	%DB.	Btu.	Btu.
1							
2							
3							
Average							

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Data Summary – Part 2

		E_T	E	E	$E_{PMg/hr}$	$E_{g/kg}$	$E_{CO\ g/hr}$	$E_{Cog/kg}$
Run No	Date	Total PM Emissions	PM Output Based	PM Output Based	PM Rate	PM Factor	CO Rate	CO Factor
		g	Lb./MM Btu Out	g/MJ	g/hr.	g/kg fuel	g/hr.	g/kg fuel
1								
2								
3								
Average								

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Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 6/22/2021 12:41:58 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
CC: Burkhard, Ellen G (NYSERDA) [Ellen.Burkhard@nyserda.ny.gov]; Alice.Edwards@alaska.gov
Subject: slightly revised test method
Attachments: NYSERDA IDC Stove Test Method for Certification of Cordwood Stoves 6 22 21 filter use.pdf

Stef, attached is a very slightly revised protocol for Alt-140. On page 28, I dropped the g in kJ/kgmol, so it was kJ/kmol. I have revised the formula accordingly. Please note that the "g" is in the research protocol, so no need to modify that protocol.

NESCAUM

Lisa Rector, Policy and Program Director at **NESCAUM**
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| lrector@nescaum.org

THIS INTEGRATED-DUTY-CYCLE (IDC) PROTOCOL FOR WOOD STOVES IS THE PROPERTY OF THE NEW YORK STATE ENERGY RESEARCH AND DEVELOPMENT AUTHORITY (NYSERDA) AND CAN BE USED TO TEST TECHNOLOGIES IN A LABORATORY SETTING. ANY DEVIATIONS OR CHANGES TO THIS IDC PROTOCOL FOR WOOD STOVES ARE NOT APPROVED OR SANCTIONED BY NYSERDA. DO NOT CITE, COPY, or DISTRIBUTE THIS IDC PROTOCOL FOR WOOD STOVES WITHOUT THE WRITTEN PERMISSION OF NYSERDA

NYSERDA Integrated Duty Cycle Test Method for Certification of Wood-Fired Stoves Using Cordwood: Measurement of Particulate Matter (PM) and Carbon Monoxide (CO) Emissions and Heating Efficiency

Note: This method does not include all the specifications (e.g. equipment and supplies) and procedures (e.g., sample and analytical) essential to its performance. Some material is incorporated by reference from other methods. Therefore, to obtain reliable results, persons using this method shall have a thorough knowledge of at least the following EPA Tests:

- Method 1- Sample and Velocity Traverses for Stationary Sources
- Method 2- Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube)
- Method 3 – Gas Analysis for the Determination of Dry Molecular Weight
- Method 4 – Determination of Moisture Content in Stack Gases
- Method 5G – Determination of Particulate Matter from Wood Heaters (Dilution Tunnel Sampling Location)
- Method 10 - Carbon Monoxide - Instrumental Analyzer
- Method 28 – Certification and Auditing of Wood Heaters

1. Scope and Application

1.1. This test method specifies operation and fueling for certification and auditing of manually operated wood-fired stoves and heaters.

1.2. This test method measures particulate matter (PM) emissions, carbon monoxide, and efficiency.

1.3. Particulate emissions are measured in the dilution tunnel method as specified in ASTM E2515-11, Standard Test Method for Determination of Particulate Matter Emissions Collected in a Dilution Tunnel, using the Tapered Element Oscillating Microbalance (TEOM) continuous PM method as detailed in this test method.

1.4. Analyte. Particulate matter (PM). No CAS number assigned. Carbon monoxide (CO). No CAS number assigned.

1.5. Applicability. This method is applicable for the certification and auditing of wood space heaters, which burn cordwood fuel. The test quantifies PM and CO emissions and provides overall efficiency ratings, maximum burn time, and heat output.

1.6. Data Quality Objectives. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods.

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1.7. Distinguishing features of appliances covered by this standard include:

1.7.1. Cordwood fuel is hand-fed into firebox.

1.7.2. A chimney or vent that exhausts combustion products from the appliance.

1.8. The values stated are to be regarded as the standard, whether in I-P or SI units. The values given in parentheses are for information only.

1.9. Data Quality Objectives.

1.9.1. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods.

1.9.2. Measurement of emissions and heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

1.9.3. This is a laboratory method intended to capture operating periods that are representative of actual field use without excessive test burden.

2. Referenced Methods

2.1. NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel

2.2. ASTM 2515-11: Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel.

3. Definitions

3.1. Appliance – a wood heater capable of and intended for space heating defined in the applicable regulation. The appliance includes a combustion chamber, combustion air settings, operating controls, and a thermostat if specified, and any other accessory required for standard operation, such as a barometric damper,

3.2. Certification or audit test - a series of at least three test runs (four runs, if use of a fan is an option) conducted for certification or audit purposes that meets the specifications detailed in this protocol.

3.3. Chop – using a poker or another piece of wood to strike a piece of the fuel charge to break it into smaller pieces.

3.4. Coal-bed Stirring – prior to adding a new fuel charge, using a poker or piece of wood to stir or level the coal bed of the appliance for the sole purpose of ensuring ease of loading of the fuel charge. No special formations can be made, such as creating coal bed formations or pushing coals to one side or creating slopes with the coals.

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3.5. East-west stove – a stove where the firebox dimension parallel to the loading door is greater or equal to the stove depth measurement. Logs are loaded so that they are viewed on the long length of the stove.

3.6. Emission factor – the emission of a pollutant expressed in mass per unit of energy (typically) output from the appliance.

3.7. Firebox - the portion of the chamber in the wood heater in which the test fuel charge is placed and combusted.

3.8. Firebox depth - the horizontal length of the fire chamber dimension measured perpendicular to the loading door. If the manufacturer believes that a portion of the firebox depth is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.9. Firebox Height - the vertical distance extending above the top of the firebox to the floor of the firebox. Firebox height is not necessarily uniform. The measurement must account for variations caused by internal baffles, air channels, or other permanent obstructions. If the manufacturer believes that a portion of the firebox height is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.10. Firebox width - the horizontal fire chamber dimension that is parallel to the loading door. If the manufacturer believes that a portion of the firebox width is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.11. Fuel Adjustment – manipulations to the fuel charge to reflect typical owner practices that allow the cordwood fuel to burn appropriately during the test period. A fuel adjustment includes minor changes in fuel placement. It does not include chopping the wood, stirring the coal bed, or reorganizing fuel placement.

3.12. Fuel load calculator – The locked excel spreadsheet tool that determines the allowable test fuel load weights and required piece sizes for each individual load.

3.13. Fuel loading direction – For loads 2, 3, and 4 fuel shall be loaded based parallel to the dimension with the largest value. If the firebox length and width are within 2", fuel shall be loaded in an east/west fashion, parallel to the loading door. A crisscross configuration is allowed for L1 but cannot be used as a load configuration for loads 2, 3, or 4.

3.14. Kindling pieces – small pieces of wood less than 1" in diameter. No bark or moisture requirements for these pieces, however kindling pieces shall not be dried or stored anywhere but in laboratory ambient conditions. Kindling length shall be of the same wood species as the fuel charge length. Individually kindling pieces may weigh no less than 1.5 ounces.

3.15. Large fuel pieces – pieces that are larger for the appliance as defined by the fuel load calculator.

3.16. L1 – Start-up – period of the test when the unit has kindling and startup fuel under the conditions described in Section 11.6.7.

3.17. L2 – High-fire Phase – period of the test when the unit has a small coal bed and the stoves air settings are fully open. It is intended to replicate periods when homeowners are trying to quickly heat an area, shortly after starting or restarting the appliance.

3.18. L3 - Maintenance-fire phase– period of the test when a fire is maintained with a medium-sized coal bed, and a smaller batch of wood made up of two large pieces. This is intended to simulate a period when the operator is trying to maintain consistent heat output.

3.19. L4 - Low-burn Rate Phase – period of the test when the stove has a large coal bed, the stove is fully loaded, and the adjustable air settings are set to produce the lowest possible burn rate and have the lowest air settings. It is intended to simulate when the operator is trying to maintain heat over a long time, such as overnight or while away for significant periods of time.

3.20. North-south stove: a firebox that has its longest dimension measurement perpendicular to the loading door. In this stove type, logs are loaded so that the ends of the fuel are viewed when loaded.

3.21. Phase – A distinct period in the test run with its own operational procedures and conditions.

3.22. Primary air supply – air supply that introduces air to the wood heater in the combustion chamber and is adjusted to target a desired burn rate. The wood heater manufacturer or test facility can document this through design drawings.

3.23. Secondary air supply - air supply that introduces air to the wood heater such that the burn rate is not altered by more than 10 percent when the secondary air supply is adjusted during the test run. The wood heater manufacturer or test facility can document this through design drawings that show the secondary air is introduced only into a mixing chamber or secondary chamber outside the firebox.

3.24. Significant figure – is any digit that is necessary to define the specific value or quantity. Zeros may be used either to indicate a specific value, like any other digit, or to indicate the magnitude of a number.

3.25. Small fuel pieces - pieces that are small for the appliance as defined by the fuel load calculator.

3.26. Starter fuel – pieces of cordwood that can be smaller than small and large pieces but larger than kindling, as defined by the fuel load calculator.

3.27. Test data– means the data for all test runs conducted on the wood heater, including any data collected during failed and invalid runs and includes records of preparation of standards, identification of equipment used and personnel present, records of calibrations, raw data sheets for field sampling, raw data sheets for field and laboratory analyses, chain-of-custody documentation, and example calculations for reported results.

3.28. Test facility - the area in which the wood heater is installed, operated, and sampled for emissions.

3.29. Test fuel charge - the collection of test fuel pieces used in each of the four phases of the test run. L2, L3, and L4 recommend that at least 75% of the individual pieces with at least 80% bark on

one side of the fuel piece. Bark shall not be removed for certification testing. Any fuel charge that suggests bark was purposely removed or shaped shall deem the certification test invalid. Examples of fuel piece manipulation are provided in Section 11. If 75% of the fuel load pieces for L2, L3, and L4 do not have bark, document in the test report, and provide a basis for the lack of bark.

3.30. Test fuel load – the group of test fuel pieces that are loaded, as specified by phase, throughout the test run.

3.31. Test fuel loading – the arrangement of the test fuel charge.

3.32. Total run fuel load – the amount of wood burned during the entire test run.

3.33. Test fuel loading density – the calculation that determines the weight of the as-fired test fuel load. The calculation is based on the usable volume of the firebox.

3.34. Test run – an individual emission test that includes the four operational phases required by the fueling protocol.

3.35. Usable firebox volume – the calculated volume of the firebox determined using its height, width, and depth as defined in this section. This calculation represents the area where wood is likely to be loaded. If the manufacturer claims that portions of the firebox may not be used in the calculation, a justification must be submitted with the test report. If the justification is not approved, the test results will be deemed unrepresentative for certification purposes. It is highly recommended that manufacturers obtain regulatory approval if making claims that portions of the firebox are not appropriate for inclusion in the calculation.

3.36. Wood heater – an enclosed, wood-burning appliance capable of and intended for space heating or domestic water heating, as defined in the applicable regulation.

4. Interferences

None.

5. Summary of Method

5.1. Particulate matter emissions are measured from a wood heater burning cordwood test fuel in a test facility maintained at a set of prescribed ambient conditions. Procedures for operating the appliance, measuring PM and CO emission rates, and methods for reducing data and calculating results are provided.

5.2. *Dilution Tunnel*. A dilution tunnel following the specifications detailed in ASTM E2515-11 shall be used for particulate measurements.

5.3. *Particulate Matter:* PM emissions are measured in a dilution tunnel specified in ASTM 2515-11 *Standard Test Method for Determination of Particulate Matter Emissions Collected in a Dilution Tunnel* with exceptions as defined in Section 10.1. The flow rate in the dilution tunnel is maintained at a constant rate throughout the test cycle and accurately measured. PM emissions are measured in the dilution tunnel using both the filter method specified in ASTM 2515-11 and

with a Thermo model 1405-D using NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

5.4. *Carbon Monoxide*. The CO is measured in the stack and is used to calculate efficiency determination.

5.5. *Operation*. Appliance operation is conducted on a cold-to-hot test cycle, meaning that the appliance starts the first test run at room temperature and ends with the appliance in a heated state. The second and third test runs may start at a slightly warmer temperature if the appliance is designed to retain the heat from the first run. The appliance is operated at operational phases representing start-up emissions, high heat demand, low heat demand, changing air conditions, and refueling. To complete the certification test, the appliance shall complete three valid test runs that are averaged to determine the test results.

5.6. *Repeatability.* A series of at least three test runs conducted for certification or audit purposes.

6. Significance and Use

6.1. The measurement of particulate matter emission rates is an important test method widely used in the practice of air pollution control.

6.1.1. These measurements, when approved by state or federal agencies, are often required for the purpose of determining compliance with regulations and statutes.

6.1.2. The measurements made before and after design modifications are necessary to demonstrate the effectiveness of design changes in reducing emissions and make this standard an important tool in manufacturers' research and development programs.

6.2. Measurement of heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

7. Safety

7.1. Disclaimer. This method may involve hazardous materials, operations, and equipment. This test method may not address all the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to performing this test method.

7.2. These tests involve combustion of wood, which releases substantial amounts of heat and combustion products. The heating system also produces large quantities of very hot water and the potential for steam production and system pressurization. Appropriate precautions must be taken to protect personnel from burn hazards and respiration of products of combustion. Exposure of personnel to unsafe levels of carbon monoxide must be avoided, and the use of continuous ambient carbon monoxide monitoring is strongly recommended.

8. ***Equipment and Supplies.*** The following items are required for sample collection:

THIS INTEGRATED-DUTY-CYCLE (IDC) PROTOCOL FOR WOOD STOVES IS THE PROPERTY OF THE NEW YORK STATE ENERGY RESEARCH AND DEVELOPMENT AUTHORITY (NYSERDA) AND CAN BE USED TO TEST TECHNOLOGIES IN A LABORATORY SETTING. ANY DEVIATIONS OR CHANGES TO THIS IDC PROTOCOL FOR WOOD STOVES ARE NOT APPROVED OR SANCTIONED BY NYSERDA. DO NOT CITE, COPY, or DISTRIBUTE THIS IDC PROTOCOL FOR WOOD STOVES WITHOUT THE WRITTEN PERMISSION OF NYSERDA

8.1. Anemometer. A device capable of detecting air velocities less than 0.10 m/sec (20 ft/min), for measuring air velocities near the test appliance.

8.2. *Appliance Flue.*

8.2.1. Steel flue pipe extending to 8.5 ±0.5 ft. (2.6 ±0.15 m) above the top of the platform scale, and above this level, insulated solid pack type chimney extending to 15 ±1 ft (4.6 ±0.3 m) above the platform scale, and of the size specified by the appliance manufacturer. This applies to both freestanding and inserts type appliances.

8.2.2. Other chimney types (e.g., solid pack insulated pipe) may be used in place of the steel flue pipe if the appliance manufacturer's written appliance specifications require such chimney for home installation (e.g., zero clearance appliance inserts). Such alternative chimney or flue pipe must remain and be sealed with the appliance following the certification test. This applies only to appliances requiring a specialized chimney.

8.2.3. Solid pack insulated chimneys shall have a minimum of 2.5 cm (1 in.) solid-pack insulating material surrounding the entire flue and possess a label demonstrating conformance to U.L. 103 (incorporated by reference—see §60.17).

8.3. Appliance Platform Scale and Monitor. For monitoring of fuel load weight change. The scale shall be capable of measuring weight to within 0.01 kg (0.02 lb.) and calibrated to NIST traceable standards at least annually.

8.4. Barometer. Aneroid or another barometer capable of measuring atmospheric pressure to within 0.1 in. Hg (2.5 mm Hg) with an uncertainty of +/- 0.05 in. Hg (+/- 1.27 mm Hg).

8.5. Dilution Tunnel must meet the requirements of ASTM E2515-11, clauses 6.1.6 and 9.2.

8.6. Dilution Tunnel temperature and relative humidity measurement. A probe with analog or digital data outputs capable of measuring tunnel temperature to within 0.5 °C (1.0 °F) and tunnel RH to within 2% between 5 and 95% RH at maximum tunnel temperatures, such as the Omega HX85A or equivalent. The probe should also report calculated dewpoint.

8.7. Draft Gauge. Electromanometer or other devices for the determination of flue draft or static pressure readable to within 0.005 in. H2O (1.2 Pa)

8.8. Flue Gas Temperature Measurement. A type K thermocouple or equivalent located in the centroid of the stack located 8.0 +/- 0.5 ft (2.44 m +/- 150 mm) above the platform scale, capable of measuring with an accuracy of 4.0°F (2.2°C) or 0.75% of reading, whichever is greater.

8.9. Flue Gas Composition Measurement. A sample probe and continuous infrared analyzer or equivalent capable of measuring span of carbon monoxide (CO) and carbon dioxide (CO_2) in the

flue gas produced by the appliance tested. Continuous analyzers (or equivalent) shall have maximum zero and span drift, over a 24 h period, of 1% of full scale.

8.10. Fuel Scale. Balance capable of weighing the test fuel charge to within 0.02 kg (0.05 lb.) and calibrated to NIST traceable standards at least annually.

8.11. Humidity Gauge. Psychrometer or hygrometer for measuring room humidity to within +/- 4% from 25 to 95% RH.

8.12. Moisture Meter. Calibrated electrical resistance meter for measuring test fuel moisture to within 2 percent moisture content.

8.13. Surface Temperatures. Capable of measuring temperature to within 1.5 percent of expected absolute temperatures with an accuracy of 4.0°F (2.2°C) or 0.75% of reading, whichever is greater.

8.14. Test Facility Temperature Monitor. A thermistor, RTD, Type T-Special thermocouple, or other equivalent device, located centrally in a vertically oriented 150 mm (6 in.) long, 50 mm (2 in.) diameter pipe shield that is open at both ends, capable of measuring temperature to within 1°F of expected temperatures.

8.15. TEOM – Thermo Fisher Scientific TEOM model 1405-D (Thermo part # 1405D-ANF, excluding models 1405, 1405-DF, or 1405-F) to measure and report continuous particulate matter (PM) measurements in an ASTM 2515-11 dilution tunnel or equivalent dilution method, and operated according to the NYSERDA Dichot TEOM Standard Operating Procedures. For lab air PM measurements, Thermo Fisher Scientific TEOM model 1405 (Thermo part # 1405-ANF, excluding model 1405-F), operated according to the NYSERDA Dichot TEOM Standard Operating Procedures.

9. Calibration and Standardizations

9.1. ASTM E2515-11. Perform all calibrations required by ASTM E2515-11.

9.2. Anemometer. Calibrate the anemometer as specified by the manufacturer's instructions before the first certification test every six months thereafter.

9.3. Appliance Platform Scale. Perform a multipoint calibration (at least five points spanning the operational range) of the platform scale before its initial use. The scale manufacturer's calibration results are sufficient for this purpose. Before each certification test, audit the scale with the wood heater in place by weighing at least one calibration weight (Class F) that corresponds to between 20 percent and 80 percent of the expected test fuel charge weight. If the scale cannot reproduce the value of the calibration weight within 0.0045 kg (0.01 lb.) or 1 percent of the expected test fuel charge weight, whichever is greater, recalibrate the scale before use with at least five

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calibration weights spanning the operational range of the scale.

9.4. Barometer. Calibrate using a reference pressure monitor calibrator before the first certification test and semiannually after.

9.5. Draft Gauge. Calibrate as per the manufacturer's instructions; a liquid manometer does not require calibration (but must be properly leveled, zeroed, and the system leak checked).

9.6. Humidity Gauge. Calibrate as per the manufacturer's instructions before the first certification test and annually thereafter.

9.7. Fuel Scale. Calibrate as described in 9.2.

9.8. Moisture Meter. Calibrate as per the manufacturer's instructions before the first certification test and semiannually thereafter.

9.9. Temperature Sensors. Calibrate using at least five points within operating range within specification and in compliance with NIST Monograph 175. To be calibrated before the first certification test and semiannually thereafter.

10. Sampling, Test Specimens, and Test Appliances

10.1. Particulate matter sampling shall follow ASTM except for the following modifications listed here.

10.1.1. Liquid water should not be present anywhere in the sampling system for a valid sample. The presence of condensed water anywhere in the sampling system invalidates the test run. All data from all invalid test runs shall be included in the report. The reviewing authority shall make a final determination on invalidated runs. Data from any invalidated test run shall not be used to calculate results. If the testing agency believes a run has been invalidated, the test run shall be repeated.

10.1.2. Dilution tunnel temperature and relative humidity shall be measured electronically and logged at one-minute intervals near the sample probe to calculate dewpoint.

10.1.3. The following section details test conditions that shall be maintained for a valid test run. A valid test shall have no more than two individual deviations from the conditions below to remain a valid run. An example of an individual deviation is a single, ten-minute rolling average where the dilution tunnel exceeded temperature thresholds. Another ten-minute period exceeding the tunnel temperature requirement shall be considered a second deviation.

10.1.3.1. Tunnel temperature shall not exceed 104 deg. F (40 deg. C) based on ten-minute rolling averages derived from one-minute data, excluding periods when the appliance door is open.

10.1.3.2. Tunnel relative humidity shall not exceed 90% based on ten-minute rolling averages derived from one-minute data excluding periods when the appliance door is open.

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10.1.3.3. A minimum average tunnel flow of 600 DSCFM is required. Higher tunnel flows may be required to meet the parameters of Section 10.1.3.

10.1.3.4. All exceedances must be reported in the test anomalies section, even if deviations are within the test method tolerances.

10.1.3.5. ASTM 2515-11 filter trains 1 and 2 must meet a precision requirement of 7.5% or lower, regardless of g/kg comparison.

10.1.3.6. Use rounding requirements specified in Section 13.2 of this test method.

10.1.3.7. Use processes specified in Section 10.2.

10.2. Sample Collection. The following are required for sample collection:

10.2.1. Teflon coated glass fiber filters as supplied by the TEOM manufacturer for use with the TEOM model 1405-D. These are Pallflex Emfab (TX40) with an exposed diameter of 13 mm, without organic binder, exhibiting at least 99.95 percent efficiency.

10.2.2. *Test Specimens.* Appliances shall be supplied as complete systems, including all controls and accessories necessary for installation at the test facility. A full set of specifications, designs, and assembly drawings shall be provided when the product is placed under certification of a third-party agency.

10.2.3. Particulate Matter Sampling Uses two (2) ASTM 2515-11 sampling trains and a TEOM to obtain real-time data. TEOM data shall be used to report the first-hour emission rate, to provide data for phased emissions, and real-time data reporting requirements. All measurements shall run through the entirety of the test to obtain full run data.

10.2.3.1. Train 1 and 2 shall provide dual sampling trains that shall measure PM emissions from run start to run completion. Trains 1 and 2 must meet a precision requirement of 7.5% or lower, regardless of g/kg comparison.

10.2.3.1.1. Proportional rate variation shall meet ASTM 2515-11 requirements for all phases.

10.2.3.1.2. Filter conditions must be monitored, and filter changes are required to avoid filter clogging.

10.2.3.2. TEOM data shall be collected at 1-minute intervals for reporting. TEOM operation shall follow the procedures listed on the most recent NYSERDA Standard Operation Procedures for Thermo Scientific 1405-D TEOM for use in a dilution tunnel, found on the NESCAUM website at www.nescaum.org/topics/testmethods.html

10.3. Preparation of Apparatus

10.3.1. Wood Heater Installation for Certification Testing. Assemble the wood heater appliance and parts in conformance with the manufacturer's provided User Guide. These instructions must match all instructions materials developed by the manufacturer and/or their distributors. Place the wood heater on the platform scale and connect the chimney to the appliance. Clean the flue with an appropriately sized, wire chimney brush before initiating Run 1 of the certification test. Test documentation should include the date and time of flue cleaning.

10.3.2. Wood Heater Temperature Monitors.

10.3.2.1. For catalyst-equipped wood heaters, locate a temperature monitor (optional) about 25 mm (1 in.) upstream of the catalyst at the centroid of the catalyst face area, and locate a temperature monitor (mandatory) that will indicate the catalyst exhaust temperature. This temperature monitor is centrally located within 25 mm (1 in.) downstream at the centroid of the catalyst face area. Record these locations.

10.3.2.2. Locate wood heater surface temperature monitors at five locations on the wood heater firebox exterior surface. Position the temperature monitors centrally on the top surface, centrally on two sidewall surfaces, and centrally on the bottom and back surfaces. Position the monitor sensing tip on the exterior of the firebox surface inside of any heat shield, room air circulation walls, or other wall or shield separated from the firebox exterior surface. Surface temperature locations for unusual design shapes (e.g., spherical, etc.) shall be positioned so that there are four surface temperature monitors positioned to average stove temperature across various points on the appliance.

10.4. Conditioning

10.4.1. Wood Heater Aging Prior to Certification Testing. A wood heater of any type shall be aged at least 50 hours before initiating a certification test. The aging procedure shall be conducted by the manufacturer or a manufacturer's agent prior to sending the appliance to the testing laboratory.

During aging, the appliance shall be operated at a variety of burn rates. Documentation for wood heating aging must be included in the test report to include data on individual hourly burn rates.

10.4.1.1. The manufacturer shall supply wood heater aging information for the final test reports. Aging data that shall be reported include all fuel parameters (species, moisture content, load weights, piece amounts, and size), air settings used, time spent in each air setting phase, amount of fuel burned, and appliance burn rates.

10.4.1.2. If an appliance uses a catalytic combustor, it must be engaged according to the manufacturer's instructions and operate with the catalyst engaged for at least 50 hours during the break-in period.

In addition to the reporting requirements listed in 8.1.1, catalytic appliances shall also report hourly catalyst exit temperature data to include the dates and hours of operation.

11. Procedure

11.1. Test Facility Conditions. The test facility shall meet the following requirements during testing.

11.1.1. The test facility temperature shall be maintained between 55 and 87 °F (13 and 30.6 °C) during each test run.

11.1.2. The flue shall discharge into the same space or into a space freely communicating with the test facility. Any hood or similar device used to vent combustion products shall not induce a draft greater than 0.005 in. H_2O (1.25 Pa) on the wood heater measured when the wood heater is not operating.

11.1.3. For test facilities with artificially induced barometric pressures (e.g., pressurized chambers), the barometric pressure in the test facility shall not exceed 30.5 in. Hg (775 mm Hg) during any test run.

11.1.4. Locate the test facility temperature monitor on the horizontal plane that includes the primary air intake opening for the wood heater. Locate the temperature monitor 3 to 6 ft. (0.9 to 1.8 m) from the front of the wood heater in the 90° sector in front of the wood heater.

11.1.5. Use an anemometer, or equivalent device, to measure the air velocity. Measure and record the room air velocity before the ignition period in L1 Startup and once immediately following the test run completion. Air velocities within 0.6 m (2 ft) of the test appliance and exhaust system shall be less than 0.25 m/sec (50 ft/min) without fire in the unit.

11.1.6. Measure and record the test facility's ambient relative humidity, barometric pressure, and temperature before and after each test run using equipment as specified in Section 6.

11.2. Wood Heater Firebox Volume.

11.2.1. Determine the firebox volume using the definitions for height, width, and length. Volume adjustments due to the presence of firebrick and other permanent fixtures may be necessary. All adjustments shall be detailed in the test report and shall conform to the definition of usable firebox volume contained in this test method. Measurements shall include areas adjacent to and above a baffle.

11.2.2. If a manufacturer deems certain areas of the firebox as unusable for fuel load calculations, written documentation stating the basis for that claim and supporting photographic image(s) must be provided and approved by the regulatory authority prior to conducting the certification test. If approval is not granted prior to the test, then the test may be invalidated if the reviewing agency determines the firebox volume is inaccurate.

11.3. Test Fuel. The test fuel shall conform to the following requirements and meet specifications as required by the fuel loading calculator:

11.3.1. Fuel Species. Untreated, air-dried, cordwood fuel.

11.3.1.1.For EPA research purposes, allowable species: maple (big leaf, red, silver), or birch (black, white, yellow, paper).

11.3.1.2.Kiln-dried fuel is not permitted. Kiln-dried fuel includes drying at elevated air temperature settings above 90 °F.

11.3.1.3.Fuel shall be free of decay, fungus, or other contaminants.

11.3.2. Fuel Moisture.

11.3.2.1.Determine fuel moisture for each fuel piece by averaging four moisture meter readings, one from each of three sides, measured parallel to the wood grain.

11.3.2.2.The test fuel load shall have an average moisture content from 19% to 25%, dry basis.

11.3.2.3.Average individual piece moisture content shall have an average moisture content 18% to 27% dry basis.

11.3.2.4.The addition of moisture to previously dried wood is not allowed.

11.3.2.5.It is recommended that the test fuel be stored in a temperature and humidity-controlled room.

11.3.2.6. Fuel moisture shall be measured within 24 hours of using the fuel for the test and shall be bagged or stored in a humidity-controlled environment until 2 hours prior to testing. A humidity-controlled environment is one where fuel is not subject to conditions that would remove moisture from the fuel, such as fans or a heating source, and maintain relative humidity levels greater than 75%.

11.3.3.Fuel Temperature. The test fuel shall be at the test facility temperature of 55 to 87 °F (13 to 30.6 °C) +/-2 °F.

11.3.4. Fuel Dimensions. The dimensions of each test fuel piece shall conform to definitions specified by the protocols using the fuel load calculator.

11.3.4.1.Fuel length:

11.3.4.1.1.The length of the fuel pieces will be determined by the fuel load calculator.

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11.3.4.1.2.Measurements shall be taken, and the length of the test fuel will be determined by entering the firebox dimensions, which calculates the length for all the fuel pieces into a generally available commercial size (14, 16, 18, 20, or 22 inches in length).

11.3.4.1.3.Piece length specified by the fuel calculator shall be communicated and specified for use in the owner's manual and website. Piece size shall be within 0.5" of the log length determined by the calculator, as measured on the shortest length measurement.

11.3.5.Fuel Loading Direction

11.3.5.1.Fuel loading direction shall be determined by the firebox measurement.

11.3.5.1.1.Stoves with a depth measurement greater than two inches from the width measurement shall be tested with the fuel in a north-south configuration and may not test with fuel in an east/west or crisscross configuration in any load other than Load 1 and Load 2.

11.3.5.1.2.Stoves with a width measurement greater than the depth measurement or a width measurement within two inches of the depth measurement shall be tested with the fuel loaded in an east-west configuration and may not test with fuel in a north/south configuration or crisscross configuration in any load other than Load 1 and Load 2.

11.3.6.Fuel piece weight for each phase of the protocol shall be determined by the fuel load calculator.

11.3.6.1.Kindling – shall be:

11.3.6.1.1.Pieces of wood less than or equal to 1" in diameter.

11.3.6.1.2.No bark requirements for kindling fuel.

11.3.6.1.3.Fuel species may be any species allowed in 7.2.1.1.

11.3.6.1.4.No moisture requirements.

11.3.6.1.5.Length of kindling shall be the fuel length specified by the fuel load calculator.

11.3.6.1.6.Kindling fuel shall conform to the rule that 7 to 10 pieces of kindling equal 1 pound of kindling fuel (+/- 5%).

11.3.6.2. Starter fuel: pieces of cordwood shall be used during the startup phase. Individual piece weight for starter fuel shall be determined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall be not be used in testing (see

Figure 1). Pieces that have squared cross sections shall be split to represent the typical triangle nature of wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible and fuel load pieces shall be composed to include different shapes of wood if using any trapezoidal pieces. .

11.3.6.3.Small fuel pieces: smaller pieces of cordwood by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall not be used (see figure 1). Pieces that have square cross-sections shall be split to represent the typical triangle nature of wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible. No more than two (2) small fuel pieces can be trapezoidal in shape (Figure 2) per fuel load.

11.3.6.4.Large fuel pieces: larger pieces of cordwood, by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall be not be used (see figure 1). Pieces that have square cross-sections shall be split to represent the typical triangle nature of wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible. No more than one (1) large fuel piece can be trapezoidal in shape (Figure 2) per fuel load.

Figure 1. Schematic of unacceptable cross-sectional profiles

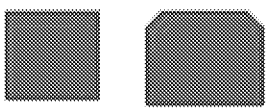


Figure 2. Schematic of undesirable and limited use shapes

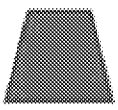
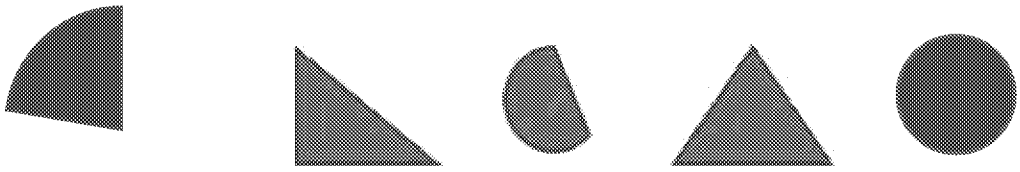


Figure 3. Schematics of acceptable cross-sectional profiles



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11.4. Sampling Equipment.

11.4.1. Prepare the tunnel and lab air PM sampling equipment as defined by the NYSERDA Standard Operation Procedures for Thermo Scientific 1405-D TEOM for use in a dilution tunnel.

11.4.2. Prepare all other equipment as defined by method EPA Method 1, 2, 3, 4, and ASTM 2515-11, unless deviations from ASTM 2515-11 are specified in this test method.

11.5. Manufacturer participation in certification testing.

11.5.1. A representative of the manufacturer may observe testing but may not provide instructions to the certification lab, in any form, with testing staff or equipment once the certification tests begin. The names of testing witnesses cannot be withheld as confidential business information (CBI).

11.6. Test Run Procedure.

11.6.1. Before each test series, the firebox shall be vacuumed. Testing shall begin without any ash or other materials in the appliance.

11.6.2. Before initiating the compliance test series, clean the flue and dilution tunnel with an appropriately sized wire chimney brush before each certification test. Test documentation should include the date and time of flue cleaning.

11.6.3. Record fuel weight data, temperature measurements, and gas concentrations at 1-minute intervals.

11.6.4. Wood Heater Operation and Adjustments. Record all adjustments made to the air supply controls, adjustments to and additions or subtractions of fuel, and any other changes to wood heater operations that occur during the test period.

11.6.5. Appliance operation -bypass operation for catalytic and hybrid models shall follow operational instructions contained in the appliances owner's manual.

11.6.6. The weight of fuel remaining at the end of the test run is determined as the difference between the weight of the wood heater with the remaining coals and fuel and the weight after loading the fuel charge. The starting weight is the tare weight of the cleaned, dry wood heater.

11.6.7. All runs shall be video-recorded in their entirety. Video shall be of sufficient quality to determine fuel characteristics, fuel loading procedures, and firebox conditions during any testing or aging conducted by the test lab. The testing lab shall have the capacity to allow appropriate agencies the opportunity to remotely witness the test.

11.6.8.L1: Start-up Phase.

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11.6.8.1.L1 Appliance requirements.

11.6.8.1.1.Stove temperature: internal and external stove temperature must not be greater than the ambient temperature +/- 2°F (1.1°C) for Run 1. There is no stove starting temperature requirement for Runs 2 and 3 except in the case of a failed first run. In this case, if Run 1 is invalid or incomplete, the stove must meet Run 1 conditions for at least one valid run. Temperature measurements for the external and internal temperatures shall be taken within 15 minutes before starting the test and shall be reported in the test report.

11.6.8.1.2.Tare the appliance scale before starting the test. Record appliance scale weights at the start and end of L1 phase.

11.6.8.2.L1 Fuel requirements.

11.6.8.2.1.L1 Fuel type – during the startup phase newspaper (optional up to six full sheets traditional newspaper size), kindling, and starter fuel pieces are used. No other additions are allowed.

11.6.8.2.2.L1 loading density

11.6.8.2.2.1.Kindling loading density: 1 lb. per cubic foot for dry kindling, +/- 5%. The fuel load calculator determines the amount of kindling that can be used.

11.6.8.2.2.2.Starter Fuel loading density: 3 lb. per cubic foot, +/- 5%. The fuel load calculator will determine the minimum piece weight that can be used as starter fuel.

11.6.8.2.3.L1 fuel loading structure: The loading structure of the fire shall be a bottom-up configuration with newspaper on the bottom, kindling on top of the paper, and starter fuel on top of the kindling. Kindling and starter fuel shall be loaded in a crisscross configuration.

11.6.8.3.L1 Operational parameters.

11.6.8.3.1.All kindling, starter fuel, and newspaper must be in the firebox for light off.

11.6.8.3.2.Air settings are fully open.

11.6.8.3.3.Light the fire with a torch for a period of no more than 30 seconds.

11.6.8.3.4. Immediately after lighting the fire and completing the photo requirement, the appliance door shall be moved to a cracked open position. Cracked open position is defined as opening no more than one inch. The appliance door shall be closed 5 minutes after ignition.

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11.6.8.4.L1 Fuel Adjustments: up to three fuel adjustments are allowed in the startup phase. The door may be open for 30 seconds during each fuel adjustment.

11.6.8.5.L1 End of Phase – the end of the startup phase is defined by the weight specified by the fuel load calculator.

11.6.8.6. L1 Documentation – Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed, and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge.

11.6.9. *L2: High-fire Phase* – the high-fire phase commences immediately after the startup phase ends.

11.6.9.1.L2 Appliance requirements.

11.6.9.1.1.Record the weight of the stove prior to loading the L2 fuel charge, the weight of the fuel charge prior to loading, and the scale weight after loading the L2 fuel charge.

11.6.9.2. L2 Fuel requirements.

11.6.9.2.1. L2 piece size – during the high-fire phase, small cordwood pieces by weight, as defined by the fuel load calculator, are used.

11.6.9.2.2. L2 loading density: 7 lb. per cubic foot, +/- 5%. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.9.3.L2 Operational parameters: Open the door upon completion of the startup phase and load the L2 fuel load within 60 seconds. Once the fuel has been loaded, the appliance doors shall be closed immediately. Air settings shall be left fully open. When 50% of the L2 fuel load mass has been consumed, the air settings shall be moved to the lowest settings.

11.6.9.4.L2 Fuel Adjustments.

11.6.9.4.1.One fuel adjustment shall be made during the high-fire phase prior to moving the primary air control(s) to their lowest setting. The fuel adjustment shall optimize fuel placement for burn conditions. The door shall remain open for 30 seconds for fuel adjustments.

11.6.9.4.2.Additional fuel adjustments shall be made if there is a five-minute period without a weight change of 0.10 pounds at any point during the high-fire phase.

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11.6.9.4.3.If there is a five-minute period without a weight change (0.10 lb) at any point during the high-fire phase. The door may only be open for 30 seconds for fuel adjustments.

11.6.9.4.4.All fuel adjustments must be documented in the test report notes and summary.

11.6.9.5.End of L2 Phase –The high-fire phase ends when the scale indicates that 90% of the high-fire fuel mass has been consumed.

11.6.9.6. L2 Documentation – Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed, and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge prior to loading.

11.6.10. *L3: Maintenance-fire Phase* – the L3 maintenance-fire phase commences immediately after the L2 high-fire phase ends.

11.6.10.1.L3 Appliance Requirements.

11.6.10.1.1. Record the weight of the stove prior to loading the maintenance-fire fuel charge, the weight of the fuel charge prior to loading, and the scale weight after loading the maintenance-fire fuel charge.

11.6.10.2.L3 Fuel Requirements.

11.6.10.2.1.Fuel type – during the L3 phase, large cordwood pieces are used. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.10.2.2.L3 Fuel loading structure: fuel shall be loaded in the direction specified by the fueling calculator.

11.6.10.2.3. L3 loading density: 5 lb. per cubic foot, +/- 5%. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.10.3. L3 Operational Parameters:

11.6.10.3.1.Open door upon completion of the L2 phase and load the maintenance-fire fuel charge.

11.6.10.3.2.Air controls may be placed in the fully open position for the first five minutes of the phase, and then returned to the low air setting.

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11.6.10.3.3.L3 Load - L3 fuel loaded within 30 seconds of the door opening. Close the loading door immediately.

11.6.10.4. L3 Fuel Adjustments: Fuel Adjustments: If there is a ten-minute period without weight change (0.10 lb.) at any point during the L3-fire phase, a fuel adjustment shall be made to increase the burn rate. The door may be open for up to 30 seconds for fuel adjustments. Only two fuel adjustments may be made during this phase. If after the second fuel adjustment, another ten-minute period of no weight change (0.10 lb.) occurs, the run ends, and it is a failed test run.

11.6.10.5.L3 End of Phase – The L3-fire phase ends when the scale indicates that 90% of the maintenance-fire fuel mass has been consumed.

11.6.10.6.L3 Documentation – Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed, and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge prior to loading.

11.6.11.*L4: Low burn rate phase* – L4 phase commences immediately after the L3-fire ends.

11.6.11.1.L4 Appliance Requirements.

11.6.11.1.1.Record the weight of the stove prior to loading the L4-fire fuel charge, the load of the fuel charge prior to loading, and the scale weight after loading the overnight-fire fuel charge. Alternatively, if the scale was zeroed prior to starting the test, record the scale weight before and after loading the overnight-fire fuel charge.

11.6.11.2.L4 Fuel requirements

11.6.11.2.1. L4 fuel type –a mix of small and large cordwood pieces are used. At least 50% of the fuel charge load, by the number of pieces, must be large pieces.

11.6.11.2.2.L4 Loading structure: fuel will be loaded in one direction.

11.6.11.2.3.L4 loading density: The fuel load calculator specifies a load volume of 12 lb/ft^3 +/-5%. Fuel shall be loaded in a manner to maximize the number of pieces that will fit in the stove without using force.

11.6.11.3. L4 Operational Parameters:

11.6.11.3.1. Open the loading door upon completion of the L3 maintenance-fire phase.

11.6.11.3.2.Load the L4 fuel charge within two minutes (120 seconds).

11.6.11.3.3.Keep the door in the 1" cracked position for five minutes from the beginning of the L4 phase.

11.6.11.3.4.Air controls may be placed in the fully open position for the first ten minutes of the phase, and then returned to the low air setting.

11.6.11.4.L4 Fuel Adjustments.

11.6.11.4.1.Unlimited fuel adjustments are allowed within the first five minutes of the phase. After ten minutes, air control(s) shall be moved to their lowest position. A picture of the air setting used must be included in the test report. The door may be open for up to 30 seconds for fuel adjustments.

11.6.11.4.2.If there is a ten-minute period without weight change (0.10 lb.) during the first hour of the L4- phase, a fuel adjustment shall be made. The door may be open for up to 30 seconds for fuel adjustments.

11.6.11.4.3.Only two fuel adjustments may be made during the first hour. If after the second fuel adjustment, another period of no weight change (0.10 lb.) is observed, the run ends, and it is a failed test run.

11.6.11.4.4.No fuel adjustments are allowed after the first hour of the phase.

11.6.11.4.5.If there is no weight change (0.10 lb) for a consecutive period of 20 minutes at any point after the first hour of the phase, the unit has failed the test run.

11.6.11.5.L4 End of Phase – The L4 phase shall end when the scale indicates that 90% of the total L4 fuel mass has been consumed. If the fuel load does not burn to 90%, it is a failed test run.

11.6.11.6. L4 Documentation - Video of the test to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coal-bed, and fire when the door is closed sufficient to determine fueling positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge prior to loading.

11.7. Test Run. A complete test run requires the completion of all four burn phases and loads. For any appliance that will not accommodate the loading arrangement specified in this test method, the test facility personnel shall contact the Agency Administrator to obtain written approval for an alternative loading arrangement.

11.8. Test Run Requirements. The following describes the required parameters for each test run. Each emission test run shall include all phases of the operational and fueling protocol run in order as described.

11.8.1. Consecutive Test Runs. Consecutive test runs may be conducted, provided that the following requirements are met:

11.8.1.1. Run 1 – The appliance shall have an internal and external starting temperature within +/- 2 °F (1.1°C) of ambient laboratory temperature at the beginning of Run 1.

11.8.1.2. Run 2 – The second test run may commence 24 hours after the start of Run 1. Stove coals and ash can remain in the stove until 1 hour before conducting Run 2. All coals and ash shall be removed at least one hour prior to commencing Run 2.

11.8.1.3. Run 3 – The third test run may commence 24 hours after the start of Run 2. Stove coals and ash may remain in the stove until 1 hour before conducting Run 3. All coals and ash shall be removed at least one hour prior to commencing Run 2.

11.9. *Failure to Operate at All Test Conditions*

11.9.1. If the appliance fails two runs due to incomplete or invalid test runs, it shall be determined that the appliance has failed the certification test and requires a modification to appliance design. All data for incomplete runs shall be reported. Incomplete failed test runs are defined as the following:

11.9.1.1. If a wood heater fails to complete all four phases of the test run, the run shall be considered a failed test run.

11.9.1.2. If there is no weight change, defined as 0.10 lb., for a consecutive period of 20 minutes at any point during the test, the unit has failed the test run.

11.9.2. If a test run violates the test method parameters, the run is invalid.

11.9.3. If during certification testing a critical component of the stove is damaged or breaks, the certification test will be stopped and considered invalid.

11.9.3.1. If damage is noted during a test, repairs shall be made by the manufacturer (or by laboratory personnel with written direction from the manufacturer). If the repair involves components that would need aging, the appliance shall then undergo another round of wood heater aging as specified in section 10.6. These components may include but are not limited to catalyst elements, gaskets, and refractory components. The aging process is intended not only to 'cure' the stove but

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also to cycle parts that may fail with extended use. Alternate aging techniques may be approved by the administrator, depending on the nature of the failure, material, and critical nature.

11.10. Test Run Completion. Once three valid runs have been completed, the testing is complete. No additional runs may be completed.

11.10.1. *Additional Test Runs*. If there is an invalid run, another additional run may be attempted to complete the test series. If more than three test runs are conducted, the results from all valid test runs shall be used in calculating the average emission rate. The measurement data and results of all test runs shall be reported regardless of which values are used in calculating the emission rate. No test run data can be eliminated from the reporting requirements of this method. A maximum of five runs attempts can be completed. If a wood heater cannot complete three valid runs after five attempts, the appliance has failed the certification test.

11.10.2. *Invalid Runs.* When a test run fails to meet one of the QA/QC criteria stipulated in the test method, the data are invalid, and the run must be repeated. Data for the invalidated test run must be included in the test report, but the data must not be used in the calculation of average emission values.

11.10.3. *Incomplete Runs:* When an appliance cannot successfully complete all operational elements of the protocol specified in Section 11.6.7 through 11.6.10, it is an incomplete run

11.11. Auxiliary Wood Heater Equipment Operation. If optional heat exchange blowers are sold for use with the wood heater, three runs without the fan and an additional run with the fan shall be completed. If emissions are more than 1 gram per higher with the fan on, an additional two runs must be completed with the fan on. Heat exchange blowers shall operate in the highest airflow setting. (Automatically operated blowers shall be operated as designed) during the entire test.

11.12. PM Data Recording.

11.12.1. All TEOM data shall be collected and recorded at intervals of 1 minute. TEOM operation shall follow the procedures listed in NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

11.12.2. Tunnel and lab air PM TEOM Data shall be reported using the Excel data analysis spreadsheet templates that are part of the NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel. These data analysis spreadsheets shall be submitted as part of the test report.

11.12.3. Lab PM measurement – TEOM. A single channel TEOM shall be used to measure ambient lab air PM during the test, as configured in NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel. The sample flow shall be 3 LPM.

12. Quality Control Measures

12.1. Dilution tunnel - Conduct sampling equipment leak check and calibration pre- and post-test.

12.2. TEOM – Flow and Leak checks are done before and after every test run per NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel. Additional quality control measures are included in the TEOM Operating Procedure.

12.3. Conduct all checks and calibrations per ASTM 2515-11.

13. Data Analysis and Calculations.

Proportioning of emission factors and rates per phase according to Appendix A, variables shall have subscript added to determine the relevancy of phase, i.e. $E_{T(P1)}$ indicates Total particulate emissions for Phase 1 and $E_{g/hr(P2)}$ indicates emissions factor in grams per hour for Phase 2.

13.1. Emission Calculations. Particulate matter, carbon dioxide, and carbon monoxide shall be calculated using the following methodology and reported in grams per hour, grams per kilogram and pounds per million British Thermal Unit (BTU) heat output.

13.2. Rounding

13.2.1. All calculations shall be conducted using all decimal values provided by the instrumentation or recorded by the operator.

13.2.2. No truncation of data is acceptable until the final result has been calculated.

13.2.3. Only the final calculation of the PM emissions rate shall be rounded to three significant figures.

13.2.4. When rounding off a figure, the following procedure should be used. If the first digit to be discarded is less than five, the last digit retained should not be changed. When the first digit discarded is greater than five, or if it is a five followed by at least one digit other than zero, the last figure retained should be increased by one unit. When the first digit discarded is exactly five, followed only by zeros, the last digit retained should be rounded upward if it is an odd number, but no adjustment made if it is an even number.

13.3. TEOM data shall be reported as follows.

13.3.1. Emissions from each of the 4 phases of the test shall be reported as individual results in grams per hour, grams per kilogram, and lb/MMBtu (heat output). Calculations shall use Section 7 of the NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM protocol.

13.3.2. Emissions from the entire test run in grams per hour, grams per kilogram, and lb/MMBtu (heat output) using the ASTM 2515-11 filter data.

14. Emissions from the entire test run in grams per hour, grams per kilogram, and lb/MMBtu (heat output) using the TEOM data.

Nomenclature

BR – average dry fuel burn rate, lb/hour
$BR_{(x)}$ – Burn rate for specific phase, BR_{L1}, BR_{L2}, BR_{L3}, BR_{L4}
CO – Carbon Monoxide
CO_2 – Carbon Dioxide
BT = time of 90% of overnight load consumed – time of overnight loading
C_{steel} – Specific heat of steel (0.1 Btu/ lb)
E_T – Total particulate emissions for the full test run in grams
$E_{g/MJ}$ – PM emissions rate in grams per megajoule of heat output
$E_{g/kg}$ – PM emissions factor in grams per kilogram of dry fuel burned
$E_{g/hr}$ – PM emissions rate in grams per hour
HHV – Higher heating value of dry fuel (Btu/lb), measured with ASTM E711
kJ/kgmol K - kilojoules per kilogram-mol Kelvin
$\%M_d$ - Fuel moisture content, dry basis, percent
$\%M_w$ - Average moisture in test fuel charge, wet basis, percent
PCTCO2 – average CO_2 in the dry flue gas (%)
PPMco – average CO in the dry flue gas (ppm)
Q_{out} – Total heat output in BTU's (megajoules)
SC_i – Scale weight at specific time interval, lb.
T1 – Surface Temperature 1 °F (°C)
T2 – Surface Temperature 2 °F (°C)
T3 – Surface Temperature 3 °F (°C)
T4 – Surface Temperature 4 °F (°C)
T5 – Surface Temperature 5 °F (°C)
T6 - Flue Gas Temperature °F (°C)
T7 – Room Temperature °F (°C)
$TS_{avg(i)}$ – Initial Average Surface Temperature °F (°C)
$TS_{avg(f)}$ – Final Average Surface Temperature °F (°C)
W_{fuel} – Fuel charge weight in pounds (kg)
Θ – Total length of test run, hours
$\Theta_{(x)}$ – Total length of test run in hours per phase, X
$\%M_w = 100(\%M_d)/100 + \%M_d$

14.1. Average Wood Heater Surface Temperatures. Calculate the average of the wood heater surface temperatures at the start of the phase (L4) and end at the end of the test (L4) of the test run.
L4 $TS_{avg(i)} = (T1 + T2 + T3 + T4 + T5) / 5$
L4 $TS_{avg(f)} = (T1 + T2 + T3 + T4 + T5) / 5$
Average surface temperatures at the start and end of any phase can be determined by averaging all five sensors at the beginning and end of each phase.
L_x $TS_{avg(i)} = (T1 + T2 + T3 + T4 + T5) / 5$
L_x $TS_{avg(f)} = (T1 + T2 + T3 + T4 + T5) / 5$

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14.2. Burn Time Rating– A standardized burn time rating shall be determined by rounding the duration of the overnight-fire phase of the test up to the nearest 1 hour. Burn time shall be calculated as the time L4 is loaded into the stove until 90% of the fuel has been consumed. This provides an important rating for consumers and is not intended for any calculation purposes and shall be reported by all manufacturers materials that provide specifications on appliance performance. Language such as "this stove has demonstrated a low setting burn time of x hours in official testing."

14.3. Determine Burn Rates

BR_{L1} = not applicable
BR_{L2} = (L2 Initial SC_i – L2 Final SC_i) / $\Theta_{(L2)}$, lbs./hr
BR_{L3} = (L3 Initial SC_i – L3 Final SC_i) / $\Theta_{(L3)}$, lbs./hr
BR_{L4} = (L4 Initial SC_i – L4 Final SC_i) / $\Theta_{(L4)}$, lbs./hr

14.4. Emissions

14.4.1. Determine emission rates and emission factors, reporting results from both TEOM and filter data, as:

$E_{g/MJ} = E_T/(Q_{out} \times 0.001055)$, g/MJ
$E_{g/kg} = E_T/(W_{fuel}/(1+M\%M_d/100))$, g/dry kg
$E_{g/hr} = E_T/\Theta$, g/hr

14.5. Efficiency calculation.

The following nomenclature is defined specifically for the efficiency calculation in this section.
Ultimate Analysis of dry fuel (% by weight, ASTM D5373)
Carbon – CA
Hydrogen – HY
Oxygen – OX
Moisture Content – mass of water per mass of dry fuel – Mcdb
Ambient Humidity Ratio[1] – mass of water per unit mass of dry air – ω
Flue gas temperature (F) – Ts
Room temperature (F) – Tr
CO in the dry flue gas (ppm) – PPMco
CO2 in the dry flue gas (%) – PCTCO2
Higher heating value of the dry fuel (lb/MMBtu, ASTM E711) – HHV

1. Humidity ratio is a commonly used term to express the moisture content in air. It can be determined from ambient temperature and relative humidity using, for example, a Psychrometric Chart. [ASHRAE Handbook of Fundamentals, Chapter 1, p. 1.15, American Society of Heating,

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Refrigeration, and Air Conditioning Engineers (2017)] For example, air at 65°F and 70% relative humidity has a humidity ratio of .0092 lb of water vapor per pound of dry air.

Combustion Balance Equation:

$$C_xH_yO_z + (1 + \alpha) * \gamma(O_2 + 3.76N_2) + \left[\omega * \left(\frac{(1+\alpha) \bullet \gamma \bullet (32 + 3.76 \bullet 28)}{18}\right) + \frac{Mcdb}{18}\right] H_2O$$

$$\rightarrow (x-\beta)\ CO_2 + \beta CO + (\alpha \bullet \gamma + \frac{\beta}{2})\ O_2 + (1+\alpha) \bullet \gamma \bullet 3.76N_2 + \left[\frac{y}{2} + \omega \bullet \left(\frac{(1+\alpha) \bullet \gamma \bullet (32 + 3.76 \bullet 28)}{18}\right) + \frac{Mcdb}{18}\right] H_2O$$

Where:

$x = CA/12$

$y = HY$

$z = OX/16$

$\gamma = (x + \frac{y}{4} - \frac{z}{2})$

α = excess air parameter, e.g. if $\alpha = 0.5$, there is 50 % excess air

From this:

$$PPMco = \frac{1E6 * \beta}{x + \left(\alpha * \gamma + \frac{\beta}{2}\right) + (1+\alpha) * \gamma * 3.76}$$

$$PCTCO2 = \frac{100 * (x - \beta)}{x + \left(\alpha * \gamma + \frac{\beta}{2}\right) + (1+\alpha) * \gamma * 3.76}$$

With flue gas CO and CO_2 measured, these two equations can be solved simultaneously for β and α.

$$\frac{100 * x * PPMco}{1E6 * PCTCO2 + 100 * PPMco}$$

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$$\alpha = \frac{\frac{100 * (x - \beta)}{PCTCO2} - x - \frac{\beta}{2} - 3.76 * \gamma}{4.76 * \gamma}$$

Calculation of the Molar Coefficient for Each of the Products

For the assumption of 100 kg of dry fuel, this is the number of moles of each product for the input conditions

$MFCO = \beta$ Molar Coefficient for CO

$MFCO2 = x - \beta$ Molar Coefficient for CO_2

$MFH2O = \frac{\gamma}{2} + \frac{Mcdb}{18} + \frac{\omega * (1+\alpha) * \gamma * (32+3.76*28)}{18}$ Molar Coefficient for H_2O

$MFO2 = \alpha * \gamma + \frac{\beta}{2}$ Molar Coefficient for O_2

$MFN2 = (1 + \alpha) * \gamma * 3.76$ Molar Coefficient for N_2

Conversion of Molar Coefficients to Mass of Products per Unit Mass of Dry Fuel

$MCO = MFCO * 28/100$ kg CO in flue products per kg dry fuel fired

$MCO2 = MFCO2 * 44/100$ kg CO_2 in flue products per kg dry fuel fired

$MH2O = MFH2O * 18/100$ kg H_2O in flue products per kg dry fuel fired

$MO2 = MFO2 * 32/100$ kg O_2 in flue products per kg dry fuel fired

$MN2 = MFN2 * 28/100$ kg N_2 in flue products per kg dry fuel fired

Heat Capacity of Exhaust Products

The general equation for representing how the heat capacity of the exhaust products varies with temperature is:

$C = A * Tk + B$

Where:

C = heat capacity J/mol K or kJ/kgmol K

A and B are constants

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Tk = Temperature in °K

The values for A and B for the exhaust components are provided in the table below

Component	A	B
CO	.0056	27.162
CO2	.029	29.54
H2O	.0057	32.859
O2	.009	26.782
N2	.0062	26.626

For each component, heat capacity is calculated at the stack temperature and at room temperature. The average of these is used to calculate sensible heat loss.

<u>Calculation of Heat Losses for Efficiency Determination</u>

$HHVJ = HHV * 2.326$ Higher heating value in kJ/kg (conversion from Btu/lb)

$LHWV = 43969$ Latent heat of water vapor in kJ/kmol

$Llat = MFH2O * LHWV/HHVJ$ Heat loss in latent heat of water vapor, % of input energy

$Lco = MFCO * 282993/HHVJ$ Heat loss in chemical energy in CO, % of input energy

$Lsens = (MFCO * C_{COm} + MFCO2 * C_{CO2m} + MFH2O * C_{H2Om} + MFO2 * C\_O2m$

$+MFN2 * C\_N2)/HHVJ$ Heat loss in sensible heat in flue gas, % of input energy

<u>Note – T6 and T7 in this expression must be expressed in °C or K.</u>

$Efficiency = 100 - Llat - Lco - Lsens$ Stack loss efficiency, %

15. ***Reporting Requirements.*** The report shall include the following:

15.1.1.Introduction

15.1.2.Purpose of test: certification, audit, efficiency,

15.1.3.Name and location of the laboratory conducting the test.

15.1.4. Wood appliance identification – manufacturer, model number/name, design type, description of the appliance tested, stove condition, and date of receipt.

15.1.5. Test information – location of testing, date of tests, sampling methods used, number of test runs, a statement detailing any previous certification testing completed on the wood appliance.

15.1.6. A list of people who conducted research on the appliance, participated in testing preparation, or witnessed the certification testing. This list shall clearly specify their roles in the testing program for the appliance. The list shall include the participant's name, title, company, contact information and the purpose of their participation.

15.1.7. A statement that the test results apply only to the specific appliance tested.

15.2. Summary and Discussion of Results

15.2.1. Table of results to include test run number, average burn rate for entire run and each phase, carbon monoxide and particulate emission rate for full run, particulate and carbon monoxide emission rate for each load phase (L1, L2, L3, L4), efficiency for the full run and each phase, burn time for total run and each phase.

15.2.2. For each test run and pollutant with real-time data to include: Θ_1,Θ_2, Θ_3, CO, CO_2, PM, and efficiency for (1) L1 - the startup phase and (2) L2 - high-, (3) L3-maintenance-, and (4) L4 low burn rate fire phases. Calculated results for PM emissions shall be reported as total emissions in grams, pounds per million Btu output, grams per MJ, grams per kilogram of dry fuel and grams per hour, and pounds per hour. Calculated results for Θ_1,Θ_2, Θ_3, CO, and CO_2 emissions shall be reported as grams per kilogram of dry fuel and parts per million for CO and percent for CO and CO_2. Efficiency shall be reported for each load. CO measurements shall be obtained from the dilution tunnel.

15.2.3. A narrative discussion detailing any issues or anomalies that arose during each test run and how those were handled, including comments about the fuel, and loading of the appliance.

15.2.4. TEOM PM Plots

15.2.4.1. A plot of PM emission rate in grams/hour vs. time at 1-minute intervals, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

15.2.5. Summary of other data – test facility conditions, surface temperature averages, catalyst temperature averages, pretest fuel weights, test fuel charge weights – total and by phase.

15.3. Discussion. Test run result, specific test run problems, and solutions. Comments on fuel, loading, analysis, and anything that may impact the reported result(s).

15.3.1. Details of deviations from, additions to or exclusions from the test method, and their data quality implications on the test results (if any), as well as information on specific test conditions, such as environmental conditions. An explanation of the deviations, additions, or exclusions shall be provided along with an analysis as to why these elements had no impact.

15.4. Process description:

15.4.1. Data and drawings indicating the firebox size and location of the fuel charge.

15.4.2. Drawings and calculations used to determine firebox volume to include volume, height, width, and lengths, weight, and volume adjustments.

15.4.3. Firebox configuration – At a minimum to include air supply locations and operation, air supply introduction location, refractory location and dimensions, catalyst location, baffle and by-pass location and operation (include line drawings or photographs)

15.4.4. Appliance operation during the test – shall supply details on air supply settings and adjustments.

15.5. Test fuel properties – the report shall provide information on the species, density, fuel moisture, fuel temperature, and load details from the fuel load calculator to include all measurements including the number of pieces, individual piece weights, piece length, moisture content and weight.

15.6. Sampling

15.6.1. A description of the test procedures and test equipment, including a schematic or other drawing showing the location of all required test equipment. Also, a description of test fuel sourcing, handling and storage practices shall be included.

15.6.2. Describe the sampling location relative to the wood heater, include drawing or photographs.

15.6.3. Provide data on sampling blanks.

15.7. Quality Control and Assurance Procedures

15.7.1. Calibration procedures and results certification procedures, sample and analysis procedures.

15.7.2. Test method quality control procedures to include TEOM leak and flow checks, stratification (velocity) checks, tunnel flow range results, filter temperature range verification and dilution tunnel RH verification.

15.8. Appendices

15.8.1. Results and Example Calculations. Raw data and complete calculations for data included in summary tables.

15.8.2. Raw data. Copies of all files or sheets for sampling measurement, temperature records, and other materials used by lab related to testing.

15.8.3. Calibration Results. Summary of all calibrations, check, and audits pertinent to the certification.

15.8.4. Sampling and Operation Records. Copies of all uncorrected records of activities not included in raw data sheets (e.g., wood heater door open, times and durations) as well as photographs of fuel loading and air flow settings.

15.8.5. Correspondence. Any correspondence to include written, electronic or verbal communications regarding appliance testing. Items shall include:

15.8.5.1. Request to conduct testing

15.8.5.2. Scheduling of testing

15.8.5.3. Notice to EPA to conduct test, and any modifications to that request.

15.8.6. Test Facility Information. Report test facility temperature, air velocity, and humidity

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information.

15.8.7. Test Equipment Calibration and Audit Information. Report calibration and audit results for the platform scale, test fuel balance, test fuel moisture meter, and sampling equipment including volume metering systems and gaseous analyzers.

15.8.8. Pretest procedures. Report all pretest procedures conducted at the lab on the appliance to burns, rates, and amounts.

15.8.9. All required data for each test run shall be provided in spreadsheet format both in the printed report and in a computer file such that the data can be easily analyzed and calculations easily verified. Formulas used for all calculations shall be accessible for review.

15.8.10. For each test run: report TEOM flow and temperature and verification of all TEOM data validation parameters as required in NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

15.8.11. Raw data, calibration records, and other relevant documentation shall be retained by the laboratory for a minimum of 7 years.

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Message

From: Toney, Mike [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=F0BC151675F34C3BB54F3BD1312B062D-MTONEY]
Sent: 1/3/2020 8:34:19 PM
To: lisa rector [lrector@nescaum.org]
CC: Johnson, Steffan [johnson.steffan@epa.gov]
Subject: Revised IDC Jan 3, 2020
Attachments: (Martin Westermayer) ATM IDC approval letter Jan 3, 2020.pdf

Hi Lisa,

I am having a hard time sending you the approval letter with the method because it is 40 MB and not under 36MB. So I am attaching the approval letter by itself since you have the revised IDC 1/3/2020.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

JAN 0 3 2020

OFFICE OF
AIR QUALITY PLANNING
AND STANDARDS

Mr. Martin Westermayer
Windhager Zentralheizung Technik GmbH
Anton Windhager Straße 20
A 5201 Seekirchen

Dear Mr. Westermayer,

I am writing in response to your correspondence, dated October 22, 2019, regarding certification testing of your BioWIN series of pellet-fueled hydronic heaters. You are planning to test this model line to obtain 2020 certification under 40 CFR 60, Subpart QQQQ - Standards of Performance for New Residential Hydronic Heaters and Forced Air Furnaces (Subpart QQQQ), Section 60.5476(e). You are requesting an alternative certification testing procedure to use the Integrated Duty Cycle (IDC) Test Method for Certification of Thermostatically Controlled Pellet-Fired Hydronic Heating Appliances with external thermal storage: Measurement of Particulate Matter (PM), Carbon Monoxide (CO) Emissions and Heating Efficiency (Attachment dated 1/3/20) in lieu of the Method 28 WHH (40 CFR 60, Appendix A) procedures required by Subpart QQQQ.

In your correspondence, you are requesting an alternative certification testing procedure for your BioWIN Series of pellet-fueled hydronic heaters. This series consists of five heaters, the BioWIN 102, 152, 212, 262 and 332. You state that the pellets are either fed fully automatically with an external suction turbine from the pellet storage to the hopper, or manually fed into the hopper. The pellets are transported from the hopper by a stoker screw to the downpipe and fall in a metered quantity onto the combustion grate of the sturdy steel combustion chamber. Hot air is added by an automatic ignition element to ignite the pellets. The heat generated during combustion is used in the heat exchanger to heat the water. Flue gases produced during the combustion process are channelled outside through the chimney. The movement of the integrated cleaning mechanism cleans the heat exchanger automatically. The ash from the steel combustion chamber falls through an automatic sliding grate into an ash chamber where it is transported via an ash screw into an ash container. The boiler's output is controlled via a speed controlled inner diameter fan depending on boiler water temperature and on combustion temperature. You are requesting to use the IDC Method because EPA Method 28 WHH test procedure does not address the use of pellet fuel where as the IDC Method does include pellet fuel.

With the caveats set forth below, we are approving your alternative method request for certification testing of the BioWIN series of thermostatically-controlled hydronic heaters with the limitations explained below. This series of hydronic heaters cannot be sold with thermal storage that is less capcity than was used during certification testing. A copy of this letter must be included in each certification report.

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As required in Subpart QQQQ, Section 60.5476(c)(6), the manufacturer or approved test lab must also measure the first hour of particulate matter emissions for each test run using a separate filter in one of the two parallel sampling trains. These results must be reported separately and also included in the total particulate matter emissions per run. Also, as required in Subpart QQQQ, Section 60.5476(a), the manufacturer must have the approved test laboratory measure the efficiency, heat output, and carbon monoxide emissions of the tested wood heater using CSA Method B415.1-10. For particulate matter emission concentrations, ASTM E2515-11 "Standard Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel" must be used; four inch filters are acceptable

The following changes to ASTM E2515-11 "Standard Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel" must be followed for the certification testing:

1. Filters must be weighed in pairs to reduce weighing error propagation. See ASTM E2515-11, Section 10.2.1, Analytical Procedure.
2. Sample filters must be Pall TX-40 or equivalent Teflon-coated glass fiber filters, and 47 mm, 90 mm, 100 mm, or 110 mm in diameter.
3. Only one point is allowed outside the +/- 10 percent proportionality range per test run.

The BioWIN series of hydronic heaters incorporates a low setting on the controller which is the design of the lowest heat output (Btu/hr) setting available to the user and corresponds to the lowest burn rate to be evaluated during certification testing; this is consistent with 40 CFR part 60, Subpart QQQQ, section 60.5476, which states "The burn rate for the low burn category must be no greater than the rate that an operator can achieve in home use and no greater than is advertised by the manufacturer or retailer."

If you have additional questions regarding this approval, please contact Michael Toney of my staff at 919-541-5247 or *toney.mike@epa.gov*.

Sincerely,

Steffan M. Johnson, Group Leader
Measurement Technology Group

cc: Amanda Aldridge, EPA/OAQPS/OID
Adam Baumgart-Getz, EPA/OAQPS/OID
Rochelle Boyd, EPA/OAQPS/SPPD
Chuck French, EPA/OAQPS/SPPD
Rafael Sanchez, EPA/OECA
Michael Toney, EPA/OAQPS/AQAD

Message

From: Lisa Rector [lrector@nescaum.org]
Sent: 12/23/2020 1:21:29 PM
To: Johnson, Steffan [johnson.steffan@epa.gov]
CC: Burkhard, Ellen G (NYSERDA) [Ellen.Burkhard@nyserda.ny.gov]
Subject: Revised IDC protocol and calculator
Attachments: NYSERDA IDC Protocol for Wood Stoves draft versuin 12 21 20.docx; Fuel Calculator - Woodstoves-12-21-20.xlsm

Stef, attached to this email is the revised IDC stove protocol for your review and comment.

NESCAUM

Lisa Rector, Policy and Program Director at **NESCAUM**
89 South Street, Suite 602, Boston, Massachusetts, 02111 | 802.899.5306| 617.259.2095 | Fax: 617.742.9162
| lrector@nescaum.org

THIS INTEGRATED-DUTY-CYCLE (IDC) PROTOCOL FOR WOOD STOVES IS THE PROPERTY OF THE NEW YORK STATE ENERGY RESEARCH AND DEVELOPMENT AUTHORITY (NYSERDA) AND CAN BE USED TO TEST TECHNOLOGIES IN A LABORATORY SETTING. ANY DEVIATIONS OR CHANGES TO THIS IDC PROTOCOL FOR WOOD STOVES ARE NOT APPROVED OR SANCTIONED BY NYSERDA.

DO NOT CITE, COPY, or DISTRIBUTE THIS IDC PROTOCOL FOR WOOD STOVES WITHOUT THE WRITTEN PERMISSION OF NYSERDA

Integrated Duty Cycle Test Method for Certification of Wood-Fired Stoves Using Cordwood: Measurement of Particulate Matter (PM) and Carbon Monoxide (CO) Emissions and Heating Efficiency

Note: This method does not include all the specifications (e.g. equipment and supplies) and procedures (e.g., sample and analytical) essential to its performance. Some material is incorporated by reference from other methods. Therefore, to obtain reliable results, persons using this method shall have a thorough knowledge of at least the following EPA Tests

- Method 1- Sample and Velocity Traverses for Stationary Sources
- Method 2- Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube)
- Method 3 – Gas Analysis for the Determination of Dry Molecular Weight
- Method 4 – Determination of Moisture Content in Stack Gases
- Method 5G – Determination of Particulate Matter from Wood Heaters (Dilution Tunnel Sampling Location)
- Method 10 - Carbon Monoxide - Instrumental Analyzer
- Method 28 – Certification and Auditing if Wood Heaters

1. Scope and Application

1.1. This test method specifies operation and fueling for certification and auditing of manually operated wood-fired stoves and heaters.

1.2. This test method measures particulate matter (PM) emissions, carbon monoxide, and efficiency.

1.3. Particulate emissions are measured by the dilution tunnel method as specified in ASTM E2515 Standard Test Method for Determination of Particulate Matter Emissions Collected in a Dilution Tunnel using only Emfab Pallflex filters. Additional particulate matter emissions measurements may also use the Tapered Element Oscillating Microbalance (TEOM) continuous PM method, as detailed in this test method.

1.4. Analyte. Particulate matter (PM). No CAS number assigned. Carbon monoxide (CO). No CAS number assigned.

1.5. Applicability. This method is applicable for the certification and auditing of wood space heaters, which burn cordwood fuel. The test quantifies PM and CO emissions and provides overall efficiency ratings, maximum burn time, and heat output.

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1.6. Data Quality Objectives. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods

1.7. Distinguishing features of appliances covered by this standard include:

1.7.1. Cordwood fuel is hand-fed into firebox.

1.7.2. A chimney or vent that exhausts combustion products from the appliance.

1.8. The values stated are to be regarded as the standard, whether in I-P or SI units. The values given in parentheses are for information only.

1.9. Data Quality Objectives.

1.9.1. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods.

1.9.2. Measurement of emissions and heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

1.9.3. This is a laboratory method intended to capture operating periods that are representative of actual field use without excessive test burden.

2. Referenced Methods

2.1. NESCAUM Standard Operating Practices for Thermo 1405 TEOM

2.2. ASTM 2515: Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel.

3. Definitions

3.1. Appliance – a wood heater capable of and intended for space heating defined in the applicable regulation. Appliance includes combustion chamber, combustion air settings, operating controls, and a thermostat, if specified, and any other accessory required for standard operation, such as a barometric damper,

3.2. Catch - any mass from the sample probe system on the filter.

3.3. Certification or audit test - a series of at least three test runs conducted for certification or audit purposes that meets the specifications detailed in this protocol.

3.4. Chop – using a poker or another piece of wood to strike a piece of the fuel charge to break it into smaller pieces.

3.5. Coal-bed Stirring – prior to adding a new fuel charge, using a poker or piece of wood to stir or level the coal bed of the appliance for the sole purpose of ensuring ease of loading of the fuel

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charge. No special formations can be made, such as creating coal bed formations or pushing coals to one side or creating slopes with the coals.

3.6. East-west stove – a stove where the firebox dimension parallel to the loading door is greater or equal to the stove depth measurement. Logs are loaded so that they are viewed on the long length of the stove.

3.7. Emission factor – the emission of a pollutant expressed in mass per unit of energy (typically) output from the appliance.

3.8. Firebox - the portion of the chamber in the wood heater in which the test fuel charge is placed and combusted.

3.9. Firebox depth - the horizontal length of the fire chamber dimension measured perpendicular to the loading door. If the manufacturer believes that a portion of the firebox depth is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.10. Firebox Height - the vertical distance extending above the top of the firebox to the floor of the firebox. Firebox height is not necessarily uniform. The measurement must account for variations caused by internal baffles, air channels, or other permanent obstructions. If the manufacturer believes that a portion of the firebox height is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.11. Firebox width - the horizontal fire chamber dimension that is parallel to the loading door. If the manufacturer believes that a portion of the firebox width is not usable for firebox volume calculation, photo documentation and a written basis must be included in the test report.

3.12. Fuel Adjustment –manipulations to the fuel charge to reflect typical owner practices that allow the cordwood fuel to burn appropriately during the test period. A fuel adjustment does not include chopping the wood or stirring the coal bed.

3.13. Fuel load calculator – The locked excel spreadsheet tool that determines the allowable test fuel load weights and required piece sizes for each individual load.

3.14. Fuel loading direction – Fuel shall be loaded parallel to the greater of the width and depth dimensions for loads 2, 3 and 4. Criss-cross is allowed for startup phase and cannot be used as a load configuration for loads 2, 3 or 4. If the firebox length and width are within 2" fuel shall be loaded in an east/west fashion, parallel to the loading door.

3.15. Kindling pieces – small pieces of wood less than 1" in diameter. No bark or moisture requirements for these pieces, however kindling pieces shall not be dried or stored anywhere but in laboratory ambient conditions. Kindling length shall be of the same as the fuel charge length. and shall represent weights that would enable 8 to 12 pieces equal one pound.

3.16. Large fuel pieces – pieces that are larger for the appliance as defined by the fuel load calculator.

3.17. L1 – Start-up – period of the test when the unit has kindling and startup fuel under the conditions described in Section 11.6.7.

3.18. L2 – High-fire Phase – period of the test when the unit has a small coal bed and the stoves air settings are fully open. Intended to replicate period when homeowners are trying to quickly heat an area, shortly after starting or restarting the appliance.

3.19. L3 - Maintenance-fire phase– period of the test when a fire is maintained with a medium-sized coal bed, and a smaller batch of wood. This is intended to simulate a period when the operator is trying to maintain consistent heat output.

3.20. L4 - Low-burn Rate Phase – period of the test when the stove has a large coal bed, stove is fully loaded, and the adjustable air settings are set to produce the lowest possible burn rate and have the lowest air settings. Intended to simulate a period the operator is trying to maintain heat over a long period of time, such as overnight or while away for significant periods of time.

3.21. North-south stove: a firebox which has its longest dimension measurement perpendicular to the loading door. In this stove type, logs are loaded so that the ends of the fuel are viewed when loaded.

3.22. Phase – A distinct period in the test run with its own operational procedures and conditions.

3.23. Primary air supply – air supply that introduces air to the wood heater in the combustion chamber and is adjusted to target a desired burn rate. The wood heater manufacturer or test facility can document this through design drawings.

3.24. Secondary air supply - air supply that introduces air to the wood heater such that the burn rate is not altered by more than 10 percent when the secondary air supply is adjusted during the test run. The wood heater manufacturer or test facility can document this through design drawings that show the secondary air is introduced only into a mixing chamber or secondary chamber outside the firebox.

3.25. Small fuel pieces - pieces that are small for the appliance as defined by the fuel load calculator.

3.26. Starter fuel – pieces of cordwood that can be smaller than small and large pieces but larger than kindling, as defined by the fuel load calculator.

3.27. Test data– means the data for all test runs conducted on the wood heater, including any data collected during failed and invalid runs and includes records of preparation of standards, identification of equipment used and personnel present, records of calibrations, raw data sheets for field sampling, raw data sheets for field and laboratory analyses, chain-of-custody documentation, and example calculations for reported results.

3.28. Test facility - the area in which the wood heater is installed, operated, and sampled for emissions.

3.29. Test fuel charge - the collection of test fuel pieces used in each of the four phases of the test run. L2, L3, and L4 require that at least 5% of the individual pieces with at least 80% bark on one side of the fuel piece. Bark shall not be removed for certification testing. Any fuel charge that suggests

bark was purposely removed or shaped shall deem the certification test invalid. Examples of fuel piece manipulation are provided in Section 11

3.30. Test fuel load – the group of test fuel pieces that are loaded, as specified by phase, throughout the test run. Test fuel loading means the arrangement of the test fuel charge.

3.31. Test fuel loading density - the calculation that determines the weight of the as-fired test fuel load. The calculation is based on the usable volume of the firebox.

3.32. Test run - an individual emission test that includes the four operational phases required by the fueling protocol.

3.33. Usable firebox volume - the calculated volume of the firebox determined using its height, width, and depth as defined in this section. This calculation represents the area where wood is likely to be loaded. If the manufacturer claims that portions of the firebox may not be used in the calculation a justification must be submitted with the test report. If the justification is not approved, the test results will be deemed unrepresentative for certification purposes. It is highly recommended that manufacturers obtain regulatory approval if making claims that portions of the firebox are not appropriate for inclusion in the calculation.

3.34. Wood heater - an enclosed, wood-burning appliance capable of and intended for space heating or domestic water heating, as defined in the applicable regulation.

4. *Interferences*

None.

5. *Summary of Method*

5.1. Particulate matter emissions are measured from a wood heater burning cordwood test fuel in a test facility maintained at a set of prescribed ambient conditions. Procedures for operating the appliance, measuring PM and CO emission rates, and methods for reducing data and calculating results are provided.

5.2. *Dilution Tunnel.* A dilution tunnel following the specifications detailed in ASTM E2515-11 shall be used for particulate measurements.

5.3. *Particulate Matter:* PM emissions are measured in a dilution tunnel with a Thermo model 1405-D 2-channel TEOM using the Standard Operating Procedures provides in Appendix A, with a dilution tunnel as specified in EPA Method 5G with modifications discussed in Section 10.

5.4. *Carbon Monoxide*. The CO measured in the stack and is used to calculate efficiency determination.

5.5. *Operation*. Appliance operation is conducted on a cold-to-hot test cycle, meaning that the appliance starts the first test run at room temperature and ends with the appliance in fully heated state. The second and third test runs are started a slightly warmer temperature. The appliance is

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operated at a variety of operational phases representing start-up emissions, high heat demand, low heat demand, and refueling. The appliance is operated through four phases. To complete the certification test, a minimum of three full test runs are averaged to determine the test results.

5.6. *Repeatability.* A series of at least three test runs comprised of six different heat demands or phases conducted for certification or audit purposes

6. Significance and Use

6.1. The measurement of particulate matter emission rates is an important test method widely used in the practice of air pollution control.

6.1.1. These measurements, when approved by state or federal agencies, are often required for the purpose of determining compliance with regulations and statutes.

6.1.2. The measurements made before and after design modifications are necessary to demonstrate the effectiveness of design changes in reducing emissions and make this standard an important tool in manufacturers' research and development programs.

6.2. Measurement of heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

7. Safety

7.1. Disclaimer. This method may involve hazardous materials, operations, and equipment. This test method may not address all the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to performing this test method.

7.2. These tests involve combustion of wood, which releases substantial amounts of heat and combustion products. The heating system also produces large quantities of very hot water and the potential for steam production and system pressurization. Appropriate precautions must be taken to protect personnel from burn hazards and respiration of products of combustion. Exposure of personnel to unsafe levels of carbon monoxide must be avoided, and the use of continuous ambient carbon monoxide monitoring is strongly recommended.

8. Equipment and Supplies. The following items are required for sample collection:

8.1. Anemometer. A device capable of detecting air velocities less than 0.10 m/sec (20 ft/min), for measuring air velocities near the test appliance.

8.2. Appliance Flue.

8.2.1. Steel flue pipe extending to 8.5 ±0.5 ft. (2.6 ±0.15 m) above the top of the platform scale, and above this level, insulated solid pack type chimney extending to 15 ±1 ft (4.6 ±0.3 m) above the

platform scale, and of the size specified by the appliance manufacturer. This applies to both freestanding and inserts type appliances.

8.2.2. Other chimney types (e.g., solid pack insulated pipe) may be used in place of the steel flue pipe if the appliance manufacturer's written appliance specifications require such chimney for home installation (e.g., zero clearance appliance inserts). Such alternative chimney or flue pipe must remain and be sealed with the appliance following the certification test.

8.2.3. Solid pack insulated chimneys shall have a minimum of 2.5 cm (1 in.) solid-pack insulating material surrounding the entire flue and possess a label demonstrating conformance to U.L. 103 (incorporated by reference—see §60.17).

8.3. Appliance Platform Scale and Monitor. For monitoring of fuel load weight change. The scale shall be capable of measuring weight to within 0.01 kg (0.02 lb.) and calibrated to NIST traceable standards at least annually.

8.4. Barometer. Aneroid or another barometer capable of measuring atmospheric pressure to within 0.1 in. Hg (2.5 mm Hg) with an uncertainty of +/- 0.05 in Hg (+/- 1.27 mm Hg).

8.5. Dilution Tunnel must meet the requirements of ASTM E2515, clauses 6.1.6 and 9.2.

8.6. Dilution Tunnel temperature and relative humidity measurement. A probe capable of measuring tunnel temperature to within 0.9 °F (0.5 °C)) and tunnel RH to within 2%, such as the Omega HX85-A or equivalent.

8.7. Draft Gauge. Electromanometer or other devices for the determination of flue draft or static pressure readable to within 0.005 in. H2O (1.2 Pa)

8.8. Flue Gas Temperature Measurement. A type K- thermocouple or equivalent located in the centroid of the stack located 8.0 +/- 0.5 ft (2.44 m +/- 150 mm) above the platform scale. Capable of measuring with an accuracy of 4.0°F (2.2°C) or 0.75% of reading, whichever is greater.

8.9. Flue Gas Composition Measurement. A sample probe and continuous infrared analyzer or equivalent capable of measuring span of carbon monoxide (CO) and carbon dioxide (CO_2) in the flue gas produced by the appliance tested. Continuous analyzers (or equivalent) shall have maximum zero and span drift, over a 24 h period, of 1% of full scale

8.10. Fuel Scale. Balance capable of weighing the test fuel charge to within 0.02 kg (0.05 lb.) and calibrated to NIST traceable standards at least annually.

8.11. Humidity Gauge. Psychrometer or hygrometer for measuring room humidity to within +/- 4% from 25 to 95% RH.

8.12. Moisture Meter. Calibrated electrical resistance meter for measuring test fuel moisture to within 2 percent moisture content.

8.13. Surface Temperatures. Capable of measuring temperature to within 1.5 percent of expected absolute temperatures with an accuracy of 4.0°F (2.2°C) or 0.75% of reading, whichever is greater.

8.14. Test Facility Temperature Monitor. A thermistor, RTD, or other equivalent device, located centrally in a vertically oriented 150 mm (6 in.) long, 50 mm (2 in.) diameter pipe shield that is open at both ends, capable of measuring temperature to within 1°F of expected temperatures.

8.15. TEOM – Thermo Fisher Scientific TEOM model 1405-D (Thermo part # 1405D-ANF, excluding models 1405, 1405-DF, or 1405-F) to measure and report continuous particulate matter (PM) measurements in an EPA Method 5G dilution tunnel or equivalent dilution method, and operated according to the Standard Operating Procedures detailed in Appendix A of this document.

9. Calibration and Standardizations

9.1. Anemometer. Calibrate the anemometer as specified by the manufacturer's instructions before the first certification test and monthly thereafter.

9.2. Appliance Platform Scale. Perform a multi-point calibration (at least five points spanning the operational range) of the platform scale before its initial use. The scale manufacturer's calibration results are sufficient for this purpose. Before each certification test, audit the scale with the wood heater in place by weighing at least one calibration weight (Class F) that corresponds to between 20 percent and 80 percent of the expected test fuel charge weight. If the scale cannot reproduce the value of the calibration weight within 0.0045 kg (0.01 lb.) or 1 percent of the expected test fuel charge weight, whichever is greater, recalibrate the scale before use with at least five calibration weights spanning the operational range of the scale.

9.3. Barometer. Calibrate using a reference pressure monitor calibrator before the first certification test and semiannually after

9.4. Draft Gauge. Calibrate as per the manufacturer's instructions; a liquid manometer does not require calibration (but must be properly leveled, zeroed and the system leak checked).

9.5. Humidity Gauge. Calibrate as per the manufacturer's instructions before the first certification test and annually thereafter.

9.6. Fuel Scale. Calibrate as described in 9.2.

9.7. Moisture Meter. Calibrate as per the manufacturer's instructions before the first certification test and semiannually thereafter.

9.8. Temperature Sensors. Calibrate using at least five points within operating range within specification and in compliance with NIST Monograph 175. To be calibrated before the first certification test and semiannually thereafter.

10. Sampling, Test Specimens, and Test Appliances

10.1. Modifications to EPA Method 5G requirements.

10.1.1. Liquid water should not be present anywhere in the sampling system for a valid sample. The presence of condensed water anywhere in the sampling system invalidates the test run. All data from all invalid test runs shall be included in the report. The reviewing authority shall make a final determination on invalidated runs. Data from any invalidated test run shall not be used to calculate results. If the testing agency believes a run has been invalidated, the test run shall be repeated.

10.1.2. Dilution tunnel temperature and relative humidity shall be measured electronically and logged at one-minute intervals near the sample probe to calculate dewpoint. The temperature measurement method shall have an accuracy of 0.5 degrees C (type T-Special TC or a RTD).

10.1.3. The following section details test conditions that shall be maintained for a valid test run. A valid test shall have no more than two individual deviations from any of the conditions below to remain a valid run. An example of an individual deviations is a single, five-minute rolling average where the dilution tunnel exceeded temperature thresholds. Another five-minute period exceeding the tunnel temperature requirement shall be considered a second deviation.

10.1.3.1. Tunnel temperature shall not exceed 104 deg. F (40C) based on five-minute rolling averages derived from one-minute data.

10.1.3.2. Tunnel relative humidity shall not exceed 90% based on five-minute rolling averages derived from one-minute data.

10.1.3.3. Tunnel dew point temperature shall be at least 2 deg. C less than filter temperature based on five-minute rolling averages derived from one-minute data.

10.1.3.4. A minimum tunnel flow of 500 CFM is required. Higher tunnel flows may be required to meet the parameters of 8.6.3.

10.1.3.5. All exceedances must be reported in the test anomalies section, even if deviations are within the test method tolerances.

10.2. Sample Collection. The following are required for sample collection:

10.3. Teflon coated glass fiber filters as supplied by the TEOM manufacturer for use with the TEOM model 1405-D. These are Pallflex Emfab (TX40) with an exposed diameter of 13 mm, without organic binder, exhibiting at least 99.95 percent efficiency.

10.4. *Test Specimens.* Appliances shall be supplied as complete systems, including all controls and accessories necessary for installation at the test facility. A full set of specifications, designs, and assembly drawings shall be provided when the product is placed under certification of a third-party agency.

10.5. *User Guide.* The manufacturer must supply a one-page user guide that will direct certain portions of the test protocol. The User Guide must be provided to the lab and the consumer as a single sheet and documented in the test report. The user guide shall be the only directions provided and used by the testing facility for certification purposes; it shall address key user operations for air controls and kindling loading, and it shall conform to the following requirements. Manufacturers are not allowed to direct or inform any portion of testing or deviate from operations specified in the User Guide, as the User Guide is the only information that can be used to inform appliance operation during certification testing. User Guide Layout Requirements – the User Guide shall conform to the following design specifications:

10.5.1. Directions must be illustrated by text and colored pictures

10.5.1.1. Font size – minimum font size is 12.

10.5.1.2. Use of columns allowed

10.5.1.3. Margins – must have a minimum of ¾" inch margins

10.5.1.4. A minimum of 40% of the user guide must use graphics or photos to support text directions.

10.5.1.5. Complete instructions but fit on a double sided of an 8 x11.5-inch sheet of paper

10.5.1.5.1.One side may be used to show tank setup and control settings

10.5.1.6. Must be provided in a laminated form to the consumer.

10.5.2. User Guide elements – The User Guide cannot contradict or deviate from user instructions provided in the appliance user manual. The User Guide shall include information on the following items.

10.5.2.1. Appliance preparation – what must be done to the appliance prior to starting a fire.

10.5.2.2. Appliance settings – Air settings and other necessary settings for combustion control

10.5.2.3.Fuel properties – what types of fuel and fuel moisture requirements are allowed for use in the appliance. The fuel properties detailed in the User Guide are for homeowner use, for certification testing, fuel requirements shall follow the protocols detailed in this method.

10.5.2.4. Start-up procedures – general guidelines for properly starting the appliance to include starting procedures.

10.5.2.5. Reloading procedures – If applicable, guidelines for properly reloading fuel once a fire has been started in the appliance.

10.6. Preparation of Apparatus

10.6.1. Wood Heater Installation for Certification Testing. Assemble the wood heater appliance and parts in conformance with the manufacturer's provided User Guide. These instructions must match all instructions materials developed by the manufacturer and/or their distributors. Place the wood heater on the platform scale and connect the chimney to the appliance. Clean the flue with an appropriately sized, wire chimney brush before initiating Run 1 of the certification test. Test documentation should include the date and time of flue cleaning.

10.6.2. Wood Heater Temperature Monitors.

10.6.2.1. For catalyst-equipped wood heaters, locate a temperature monitor (optional) about 25 mm (1 in.) upstream of the catalyst at the centroid of the catalyst face area, and locate a temperature monitor (mandatory) that will indicate the catalyst exhaust temperature. This temperature monitor is centrally located within 25 mm (1 in.) downstream at the centroid of the catalyst face area. Record these locations.

10.6.2.2. Locate wood heater surface temperature monitors at five locations on the wood heater firebox exterior surface. Position the temperature monitors centrally on the top surface, centrally on two sidewall surfaces, and centrally on the bottom and back surfaces. Position the monitor sensing tip on the exterior of the firebox surface inside of any heat shield, room air circulation walls, or other wall or shield separated from the firebox exterior surface. Surface temperature locations for unusual design shapes (e.g., spherical, etc.) shall be positioned so that there are four surface temperature monitors in

10.7. Conditioning

10.7.1. Wood Heater Aging Prior to Certification Testing. A wood heater of any type shall be aged at least 50 hours before initiating a certification test. The aging procedure shall be conducted by the manufacturer prior to sending the appliance to the testing laboratory. The certification lab cannot be involved with wood heater aging in any manner. The appliance shall be operated at a variety of burn rates. Documentation for wood heating aging must be included in the test report. The testing laboratory shall not conduct any firing of the appliance prior to conducting the certification test.

10.7.1.1. The manufacturer shall supply wood heater aging information for the final test reports. Aging data that shall be reported include all fuel parameters (species, moisture content, load weights, piece amounts, and size), air settings used, time spent in each air setting phase, amount of fuel burned, and appliance burn rates.

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10.7.1.2. If an appliance uses a catalytic combustor, it must be engaged according to the manufacturer's instructions and operate with the catalyst engaged for at least 50 hours during the break-in period. In addition to the reporting requirements listed in 8.1.1, catalytic appliances shall also report hourly catalyst exit temperature data to include the dates and hours of operation.

11. Procedure

11.1. Test Facility Conditions.

11.1.1. The test facility temperature shall be maintained between 55 and 90°F (13 and 32°C) during each test run.

11.1.2. The flue shall discharge into the same space or into a space freely communicating with the test facility. Any hood or similar device used to vent combustion products shall not induce a draft greater than 0.005 in. H_2O (1.25 Pa) on the wood heater measured when the wood heater is not operating.

11.1.3. For test facilities with artificially induced barometric pressures (e.g., pressurized chambers), the barometric pressure in the test facility shall not exceed 30.5 in. Hg (775 mm Hg) during any test run.

11.1.4. Locate the test facility temperature monitor on the horizontal plane that includes the primary air intake opening for the wood heater. Locate the temperature monitor 3 to 6 ft. (1 to 2 m) from the front of the wood heater in the 90° sector in front of the wood heater.

11.1.5. Use an anemometer, to measure the air velocity. Measure and record the room air velocity before the ignition period in L1 Startup and once immediately following the test run completion. Air velocities within 0.6 m (2 ft) of the test appliance and exhaust system shall be less than 0.25 m/sec (50 ft/min) without fire in the unit.

11.1.6. Measure and record the test facility's ambient relative humidity, barometric pressure, and temperature before and after each test run using equipment as specified in Section 6.

11.2. Wood Heater Firebox Volume.

11.2.1. Determine the firebox volume using the definitions for height, width, and length. Volume adjustments due to the presence of firebrick and other permanent fixtures may be necessary. All adjustments shall be detailed in the test report. Include areas adjacent to and above a baffle.

11.2.2. If a manufacturer deems certain areas of the firebox as unusable for fuel load calculations, written documentation stating the basis for that claim and supporting photographic image(s) must be provided and approved by the regulatory authority prior to conducting the certification test. If approval is not granted prior to the test, then the test may be invalidated if the reviewing agency determines the firebox volume is inaccurate.

THIS INTEGRATED-DUTY-CYCLE (IDC) PROTOCOL FOR WOOD STOVES IS THE PROPERTY OF THE NEW YORK STATE ENERGY RESEARCH AND DEVELOPMENT AUTHORITY (NYSERDA) AND CAN BE USED TO TEST TECHNOLOGIES IN A LABORATORY SETTING. ANY DEVIATIONS OR CHANGES TO THIS IDC PROTOCOL FOR WOOD STOVES ARE NOT APPROVED OR SANCTIONED BY NYSERDA.

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11.3. Test Fuel. The test fuel shall conform to the following requirements and meet specifications as required by the fuel loading calculator:

11.3.1. Fuel Species. Untreated, air-dried, cordwood fuel.

11.3.1.1.Allowable species: maple (big leaf, red, silver), oak (white), fir (Douglas), or white birch.

11.3.1.2.Kiln-dried fuel is not permitted.

11.3.1.3.Fuel shall be free of decay, fungus, or other contaminants.

11.3.2. Fuel Moisture.

11.3.2.1.Determine fuel moisture for each fuel piece by averaging four moisture meter readings, one from each of three sides, measured parallel to the wood grain.

11.3.2.2.The test fuel load shall have an average moisture content from 19% to 25%, wet basis.

11.3.2.3.Average individual piece moisture content shall have an average moisture content 18% to 27%.

11.3.2.4.The addition of moisture to previously dried wood is not allowed.

11.3.2.5.It is recommended that the test fuel be stored in a temperature and humidity-controlled room.

11.3.2.6.Fuel moisture shall be measured within 24 hours of using the fuel for the test and shall be stored in a humidity-controlled environment until 2 hours prior to testing.

11.3.3. Fuel Temperature. The test fuel shall be at the test facility temperature of 13 to 32°C (55 to 90°F).

11.3.4. Fuel Dimensions. The dimensions of each test fuel piece shall conform to definitions specified by the protocols using the fuel load calculator.

11.3.4.1.Fuel length:

11.3.4.1.1.The length of the fuel pieces will be determined by the fuel load calculator.

11.3.4.1.2.Measurements shall be taken, and the length of the test fuel will be determined by entering the firebox dimensions, which calculates the length for all the fuel pieces into a generally available commercial size (14, 16, 18, 20 or 22 inches in length).

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11.3.4.1.3.Piece length specified by the fuel calculator shall be communicated and specified for use in the owner's manual and website. Piece size shall be within 0.5" of the log length determined by the calculator, as measured on the shortest length measurement.

11.3.5.Fuel Loading Direction

11.3.5.1.Fuel loading direction shall be determined by the firebox measurement.

11.3.5.1.1.Stoves with a depth measurement greater than two inches from the width measurement shall be tested with the fuel in a north-south configuration and may not test with fuel in an east/west or crisscross configuration in any load other than Load 1 and Load 2.

11.3.5.1.2.Stoves with a width measurement greater than the depth measurement or a width measurement within two inches of the depth measurement shall be tested with the fuel loaded in an east-west configuration and may not test with fuel in a north/south configuration or crisscross configuration in any load other than Load 1 and Load 2.

11.3.6.Fuel piece weight for each phase of the protocol shall be determined by the fuel load calculator.

11.3.6.1.Kindling –shall be:

11.3.6.1.1.pieces of wood less than or equal to 1" in diameter.

11.3.6.1.2.No bark requirements for kindling fuel

11.3.6.1.3.Fuel species may be any species allowed in 7.2.1.1.

11.3.6.1.4.No moisture requirements.

11.3.6.1.5.Length of kindling shall be the fuel length specified by the fuel load calculator.

11.3.6.1.6.Kindling fuel shall conform to the rule that 7 to 12 pieces of kindling equal 1 pound of kindling fuel (+/- 10%).

11.3.6.2. Starter fuel: pieces of cordwood shall be used during the startup phase. Individual piece weight for starter fuel shall be determined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall be not be used in testing (see Figure 1). Pieces that have squared cross sections shall be split to represent the typical triangle nature of wood (see Figure 2).

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11.3.6.3. Small fuel pieces: smaller pieces of cordwood by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall not be used (see figure 1). Pieces that have square cross-sections shall be split to represent the typical triangle nature of wood (see Figure 2).

11.3.6.4. Large fuel pieces: larger pieces of cordwood, by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in cross-section. Square pieces shall be not be used (see figure 1). Pieces that have square cross sections shall be split to represent the typical triangle nature of wood (see Figure 2).

Figure 1. Schematic of unacceptable cross-sectional profiles

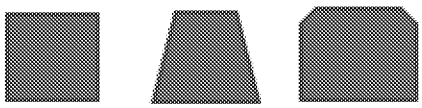
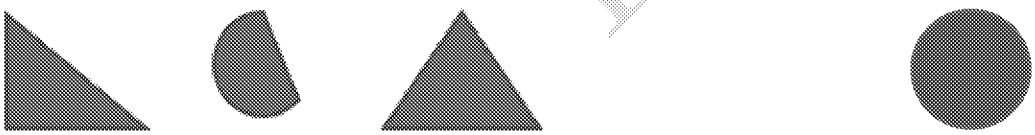


Figure 2. Schematics of acceptable cross-sectional profiles



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11.4. Sampling Equipment.

11.4.1. Prepare the PM and ambient sampling equipment as defined by the TEOM Protocol.

11.4.2. Prepare all other equipment as defined by method EPA Method 1, 2, 3, 4 and 5G.

11.5. Manufacturer participation in certification testing

11.5.1. A representative of the manufacturer may observe testing but may not provide instructions to the certification lab, in any form, with testing staff or equipment once the certification tests begin. The names of testing witnesses cannot be withheld as confidential business information (CBI).

11.6. Test Run Procedure.

11.6.1. Before each test series, the firebox shall be vacuumed. Testing shall begin without any ash or other materials in the appliance.

11.6.2. Before initiating the compliance test, clean the flue and dilution tunnel with an appropriately sized wire chimney brush before each certification test. Test documentation should include the date and time of flue cleaning.

11.6.3. Record fuel weight data, temperature measurements, and gas concentrations at 1-minute intervals.

11.6.4. Wood Heater Operation and Adjustments. Record all adjustments made to the air supply controls, adjustments to and additions or subtractions of fuel, and any other changes to wood heater operations that occur during the test period.

11.6.5. The weight of fuel remaining at the end of the test run is determined as the difference between the weight of the wood heater with the remaining coals and fuel and the weight after loading the fuel charge. The starting weight is the tare weight of the cleaned, dry wood heater.

11.6.6. All runs shall be videotaped in their entirety. Video tape shall be of sufficient quality to determine fuel characteristics, fuel loading procedures, and firebox conditions during any testing or aging conducted by the test lab. The testing lab shall have the capacity to allow appropriate agencies the opportunity to remotely witness the test.

11.6.7.L1: Start-up Phase.

11.6.7.1.L1 Appliance requirements.

11.6.7.1.1. Stove temperature: internal and external stove temperature must not be greater than the ambient temperature +/- 2˚F (1.1˚C) for Run 1. There is no stove starting temperature requirement for Runs 2 and 3 except in the case of a failed first run. In this case, if Run 1 is invalid or incomplete and, the stove must meet Run 1 conditions for at least one valid run. Temperature measurements for the external and internal temperatures shall be taken within 15 minutes before starting the test and shall be reported in the test report.

11.6.7.1.2. Tare the appliance scale before starting the test. Record appliance scale weights at the start and end of L1 phase

11.6.7.2.L1 Fuel requirements.

11.6.7.2.1.L1 Fuel type – during the startup phase newspaper (optional up to six full sheets traditional newspaper size), kindling, and starter fuel pieces are used. No other additions are allowed.

11.6.7.2.2.L1 loading density

11.6.7.2.2.1.Kindling loading density: 1 lb. per cubic foot for dry kindling, +/- 5%. The fuel load calculator determines the amount of kindling that can be used.

11.6.7.2.2.2.Starter Fuel loading density: 3 lb. per cubic foot, +/- 5%. The fuel load calculator will determine the minimum piece weight that can be used as starter fuel.

11.6.7.2.3.L1 fuel loading structure: The loading structure of the fire shall be a bottom-up configuration with newspaper on the bottom, kindling on top of the paper, and starter fuel on top of the kindling. Kindling and starter fuel shall be loaded in a crisscross configuration.

11.6.7.3.L1 Operational parameters.

11.6.7.3.1.All kindling, starter fuel, and newspaper must be in the firebox for light off.

11.6.7.3.2.Air settings are fully open.

11.6.7.3.3.Light the fire with a torch for a period of no more than 30 seconds.

11.6.7.3.4.Immediately after lighting the fire and completing the photo requirement, the appliance door shall be moved to a cracked open position. Cracked open position is defined as opening no more than one inch. The appliance door shall be closed 5 minutes after ignition.

11.6.7.4.L1 Fuel Adjustments: up to three fuel adjustments are allowed in the startup phase. The door may be open for 30 seconds during each fuel adjustment.

11.6.7.5.L1 End of Phase – the end of the startup phase is defined by the weight specified by the fuel load calculator.

11.6.7.6.L1 Photo documentation – Clear, close-up pictures shall be documented with individual pictures that must be included in the test report sufficient to determine fueling positioning and coal bed conditions.

11.6.7.6.1.Picture(s) of the air setting before light-off

11.6.7.6.2.Picture(s) of the air setting at the end of L1 phase

11.6.7.6.3.Picture(s) fuel loaded in the stove prior to light-off

11.6.7.6.4.Picture(s) fuel just after light-off but prior to door cracked open period.

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11.6.7.6.5.Picture(s) of the coal bed at the end L1 phase

11.6.8. *L2: High-fire Phase* – the high-fire phase commences immediately after the startup phase ends.

11.6.8.1.L2 Appliance requirements.

11.6.8.1.1.Record the weight of the stove prior to loading the L2 fuel charge, the weight of the fuel charge prior to loading, and the scale weight after loading the L2 fuel charge.

11.6.8.2. L2 Fuel requirements.

11.6.8.2.1. L2 piece size – during the high-fire phase, small cordwood pieces by weight, as defined by the fuel load calculator, are used.

11.6.8.2.2. L2 loading density: 7 lb. per cubic foot, +/- 5%. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.8.3.L2 Operational parameters: Open the door upon completion of the startup phase and load the L2 fuel load within 60 seconds. Once the fuel has been loaded, the appliance doors shall be closed immediately. Air settings shall be left fully open. When 50% of the L2 fuel load mass has been consumed, the air settings shall be moved to the lowest settings.

11.6.8.4.L2 Fuel Adjustments.

11.6.8.4.1.One fuel adjustment shall be made during the high-fire phase prior to moving the primary air control(s) to their lowest setting. The door shall remain open for 30 seconds for fuel adjustments.

11.6.8.4.2.Additional fuel adjustments shall be made if there is a five-minute period without a weight change at any point during the high-fire phase. The door may only be open for 30 seconds for fuel adjustments.

11.6.8.4.3.All fuel adjustments must be documented in the test report notes and summary.

11.6.8.5.End of L2 Phase –The high-fire phase ends when the scale indicates that 90% of the high-fire fuel mass has been consumed.

11.6.8.6. L2 Photo documentation

11.6.8.6.1.Picture(s) of the L2 loaded into the stove with the door open and fuel loading pattern distinguishable.

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11.6.8.6.2. Picture(s) of the air settings at the beginning of the L2 phase

11.6.8.6.3.Picture(s) of the air setting after 50% fuel consumption

11.6.8.6.4.Picture(s) of the air settings at the end of the L2 phase.

11.6.8.6.5.Picture(s) of the coal bed at the end of L2 phase.

11.6.8.6.6.Pictures before and after L2 fuel adjustments.

11.6.9. *L3: Maintenance-fire Phase* – the L3 maintenance-fire phase commences immediately after the L2 high-fire phase ends.

11.6.9.1.L3 Appliance Requirements.

11.6.9.1.1. Record the weight of the stove prior to loading the maintenance-fire fuel charge, the weight of the fuel charge prior to loading, and the scale weight after loading the maintenance-fire fuel charge.

11.6.9.2.L3 Fuel Requirements.

11.6.9.2.1.Fuel type – during the L3 phase, large cordwood pieces are used. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.9.2.2.L3 fuel loading structure: fuel shall be loaded in the direction specified by the fueling calculator.

11.6.9.2.3. L3 loading density: 5 lb. per cubic foot, +/- 5%. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.6.9.3. L3 Operational Parameters:

11.6.9.3.1.Open door upon completion of the L2 phase and load the maintenance-fire fuel charge.

11.6.9.3.2.L3 Load - L3 fuel loaded within 30 seconds of the door opening. Close the loading door immediately.

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11.6.9.4. L3 Fuel Adjustments: If there is a fifteen-minute period without weight change at any point during the L3-fire phase, a fuel adjustment shall be made to increase the burn rate. The door may be open for up to 30 seconds for fuel adjustments.

11.6.9.5.L3 End of Phase – The L3-fire phase ends when the scale indicates that 90% of the maintenance-fire fuel mass has been consumed.

11.6.9.6.L3 Photo documentation

11.6.9.6.1.Picture(s) of the L3 loaded into the stove with the door open and fuel loading pattern distinguishable.

11.6.9.6.2. Picture(s) of the air settings at the beginning of the L3 phase

11.6.9.6.3.Picture(s) of the air settings at the end of the L3 phase.

11.6.9.6.4.Picture(s) of the coal bed at the end of L3 phase.

11.6.9.6.5.Pictures before and after fuel adjustments in L3.

11.6.10.*L4: Low burn rate phase* – L4 phase commences immediately after the L3- ends.

11.6.10.1.L4 Appliance Requirements.

11.6.10.1.1.Record the weight of the stove prior to loading the L4-fire fuel charge, the load of the fuel charge prior to loading, and the scale weight after loading the overnight-fire fuel charge. Alternatively, if the scale was zeroed prior to starting the test, record the scale weight before and after loading the overnight-fire fuel charge.

11.6.10.2.L4 Fuel requirements

11.6.10.2.1. L4 fuel type –a mix of small and large cordwood pieces are used. At least 50% of the fuel charge load, by the number of pieces, must be large pieces.

11.6.10.2.2.L4 Loading structure: fuel will be loaded in one direction.

11.6.10.2.3.L4 loading density: The fuel load calculator specifies a load volume of 12 lb/ft^3 .+/-5%. Fuel shall be loaded in a manner to maximize the number of pieces that will fit in the stove without using force.

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11.6.10.3. L4 Operational Parameters:

11.6.10.3.1. Open the loading door upon completion of the L3 maintenance-fire phase.

11.6.10.3.2.Load the L4 fuel charge within two minutes (120 seconds).

11.6.10.3.3.Keep the door in the 1" cracked position for five minutes from the beginning of the L4 phase.

11.6.10.3.4.Air controls shall be placed in the fully open position for the first ten minutes of the phase.

11.6.10.4.L4 Fuel Adjustments.

11.6.10.4.1.Unlimited fuel adjustments are allowed within the first five minutes of the phase. After ten minutes, air control(s) shall be moved to their lowest position. A picture of the air setting used must be included in the test report. The door may be open for up to 30 seconds for fuel adjustments.

11.6.10.5.L4 End of Phase – The L4 phase shall end when the scale indicates that 90% of the total L4 fuel mass has been consumed.

11.6.10.6.L3 Photo documentation

11.6.10.6.1.Picture(s) of the L4 loaded into the stove with the door open and fuel loading pattern distinguishable.

11.6.10.6.2. Picture(s) of the air settings at the beginning of the L4 phase

11.6.10.6.3.Picture(s) of the air settings at the end of the L4 phase.

11.6.10.6.4.Picture(s) of the coal bed at the end of L4 phase.

11.6.10.6.5.Pictures before and after fuel adjustments in L4.

11.6.10.7.L4 Photo documentation

11.7. Test Run. A complete test run requires completion of all four burn phases and loads. For any appliance that will not accommodate the loading arrangement specified in this test method, the test facility personnel shall contact the Agency Administrator to obtain written approval for an alternative loading arrangement:

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11.8. Test Run Requirements. The following describes the required parameters for each test run. Each emission test run shall include all phases of the operational and fueling protocol run in order as described.

11.8.1. Consecutive Test Runs. Consecutive test runs may be conducted, provided that the following requirements are met:

11.8.1.1. Run 1 – The appliance shall have an internal and external starting temperature within +/- 2 °F (1.1°C) of laboratory ambient temperature at the beginning of Run 1

11.8.1.2. Run 2 – The second test run may commence 24 hours after the start of Run 1. Stove coals and ash can remain in the stove until 1 hour before conducting Run 2. All coals and ash shall be removed at least one hour prior to commencing Run 2.

11.8.1.3. Run 3 – The third test run may commence 24 hours after the start of Run 2. Stove coals and ash may remain in the stove until 1 hour before conducting Run 3. All coals and ash shall be removed at least one hour prior to commencing Run 2.

11.9. *Failure to Operate at All Test Conditions*

11.9.1. If the appliance fails two runs due to incomplete test runs, it shall be determined that the appliance has failed the certification test and requires a modification to appliance design. All data for incomplete runs shall be reported. Incomplete failed test runs are defined as the following:

11.9.1.1. If a wood heater fails to complete all four phases of the test run, the run shall be considered a failed test run.

11.9.1.2. If there is no weight change for a consecutive period of 30 minutes at any point during the test, the unit has failed the test run.

11.9.1.3. If the wood heater fails to comply with test protocol parameters

11.9.2. If a test run violates the parameters of the test method, the run is invalid.

11.9.3. If during certification testing a critical component of the stove is damaged or breaks, the certification test will be stopped and considered invalid.

11.9.3.1. If damage is noted during a test, repairs shall be made by the manufacturer (or by laboratory personnel with written direction from the manufacturer). If the repair involves components that would need aging, the appliance shall then undergo another round of wood heater aging as specified in section 10.7. These components may include but are not limited to catalyst elements, gaskets, and refractory components. The aging process is intended not only to 'cure' the stove but

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also to cycle parts that may fail with extended use. Alternate aging techniques may be approved by the administrator, depending on the nature of the failure, material, and critical nature.

11.10. Test Run Completion. Once three valid runs have been completed, the testing is complete. No additional runs may be completed.

11.10.1. *Additional Test Runs*. If there is an invalid run, may attempt two additional runs to complete the test series. If more than three test runs are conducted, the results from all valid test runs shall be used in calculating the average emission rate. The measurement data and results of all test runs shall be reported regardless of which values are used in calculating the emission rate. No test run data can be eliminated from the reporting requirements of this method.

11.11. Auxiliary Wood Heater Equipment Operation. If optional heat exchange blowers are sold for use with the wood heater, three runs without the fan and an additional run with the fan shall be completed. If emissions are more than 1 gram per higher with the fan on, an additional two runs must be completed with the fan on. Heat exchange blowers shall operate in the highest airflow setting. (Automatically operated blowers shall be operated as designed) during the entire test.

11.12. PM Data Recording.

11.12.1. All data shall be collected and recorded at intervals of no more than 1 minute. TEOM data shall be averaged up to 1-minute intervals for reporting. TEOM operation shall follow the procedures listed in Appendix A.

11.12.2. Data shall be reported in an Excel or compatible spreadsheet following the minimum data reporting requirements. All electronic files shall be submitted as part of the test report. Spreadsheet files shall be supplied as part of the publicly available test report.

11.12.3. Room PM measurement – TEOM. A TEOM shall be used to measure ambient lab air PM during the test, as configured in NESCAUM's TEOM SOP. The sample flow shall be 2 LPM

12. Quality Control Measures

12.1. Dilution tunnel - Conduct sampling equipment leak check and calibration pre- and post-test.

12.2. TEOM – Flow and Leak checks are done before and after every test run per the TEOM SOP.

12.3. Volume Metering System Checks.

13. Data Analysis and Calculations. –

13.1. Emission Calculations. Particulate matter, carbon dioxide, and carbon monoxide shall be calculated using the following methodology and reported in grams per hour, grams per kilogram and pounds per million British Thermal Unit (BTU) heat output. All calculations shall be conducted using all decimal values provided by the instrumentation or recorded by the operator. No truncation of data is acceptable. Only the final calculation of the PM emissions rate shall be rounded, to three significant figures.

13.2. TEOM data shall be reported as follows.

13.2.1. Emissions from each of the 4 phases of the test shall be reported as individual results in grams per hour, grams per kilogram, and lb/MMBtu (heat output).

Emissions from the entire test run in grams per hour, grams per kilogram, and lb/MMBtu (heat output).

Nomenclature

AER = Ei/∑N
BR – average dry fuel burn rate, lb./min
$BR_{(x)}$ – Burn rate for specific phase, BR_{L1}, BR_{L2}, BR_{L3}, BR_{L4}
CO – Carbon Monoxide
CO_2 – Carbon Dioxide
H_2- Hydrogen
O_2 – Oxygen
BT = time of 90% of overnight load consumed – time of overnight loading
C_{steel} – Specific heat of steel (0.1 Btu/ lb., °F)
E_T – Total particulate emissions for the full test run in grams
$E_{g/MJ}$ – PM Emissions rate in grams per megajoule of heat output
$E_{g/kg}$ – PM Emissions factor in grams per kilogram of dry fuel burned
$E_{g/hr}$ – PM Emissions factor in grams per hour
E_{Rco} – CO emission rate, g/hr.
EIi – Average CO emission index for interval i
E_{ICO} – CO emission index, g/kg dry fuel
EIco,avg – Average CO emission index for the run
HHV – Higher heating value of fuel = Use accredited test results
LHV – Lower heating value of fuel = Use accredited test results
$\%M_d$ = Fuel moisture content, dry basis, percent.
$\%M_w$ = Average moisture in test fuel charge, wet basis, percent
N = Total number of test runs.
PCTCO2– average CO_2 in the dry flue gas (%)
PPMco -average CO in the dry flue gas (ppm)
Q_{out} – Total heat output in BTU's (megajoules)
SC_i – Scale weight at specific time interval, lb.

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$t_{(i)}$ – Data sampling interval in minutes
T1 – Surface Temperature 1 ˚F (˚C)
T2 – Surface Temperature 2 ˚F (˚C)
T3 – Surface Temperature 3 ˚F (˚C)
T4 – Surface Temperature 4 ˚F (˚C)
T5 – Surface Temperature 5 ˚F (˚C)
T6 – Pre Catalyst Temperature 1 ˚F (˚C)
T7 – Post Catalyst Temperature 2 ˚F (˚C)
T8 – Tunnel Temperature ˚F (˚C)
T9 - Flue Gas Temperature ˚F (˚C)
T10 – Room Temperature ˚F (˚C)
$TS_{avg(i)}$ – Initial Average Surface Temperature ˚F (˚C)
$TS_{avg(f)}$ – Final Average Surface Temperature ˚F (˚C)
W_{fuel} – Fuel charge weight in pounds (kg)
W_i – Weight of fuel in pounds (kg)
W_{app} – Weight of empty appliance in pounds (kg)
Θ – Total length of test run, hours
$\Theta_{(x)}$ – Total length of test run in hours per phase, X
$\%M_w = 100(\%M_d)/100+\%M_d$

13.3. Average Wood Heater Surface Temperatures. Calculate the average of the wood heater surface temperatures at the start of the phase (L4) and end at the end of the test (L4) of the test run.
L4 $TS_{avg(i)} = (T1 + T2 + T3 + T4 + T5) / 5$
L4 $TS_{avg(f)} = (T1 + T2 + T3 + T4 + T5) / 5$
Average surface temperatures at the start and end of any phase can be determined by averaging all five sensors at the beginning and end of each phase.
L_x $TS_{avg(i)} = (T1 + T2 + T3 + T4 + T5) / 5$
L_x $TS_{avg(f)} = (T1 + T2 + T3 + T4 + T5) / 5$

13.4. Burn Time Rating– A standardized burn time rating shall be determined by rounding the duration of the overnight-fire phase of the test up to the nearest 1 hour. Burn time shall be calculated as the time L4 is loaded into the stove until 90% of the fuel has been consumed. This provides an important rating for consumers and is not intended for any calculation purposes and shall be reported on the all manufacturers materials that provides specifications on appliance performance. Language such as "this stove has demonstrated a low setting burn time of x hours in official testing"

13.5. Determine Burn Rates

BR_{L1} = not applicable
BR_{L2} = (L2 Initial SC_i – L2 Final SC_i) / $\Theta_{(L2)}$, lbs./hr
BR_{L3} = (L3 Initial SC_i – L3 Final SC_i) / $\Theta_{(L3)}$, lbs./hr

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BR_{L4} = (L4 Initial SC_i – L4 Final SC_i) / $\Theta_{(L4)}$, lbs./hr

13.6. Emissions

13.6.1. Determine emission rates and emission factors as:

$E_{g/MJ} = E_T/(Q_{out} \times 0.001055)$, g/MJ

$E_{g/kg} = E_T/(W_{fuel}/(1+M\%M_d/100))$, g/dry kg

$E_{g/hr} = E_T/\Theta$, g/hr

13.7. Efficiency calculation.

Ultimate Analysis of dry fuel (% by weight)

Carbon – CA

Hydrogen – HY

Oxygen – OX

Moisture Content – mass of water per mass of dry fuel – Mcdb

Ambient Humidity Ratio – mass of water per unit mass of dry air – ω

Flue gas temperature (F) – Ts

Room temperature (F)-Tr

CO in the dry flue gas (ppm) – PPMco

CO2 in the dry flue gas (%) – PCTCO2

Higher heating value of the dry fuel (lb/MMBtu) – HHV

Combustion Balance Equation:

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

Where:

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4] excess air parameter, e.g. if [EMBED Equation.DSMT4] 0.5 there is 50 % excess air

From this:

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[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

With flue gas CO and CO_2 measured, these two equations can be solved simultaneously for [EMBED Equation.DSMT4] and [EMBED Equation.DSMT4].

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4]

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Calculation of the Molar Coefficient for Each of the Products

For the assumption of 100 kg of dry fuel, this is the number of moles of each product for the input conditions

[EMBED Equation.DSMT4] Molar Coefficient for CO

[EMBED Equation.DSMT4] Molar Coefficient for CO_2

[EMBED Equation.DSMT4] Molar Coefficient for H_2O

[EMBED Equation.DSMT4] Molar Coefficient for O_2

[EMBED Equation.DSMT4] Molar Coefficient for N_2

Heat Capacity of Exhaust Products

The general equation for representing how the heat capacity of the exhaust products varies with temperature is:

[EMBED Equation.DSMT4]

Where:

C = heat capacity J/mol K or kJ/kgmol K

A and B are constants

Tk = Temperature in °K

The values for A and B for the exhaust components are provided in the table below

Component	A	B
CO	.0056	27.162
CO2	.029	29.54
H2O	.0057	32.859
O2	.009	26.782
N2	.0062	26.626

For each component, heat capacity is calculated at the stack temperature and at room temperature. The average of these is used to calculate sensible heat loss.

<u>Calculation of Heat Losses for Efficiency Determination</u>

[EMBED Equation.DSMT4] Higher heating value in kJ/kg (conversion from Btu/lb)

[EMBED Equation.DSMT4] Latent heat of water vapor in kJ/kgmol

[EMBED Equation.DSMT4] Heat loss in latent heat of water vapor, % of input energy

[EMBED Equation.DSMT4] Heat loss in chemical energy in CO, % of input energy

[EMBED Equation.DSMT4]

[EMBED Equation.DSMT4] Heat loss in sensible heat in flue gas, % of input energy

[EMBED Equation.DSMT4] Stack loss efficiency, %

14. Reporting Requirements. The report shall include the following:

14.1.1.Introduction

14.1.2.Purpose of test: certification, audit, efficiency,

14.1.3.Name and location of the laboratory conducting the test.

14.1.4.Wood appliance identification – manufacturer, model number/name, design type, description of the appliance tested, stove condition, and date of receipt.

14.1.5.Test information – location of testing, date of tests, sampling methods used, number of test runs,

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a statement detailing any previous certification testing completed on the wood appliance.

14.1.6. A list of people who conducted research on the appliance, participated in testing preparation, or witnessed the certification testing. This list shall clearly specify their roles in the testing program for the appliance. The list shall include the participant's name, title, company, contact information and the purpose of their participation.

14.1.7. A statement that the test results apply only to the specific appliance tested.

14.2. Summary and Discussion of Results

14.2.1. Table of results to include test run number, average burn rate for entire run and each phase, carbon monoxide and particulate emission rate for full run, particulate and carbon monoxide emission rate for each load phase (L1, L2, L3, L4), efficiency for the full run and each phase, burn time for total run and each phase.

14.2.2. For each test run use the TEOM data and use real-time gas analyzer data for other emissions to report: Θ_1,Θ_2, Θ_3, CO, CO_2, PM, and efficiency for (1) L1 - the startup phase and (2) L2 - high-, (3) L3-maintenance-, and (4) L5 low burn rate fire phases. Calculated results for the emissions shall be reported as total emissions in grams, pounds per million Btu output, grams per MJ, grams per kilogram of dry fuel and grams per hour, and pounds per hour.

14.2.3. A narrative discussion detailing any issues or anomalies that arose during each test run and how those were handled, including comments about the fuel, and loading of the appliance.

14.2.4. A plot of CO emission rate in ppm vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.5. A plot of CO_2 emission rate in ppm vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.6. A plot of PM emission rate in grams/hour vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.7. A plot of PM emission rate in g/kg vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.8. Summary of other data – test facility conditions, surface temperature averages, catalyst temperature averages, pretest fuel weights, test fuel charge weights – total and by phase.

14.3. Discussion. Test run result, specific test run problems and solutions. Comments on fuel, loading, analysis, and anything that may impact the reported result(s).

14.3.1. Details of deviations from, additions to or exclusions from the test method, and their data quality implications on the test results (if any), as well as information on specific test conditions, such as environmental conditions. An explanation of the deviations, additions, or exclusions shall be provided along with an analysis as to why these elements had no impact.

14.4.Process description:

14.4.1.Data and drawings indicating the firebox size and location of the fuel charge.

14.4.2.Drawings and calculations used to determine firebox volume to include volume, height, width, and lengths, weight, and volume adjustments.

14.4.3.Firebox configuration – At a minimum to include air supply locations and operation, air supply introduction location, refractory location and dimensions, catalyst location, baffle and by-pass location and operation (include line drawings or photographs)

14.4.4.Appliance operation during the test – shall supply details on air supply settings and adjustments.

14.5.Test fuel properties – the report shall provide information on the species, density, fuel moisture, fuel temperature, and load details from the fuel load calculator to include all measurements including the number of pieces, individual piece weights, piece length, moisture content and weight.

14.6.Sampling

14.6.1.A description of the test procedures and test equipment, including a schematic or other drawing showing the location of all required test equipment. Also, a description of test fuel sourcing, handling and storage practices shall be included.

14.6.2.Describe the sampling location relative to the wood heater, include drawing or photographs.

14.6.3.Provide data on sampling blanks.

14.7.Quality Control and Assurance Procedures

14.7.1.Calibration procedures and results certification procedures, sample and analysis procedures.

14.7.2.Test method quality control procedures to include TEOM leak and flow checks, stratification (velocity) checks, tunnel flow range results, filter temperature range verification and dilution tunnel RH verification.

14.8.Appendices

14.8.1.Results and Example Calculations. Raw data and complete calculations for data included in summary tables.

14.8.2.Raw data. Copies of all files or sheets for sampling measurement, temperature records, and other materials used by lab related to testing.

14.8.3.Calibration Results. Summary of all calibrations, check, and audits pertinent to the certification.

14.8.4.Sampling and Operation Records. Copies of all uncorrected records of activities not included in raw data sheets (e.g., wood heater door open, times and durations) as well as photographs of fuel loading and air flow settings.

14.8.5.Correspondence. Any correspondence to include written, electronic or verbal communications regarding appliance testing. Items shall include:

14.8.5.1.Request to conduct testing

14.8.5.2.Scheduling of testing

14.8.5.3. Notice to EPA to conduct test, and any modifications to that request.

14.8.5.4. Notice and submission of data to EPA after testing completed.

14.8.6. Test Facility Information. Report test facility temperature, air velocity, and humidity information.

14.8.7. Test Equipment Calibration and Audit Information. Report calibration and audit results for the platform scale, test fuel balance, test fuel moisture meter, and sampling equipment including volume metering systems and gaseous analyzers.

14.8.8. Pretest procedures. Report all pretest procedures conducted at the lab on the appliance to burns, rates, and amounts.

14.8.9. All required data for each test run shall be provided in spreadsheet format both in the printed report and in a computer file such that the data can be easily analyzed and calculations easily verified. Formulas used for all calculations shall be accessible for review.

14.8.10. For each test run: report TEOM flow and temperature and verification of all TEOM data validation parameters as required in the TEOM 1405-D SOP.

14.8.11. Raw data, calibration records, and other relevant documentation shall be retained by the laboratory for a minimum of 7 years.

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Integrated Duty Cycle Fuel Calcula

Last updated of the tool: 12/18/2020

Link to download the latest version:

Start a New Calcu

Go to the Last S

Start a New Calcu

Instruction:

1- Color Codes and Cells Lock

In this tool, the user can only select and change the content of pre-determined cells. If a cell cannot b designated to be changed by the user.

There are four main levels of color coding to help the user navigate through the tool easier:

(A) White cells with black font: these cells are either a parameter name, a parameter unit, a fixed for information about the table. The user cannot change the content of these cells directly. For example, be edited directly by the user:

Firebox volume:	3.361	ft^3

(B) Green background cells with blue font: these cells are designed to accept necessary input data by these cells are empty they will turn into yellow, meaning that data is required to be entered by the us background is green but the font is black it means the data is NOT required and the cell can be left en width, depth and height are necessary data fields but the Volume adjustment is not necessary. There cells are yellow and the volume adjustment cell is green when they are empty. After entering valid da color in the three first cells turn blue:

1.2 Firebox Information		
Firebox width:		in.

1.2 Firebo
Firebox width:

tor

ulation for a Stove

Saved Calculation

ulation for a Boiler

be selected it means it is not

mula, or some sort of
, non of these three cells can

the user. If the content of
ser. However, if the cell
mpty. For example, firebox
fore, the firebox dimension
ata into all cells, the font

x Information

14.0	in.

Firebox depth:		in.
Firebox height:		in.
Volume adjustment:		ft^3
Firebox volume:		ft^3

Firebox depth:
Firebox height:
Volume adjustment:
Firebox volume:

(C) Yellow background cells: these cells are missing data that is required. Yellow background cells are locked and cannot be directly edited, and the second type can be edited directly by the user. In the p front of the "Firebox volume" cell is the one that cannot be directly selected and edited. Rather, it ge because there is a formula in it. To change the value in it, the user should enter data in other yellow c the user set the width, height, and depth of the firebox, the volume cell gets updated and it turns wh

(D) Red background cells with yellow font: The red color of these cells is a warning that the number is and it should be modified either directly or indirectly (by changing the cells that participate in the for following table for Load 3 the "Load total" weight is red because it is higher than the allowable limit. change the total load value. Rather, she should change the value of each piece weight to make the "L range:

set the # of logs	Weight (lb)
Piece 1:	5.00
Piece 2:	5.00
Piece 3:	6.00
Load total:	16.00

set the # of logs	
Piece 1:	
Piece 2:	
Piece 3:	
Load total:	

In addition to the above color coding, there are white background cells with gray front that show hel

Load total:	16.20
	↑↑ Remove some fuel pieces or use lighter logs to reach the target weight :11.00~1
	Allowed weight of each piece: 1.00~2.26 lb

2- Starting a new calculation

2.1 To start a fresh and new fuel calculation for a stove testing click on "Start a new Calculation for a starting a new calculation all previous calculations and data will be DELETED WITHOUT UNDO. Theref calculation make sure you have made a copy of the spreadsheet to save your previous data. Preparin calculation may take several minutes.

2.2 After the tool is re-started, it will proceed to the '1-Stove' tab. In this tab the user is required to fi firebox dimensions, and test lb information. The firebox dimensions should be between 0-40 inches a value cannot be more than 1 cubic feet. After entering data, click on "Next >>" button at the bottom- proceed to the "2- Fuel Load" tab.

2.3 In the Fuel Load tab there is only one parameter to enter: Wood Species. The user can select one from the drop-down list. With each selection the wood density and all load piece details will be upda selecting the wood species, click on "Next >>" to show 4 new tabs for run details.

2.4 There are four identical and independent run details tab in this tool. Each tab contains 12 tables t The first set of tables (Table 3.1 through 3.6) are designed to enter details of wood pieces in each loa information the first step is to enter the number of pieces for each load in the last column (Actual # o

16.5	in.
18.0	in.
0.200	ft^3
2.206	ft^3

two types: the first type are
revious example the cell in
ts updated automatically
cells. In this example when
ite.

s out of the allowable range
mula). For example, in the
But user cannot directly
oad total" fall in the correct

Weight (lb)
5.00
5.00
5.10
15.10

pful information to user:

2.15 lb

Stove" in this tab. NOTE: by
ore, before starting a new
g the tool for a new

ll in stove information,
and the volume adjustment
right corner of the tab to

of the four wood species
ted automatically. After

o enter details of the run.
d. To start entering
f pieces) in Table 3.1:

Enter the number of fuel pieces first, then enter the weight and MC details in Tables 3.2 through 3.6 .

3.1 Fuel Load Data

	Target load (lb)	Actual weight (lb)	Allowed # of pieces	Actual # of pie
L1 - Kindling weight	2.75 – 3.04		20	20
L1 - Starter	8.25 – 9.12		6	5
L2 - Small pieces	19.24 – 21.27		6	6
L3 - Large pieces	13.75 – 15.19		2	2
L4 - Small pieces	11.00 – 12.15		4	3
L4 - Large pieces	21.99 – 24.31		4	4

For each load a separate table is designed in the tab that can be reached either by scrolling down or b
link.

Notice: In the load tables (Tables 3.2 through 3.6) the number of pieces cannot be changed. To add o
use the "Actual # of pieces" column in Table 3.1

By entering the actual number of pieces in Table 3.1, the tool will automatically make the correct nur
corresponding t

3.3 Load 2 - Small pieces

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)	pin 3 (%)	pin 4
Piece 1:					
Piece 2:					
Piece 3:					
Piece 4:					
Piece 5:					
Piece 6:					
Piece 7:					
Piece 8:					
Piece 9:					
Piece 10:					
Load total					

⚠ Add more fuel pieces or use heavier logs to reach the target weight. 19.24–21.27 lb
Allowed weight of each piece: 2.29–4.53 lb

In each row of the load detail table, the user should enter weight and four MC pin readings in the cor
weight, average moisture of each piece, and final weighted average moisture will update automatica
directly):

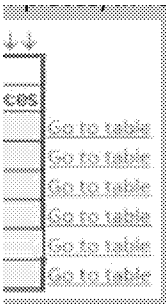
3.3 Load 2 - Small pieces

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)	pin 3 (%)	pin 4 (%
Piece 1:	2.30	22.0	21.0	22.0	21.0
Piece 2:	4.10	21.0	21.0	22.0	21.0
Piece 3:	4.00	23.0	24.0	22.0	20.0
Piece 4:	3.50	19.0	18.0	19.0	19.0
Piece 5:	3.00	21.0	21.0	22.0	22.0
Piece 6:	3.00	21.0	21.0	21.0	23.0
Piece 7:					
Piece 8:					
Piece 9:					
Piece 10:					
Load total:	19.90				

✓ Load weight is in the range

If you click on "set the # of logs" link on the top-left corner of each load table, it will take you to Table
number of pieces. Below each of the load table, there is an information cell with gray font that shows
the table.

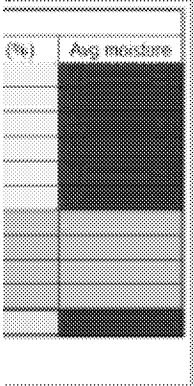
After finishing data entry in Tables 3.1 through 3.6, the user should provide information about run in
condition in Tables 3.7 and 3.8.



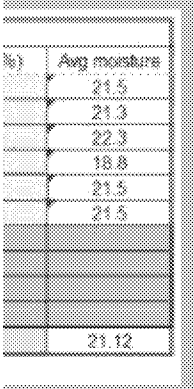
by clicking on "Go to table"

r remove pieces you should

nber of rows available in the



responding cells. The total
lly (cannot be edited



e 3.1, where you can set the
s useful hints about data in

formation and test lab

Tables 3.9 through 3.11 are designed to be filled out as the test goes on. User should enter data abou
the loads at the beginning and end of each load.

THIS INTEGRATED-DUTY-CYCLE (IDC) PROTOCOL FOR WOOD STOVES IS THE PROF

ıt the weights and timing of

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Integrated Duty Cycle Fuel Calculator

1- Stove and Lab Information

1.1 Stove Information	
Appliance manufacturer:	
Appliance model:	

1.2 Firebox Information		
Firebox width:		in.
Firebox depth:		in.
Firebox height:		in.
Volume adjustment:		ft^3
Firebox volume:		ft^3

This number will be subtracted from LxWxH. If you enter a non-zero value, you should explain the reason here ↓↓↓

1.3 Test Lab Information	
Lab name:	
Test lab location:	
Primary testing staff name:	
Test lab phone:	
Test lab contact email:	
Third party certifier:	
Third party phone:	
Third party email:	
Other people present or participating either in person or remotely in the test:	

These timestamps cannot be edited

Calculation Started at:	12/18/2020 15:13
Saved and Finished at:	Still in progress

Next >>

Integrated Duty Cycle Fuel Calculator

2- Fuel Load Information

2.1 Fuel Load General Information			
Wood species:	Oak		
Wood density:	0.7	10^3 kg/m^3	= 43.7 lb/ft3
Firebox Volume:		ft^3	
Loadind direction:	East-West		
Target log length:		in.	

2.2 Load Piece Details				
Load	Total load weight (lb)	Min. piece weight (lb)	Max. piece weight (lb)	Number of pieces allowed per load
L1 - Kindling				
L1 - Starter				
L2 - Small pieces				
L3 - Large pieces				
L4 - Small pieces				
L4 - Large pieces				

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Next >>

Poly
"Small" Volume
"Medium" Volume
"Large" Volume
Poly Small Low
Poly Small Hi
Poly Large Low
Poly Large Hi

Min. Small Log Diamter Ta
Max. Small Log Diamter Ta
Min. Large Log Diamter Ta
Max. Large Log Diamter Ta

y curve fitting paramaters for calculating log characteristics

Firebox Volume, ft^3	Sm Pc. Low (in)	Sm pc Hi (in)	Lg Pc Low (in)	Lg Pc Hi (in)
0.80	2.2	3.1	3.1	4.5
2.00	2.8	4	4	5.3
3.00	3	4.4	4.4	6.3
	x2	x	c	
	-0.136363636	0.881818182	1.581818182	
	-0.159090909	1.195454545	2.245454545	
	-0.159090909	1.195454545	2.245454545	
	0.151515152	0.242424242	4.209090909	

Range of the Log Diameters:

rget (in):				
ırget (in):				
rget:				
ırget:				

Integrat

3.1 I

	Target load (lb)	Actual weight (lb)	Allowed # of pieces
L1 - Kindling weight			
L1 - Starter			
L2 - Small pieces			
L3 - Large pieces			
L4 - Small pieces			
L4 - Large pieces			

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Kindling total:			
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Piece 7:			
Piece 8:			
Piece 9:			
Piece 10:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)

ted Duty Cycle Fuel Calculator

3.1 Run #1 Details

Detailed Fuel Information

Enter the number of fuel pieces first, then enter the weight and MC details in Tables 3.2 through 3.6 ↓↓

Fuel Load Data	
Actual # of pieces	
	Go to table
	Go to table
	Go to table
	Go to table
	Go to table
	Go to table

3.2 Load 1 - Kindling and starter fuel		
pin 3 (%)	pin 4 (%)	Avg moisture
Not applicable		

3.3 Load 2 - Small pieces		
pin 3 (%)	pin 4 (%)	Avg moisture

Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Piece 7:			
Piece 8:			
Piece 9:			
Piece 10:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Load total:			

Target load is not defined yet.

3.4 Load 3 - Large pieces

pin 3 (%)	pin 4 (%)	Avg moisture

3.5 Load 4 - Small pieces

pin 3 (%)	pin 4 (%)	Avg moisture

3.6 Load 4 - Large pieces

pin 3 (%)	pin 4 (%)	Avg moisture

3.7 Run Information	
Run date:	
Run number:	
Testing staff:	
Witnesses or others present for test:	
Start time:	
End time:	

Temperature:	
Barometric pressure:	
Relative humidity:	

3.9 Ru

Load	Actual weight at start of phase before loading (lb)	Actual weight at start of phase after loading (lb)	Target weight at end of phase (lb)
L1 (Fully Open)			
L2(A) (Fully Open)			
L2(B) (Fully Closed)		Not applicable	
L3 (Fully Closed)			
L4 (Fully Closed)			

3.10 Ru

Load	Start time	End time	Door open time
L1 (Fully Open)			
L2(A) (Fully Open)			
L2(B) (Fully Closed)			
L3 (Fully Closed)			
L4 (Fully Closed)			

Load	
L1 (Fully Open)	
L2(A) (Fully Open)	
L2(B) (Fully Closed)	
L3 (Fully Closed)	
L4 (Fully Closed)	

Other Testing Information

3.8 Test Lab Condition		
pre-test	post-test	
		F
		in. Hg
		%

n Operation Data
Actual Weight at end of phase (lb)

ın Operation Data
Door closed time

3.11 Run Operation Data
Notes on fuel adjustments/time

	3.12 Po
1) Any data points with filter temperatures outside the 80-90F?	
If yes, how many and for how long	
2) Did tunnel temperature exceed 40C during the test?	
If yes, how many and for how long	
3) Did tunnel humidity exceed 90%?	
If yes, how many and for how long	
4) Any tunnel dew point measurements within 2C of filter temp	
If yes, how many and for how long	
5) Tunnel flow for test? (dscf/min)	

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st Run Data Check

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3.1			
	Target load (lb)	Actual weight (lb)	Allowed # of pieces
L1 - Kindling weight			
L1 - Starter			
L2 - Small pieces			
L3 - Large pieces			
L4 - Small pieces			
L4 - Large pieces			

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Kindling total:			
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Piece 7:			
Piece 8:			
Piece 9:			
Piece 10:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)

ted Duty Cycle Fuel Calculator

3.2 Run #2 Details

Detailed Fuel Information

Enter the number of fuel pieces first, then enter the weight and MC details in Tables 3.2 through 3.6 ↓↓

Fuel Load Data	
Actual # of pieces	
	Go to table
	Go to table
	Go to table
	Go to table
	Go to table
	Go to table

3.2 Load 1 - Kindling and starter fuel		
pin 3 (%)	pin 4 (%)	Avg moisture
Not applicable		

3.3 Load 2 - Small pieces		
pin 3 (%)	pin 4 (%)	Avg moisture

Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Piece 7:			
Piece 8:			
Piece 9:			
Piece 10:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Load total:			

Target load is not defined yet.

3.4 Load 3 - Large pieces

pin 3 (%)	pin 4 (%)	Avg moisture

3.5 Load 4 - Small pieces

pin 3 (%)	pin 4 (%)	Avg moisture

3.6 Load 4 - Large pieces

pin 3 (%)	pin 4 (%)	Avg moisture

3.7 Run Information	
Run date:	
Run number:	
Testing staff:	
Witnesses or others present for test:	
Start time:	
End time:	

Temperature:	
Barometric pressure:	
Relative humidity:	

3.9 Ru

Load	Actual weight at start of phase before loading (lb)	Actual weight at start of phase after loading (lb)	Target weight at end of phase (lb)
L1 (Fully Open)			
L2(A) (Fully Open)			
L2(B) (Fully Closed)		Not applicable	
L3 (Fully Closed)			
L4 (Fully Closed)			

3.10 Ru

Load	Start time	End time	Door open time
L1 (Fully Open)			
L2(A) (Fully Open)			
L2(B) (Fully Closed)			
L3 (Fully Closed)			
L4 (Fully Closed)			

Load	
L1 (Fully Open)	
L2(A) (Fully Open)	
L2(B) (Fully Closed)	
L3 (Fully Closed)	
L4 (Fully Closed)	

Other Testing Information

3.8 Test Lab Condition		
pre-test	post-test	
		F
		in. Hg
		%

n Operation Data
Actual Weight at end of phase (lb)

ın Operation Data
Door closed time

3.11 Run Operation Data
Notes on fuel adjustments/time

	3.12 Po
1) Any data points with filter temperatures outside the 80-90F?	
If yes, how many and for how long	
2) Did tunnel temperature exceed 40C during the test?	
If yes, how many and for how long	
3) Did tunnel humidity exceed 90%?	
If yes, how many and for how long	
4) Any tunnel dew point measurements within 2C of filter temp	
If yes, how many and for how long	
5) Tunnel flow for test? (dscf/min)	

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3.1 I

	Target load (lb)	Actual weight (lb)	Allowed # of pieces
L1 - Kindling weight			
L1 - Starter			
L2 - Small pieces			
L3 - Large pieces			
L4 - Small pieces			
L4 - Large pieces			

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Kindling total:			
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Piece 7:			
Piece 8:			
Piece 9:			
Piece 10:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)

ted Duty Cycle Fuel Calculator

3.3 Run #3 Details

Detailed Fuel Information

Enter the number of fuel pieces first, then enter the weight and MC details in Tables 3.2 through 3.6 ↓↓

Fuel Load Data	
Actual # of pieces	
	Go to table
	Go to table
	Go to table
	Go to table
	Go to table
	Go to table

3.2 Load 1 - Kindling and starter fuel		
pin 3 (%)	pin 4 (%)	Avg moisture
Not applicable		

3.3 Load 2 - Small pieces		
pin 3 (%)	pin 4 (%)	Avg moisture

Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Piece 7:			
Piece 8:			
Piece 9:			
Piece 10:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Load total:			

Target load is not defined yet.

3.4 Load 3 - Large pieces

pin 3 (%)	pin 4 (%)	Avg moisture

3.5 Load 4 - Small pieces

pin 3 (%)	pin 4 (%)	Avg moisture

3.6 Load 4 - Large pieces

pin 3 (%)	pin 4 (%)	Avg moisture

3.7 Run Information	
Run date:	
Run number:	
Testing staff:	
Witnesses or others present for test:	
Start time:	
End time:	

Temperature:	
Barometric pressure:	
Relative humidity:	

3.9 Ru

Load	Actual weight at start of phase before loading (lb)	Actual weight at start of phase after loading (lb)	Target weight at end of phase (lb)
L1 (Fully Open)			
L2(A) (Fully Open)			
L2(B) (Fully Closed)		Not applicable	
L3 (Fully Closed)			
L4 (Fully Closed)			

3.10 Ru

Load	Start time	End time	Door open time
L1 (Fully Open)			
L2(A) (Fully Open)			
L2(B) (Fully Closed)			
L3 (Fully Closed)			
L4 (Fully Closed)			

Load	
L1 (Fully Open)	
L2(A) (Fully Open)	
L2(B) (Fully Closed)	
L3 (Fully Closed)	
L4 (Fully Closed)	

Other Testing Information

3.8 Test Lab Condition		
pre-test	post-test	
		F
		in. Hg
		%

n Operation Data
Actual Weight at end of phase (lb)

ın Operation Data
Door closed time

3.11 Run Operation Data
Notes on fuel adjustments/time

	3.12 Po
1) Any data points with filter temperatures outside the 80-90F?	
If yes, how many and for how long	
2) Did tunnel temperature exceed 40C during the test?	
If yes, how many and for how long	
3) Did tunnel humidity exceed 90%?	
If yes, how many and for how long	
4) Any tunnel dew point measurements within 2C of filter temp	
If yes, how many and for how long	
5) Tunnel flow for test? (dscf/min)	

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3.1 I

	Target load (lb)	Actual weight (lb)	Allowed # of pieces
L1 - Kindling weight			
L1 - Starter			
L2 - Small pieces			
L3 - Large pieces			
L4 - Small pieces			
L4 - Large pieces			

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Kindling total:			
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Piece 7:			
Piece 8:			
Piece 9:			
Piece 10:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)

ted Duty Cycle Fuel Calculator

3.4 Run #4 Details

Detailed Fuel Information

Enter the number of fuel pieces first, then enter the weight and MC details in Tables 3.2 through 3.6 ↓↓

Fuel Load Data	
Actual # of pieces	
	Go to table
	Go to table
	Go to table
	Go to table
	Go to table
	Go to table

3.2 Load 1 - Kindling and starter fuel		
pin 3 (%)	pin 4 (%)	Avg moisture
Not applicable		

3.3 Load 2 - Small pieces		
pin 3 (%)	pin 4 (%)	Avg moisture

Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Piece 7:			
Piece 8:			
Piece 9:			
Piece 10:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Load total:			

Target load is not defined yet.

set the # of logs	Weight (lb)	pin 1 (%)	pin 2 (%)
Piece 1:			
Piece 2:			
Piece 3:			
Piece 4:			
Piece 5:			
Piece 6:			
Load total:			

Target load is not defined yet.

3.4 Load 3 - Large pieces

pin 3 (%)	pin 4 (%)	Avg moisture

3.5 Load 4 - Small pieces

pin 3 (%)	pin 4 (%)	Avg moisture

3.6 Load 4 - Large pieces

pin 3 (%)	pin 4 (%)	Avg moisture

3.7 Run Information	
Run date:	
Run number:	
Testing staff:	
Witnesses or others present for test:	
Start time:	
End time:	

Temperature:	
Barometric pressure:	
Relative humidity:	

3.9 Ru

Load	Actual weight at start of phase before loading (lb)	Actual weight at start of phase after loading (lb)	Target weight at end of phase (lb)
L1 (Fully Open)			
L2(A) (Fully Open)			
L2(B) (Fully Closed)		Not applicable	
L3 (Fully Closed)			
L4 (Fully Closed)			

3.10 Ru

Load	Start time	End time	Door open time
L1 (Fully Open)			
L2(A) (Fully Open)			
L2(B) (Fully Closed)			
L3 (Fully Closed)			
L4 (Fully Closed)			

Load	
L1 (Fully Open)	
L2(A) (Fully Open)	
L2(B) (Fully Closed)	
L3 (Fully Closed)	
L4 (Fully Closed)	

Other Testing Information

3.8 Test Lab Condition		
pre-test	post-test	
		F
		in. Hg
		%

n Operation Data
Actual Weight at end of phase (lb)

ın Operation Data
Door closed time

3.11 Run Operation Data
Notes on fuel adjustments/time

	3.12 Po
1) Any data points with filter temperatures outside the 80-90F?	
If yes, how many and for how long	
2) Did tunnel temperature exceed 40C during the test?	
If yes, how many and for how long	
3) Did tunnel humidity exceed 90%?	
If yes, how many and for how long	
4) Any tunnel dew point measurements within 2C of filter temp	
If yes, how many and for how long	
5) Tunnel flow for test? (dscf/min)	

<< Back

st Run Data Check

Next >>

Message

From: Toney, Mike [/O=EXCHANGELABS/OU=EXCHANGE ADMINISTRATIVE GROUP (FYDIBOHF23SPDLT)/CN=RECIPIENTS/CN=F0BC151675F34C3BB54F3BD1312B062D-MTONEY]
Sent: 9/21/2020 5:18:32 PM
To: lrector@nescaum.org
Subject: FW: Winhauger
Attachments: (Martin Westermayer) BioWIN ATM approval letter with IDC method pellet fuel.pdf

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From: Johnson, Steffan <johnson.steffan@epa.gov>
Sent: Monday, September 21, 2020 11:26 AM
To: Toney, Mike <Toney.Mike@epa.gov>
Subject: FW: Winhauger

Mike,

I can't e-mail this file to Lisa (who requested it). Can you try sending from your mailbox?

Thank you!

Stef

From: Johnson, Steffan
Sent: Monday, September 21, 2020 8:33 AM
To: Lisa Rector <lrector@nescaum.org>
Subject: Winhauger

Lisa,

Apologies that it's taken me this long to reply. Here you go.

Stef

Steffan M Johnson | Leader – Measurement Technology Group | US EPA Office of Air Quality Planning and Standards | Air Quality Assessment Division | 109 T.W. Alexander Drive, RTP, NC 27710 | Mail Drop: E-143-02 | Phone: (919) 541-4790 | Cell: (919) 698-5096

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

DEC 19 2019

OFFICE OF
AIR QUALITY PLANNING
AND STANDARDS

Mr. Martin Westermayer
Windhager Zentralheizung Technik GmbH
Anton Windhager Straße 20
A 5201 Seekirchen

Dear Mr. Westermayer,

I am writing in response to your correspondence, dated October 22, 2019, regarding certification testing of your BioWIN series of pellet-fueled hydronic heaters. You are planning to test this model line to obtain 2020 certification under 40 CFR 60, Subpart QQQQ - Standards of Performance for New Residential Hydronic Heaters and Forced Air Furnaces (Subpart QQQQ), Section 60.5476(e). You are requesting an alternative certification testing procedure to use the Integrated Duty Cycle (IDC) Test Method for Certification of Thermostatically Controlled Pellet-Fired Hydronic Heating Appliances with external thermal storage: Measurement of Particulate Matter (PM), Carbon Monoxide (CO) Emissions and Heating Efficiency (Attachment dated 11/20/19) in lieu of the Method 28 WHH (40 CFR 60, Appendix A) procedures required by Subpart QQQQ.

In your correspondence, you are requesting an alternative certification testing procedure for your BioWIN Series of pellet-fueled hydronic heaters. This series consists of five heaters, the BioWIN 102, 152, 212, 262 and 332. You state that the pellets are either fed fully automatically with an external suction turbine from the pellet storage to the hopper, or manually fed into the hopper. The pellets are transported from the hopper by a stoker screw to the downpipe and fall in a metered quantity onto the combustion grate of the sturdy steel combustion chamber. Hot air is added by an automatic ignition element to ignite the pellets. The heat generated during combustion is used in the heat exchanger to heat the water. Flue gases produced during the combustion process are channelled outside through the chimney. The movement of the integrated cleaning mechanism cleans the heat exchanger automatically. The ash from the steel combustion chamber falls through an automatic sliding grate into an ash chamber where it is transported via an ash screw into an ash container. The boiler's output is controlled via a speed controlled inner diameter fan depending on boiler water temperature and on combustion temperature. You are requesting to use the IDC Method because EPA Method 28 WHH test procedure does not address the use of pellet fuel where as the IDC Method does include pellet fuel.

With the caveats set forth below, we are approving your alternative method request for certification testing of the BioWIN series of thermostatically-controlled hydronic heaters with the limitations explained below. This series of hydronic heaters cannot be sold with thermal storage that is less capcity than was used during certification testing. A copy of this letter must be included in each certification report.

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As required in Subpart QQQQ, Section 60.5476(c)(6), the manufacturer or approved test lab must also measure the first hour of particulate matter emissions for each test run using a separate filter in one of the two parallel sampling trains. These results must be reported separately and also included in the total particulate matter emissions per run. Also, as required in Subpart QQQQ, Section 60.5476(a), the manufacturer must have the approved test laboratory measure the efficiency, heat output, and carbon monoxide emissions of the tested wood heater using CSA Method B415.1-10. For particulate matter emission concentrations, ASTM E2515-11 "Standard Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel" must be used; four inch filters are acceptable.

The following changes to ASTM E2515-11 "Standard Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel" must be followed for the certification testing:

1. Filters must be weighed in pairs to reduce weighing error propagation. See ASTM E2515-11, Section 10.2.1, Analytical Procedure.
2. Sample filters must be Pall TX-40 or equivalent Teflon-coated glass fiber filters, and 47 mm, 90 mm, 100 mm, or 110 mm in diameter.
3. Only one point is allowed outside the +/- 10 percent proportionality range per test run.

The BioWIN series of hydronic heaters incorporates a low setting on the controller which is the design of the lowest heat output (Btu/hr) setting available to the user and corresponds to the lowest burn rate to be evaluated during certification testing; this is consistent with 40 CFR part 60, Subpart QQQQ, section 60.5476, which states "The burn rate for the low burn category must be no greater than the rate that an operator can achieve in home use and no greater than is advertised by the manufacturer or retailer."

If you have additional questions regarding this approval, please contact Michael Toney of my staff at 919-541-5247 or *toney.mike@epa.gov*.

Sincerely,

Steffan M. Johnson, Group Leader
Measurement Technology Group

cc: Amanda Aldridge, EPA/OAQPS/OID
Adam Baumgart-Getz, EPA/OAQPS/OID
Rochelle Boyd, EPA/OAQPS/SPPD
Chuck French, EPA/OAQPS/SPPD
Rafael Sanchez, EPA/OECA
Michael Toney, EPA/OAQPS/AQAD

Integrated Duty Cycle (IDC) Test Method for Certification of Thermostatically Controlled Pellet-Fired Hydronic Heating Appliances with external thermal storage: Measurement of Particulate Matter (PM), Carbon Monoxide (CO) Emissions and Heating Efficiency

Note: This method does not include all the specifications (e.g. equipment and supplies) and procedures (e.g., sample and analytical) essential to its performance. Some material is incorporated by reference from other methods. Therefore, to obtain reliable results, persons using this method shall have a thorough knowledge of at least the following EPA Tests

- Method 1- Sample and Velocity Traverses for Stationary Sources
- Method 2- Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube)
- Method 3 – Gas Analysis for the Determination of Dry Molecular Weight
- Method 4 – Determination of Moisture Content in Stack Gases
- Method 5G – Determination of Particulate Matter from Appliances (Dilution Tunnel Sampling Location)
- Method 10 - Carbon Monoxide - Instrumental Analyzer

1. Scope and Application

1.1. This test method applies to automatic feed, wood-fired hydronic heating that utilizes an external buffer tank(s) (sometimes called thermal storage) as integral to the appliance operation. The units typically transfer heat through the circulation of a liquid heat exchange media such as water or a water-antifreeze mixture. Throughout this document, the term "water" will be used to denote any of the heat transfer liquids approved for use by the manufacturer.

1.2. This test method measures particulate matter (PM) emissions, carbon monoxide, and delivered heating efficiency at specified heat demands based on the appliances rated heat capacity.

1.3. Particulate emissions are measured by the dilution tunnel method as specified in ASTM E2515 *Standard Test Method for Determination of Particulate Matter Emissions Collected in a Dilution Tunnel* using only Emfab Pallflex filters. Additional particulate matter emissions measurements may also use the Tapered Element Oscillating Microbalance (TEOM) continuous PM method, as detailed in this test method.

1.4. For this protocol, annual fuel use efficiency is represented by the average efficiency over the entire test run. Steady-state efficiency, which is reflective of efficiency measurements in current EPA Federal reference methods is determined by calculating the efficiency at the high load and low steady-state periods of the test run, which Phases 1, 2, and 5. Delivered efficiency is determined by measurement of the usable heat output (determined through measurement of the flow rate and temperature change of water

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circulated through a heat exchanger external to the appliance) and the heat input (determined from the mass of dry fuel burned and its higher heating value). Delivered efficiency does not attempt to account for pipeline loss.

1.5. Products covered by this test method include both pressurized and non-pressurized hydronic heating appliances intended to be fired with wood and for which the manufacturer specifies for indoor or outdoor installation. The system is commonly connected to a heat exchanger by insulated pipes and normally includes a pump to circulate heated liquid. These systems are used to heat structures such as homes, barns, schools, and greenhouses. They also provide heat for domestic hot water, spas, and swimming pools. These products may be used with or without external thermal storage only for the hot water service.

1.6. Distinguishing features of products covered by this standard include:

1.6.1. The manufacturer specifies installation either inside a building or outside.

1.6.2. Products that automatically feed fuels, such as pelletized wood or wood chips.

1.6.3. An aquastat that controls the combustion air supply to maintain the liquid in the appliance within a predetermined temperature range.

1.6.4. A chimney or vent that exhausts combustion products from the appliance.

1.7. The values stated are to be regarded as the standard, whether in I-P or SI units. The values given in parentheses are for information only.

1.8. Persons using this method should have a thorough knowledge of at least the following additional EPA test methods: Method 1, Method 2, Method 3, Method 4, Method 5, Method 5G, and Method 28.

1.9. Analyte. Particulate matter (PM). No CAS number assigned. Carbon monoxide (CO). No CAS number assigned.

1.10. Data Quality Objectives.

1.10.1. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods.

1.10.2. Measurement of emissions and heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

1.10.3. This is a laboratory method intended to capture operating periods that are representative of actual field use without excessive test burden.

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2. *Referenced Methods*

2.1. CAN/CSA-B415.1: Performance Testing of Solid-Fuel-Burning or latest approved EPA version.

2.2. ASTM 2515: Standard Test Method for Determination of Particulate matter Emissions Collected in a Dilution Tunnel or latest approved EPA version.

2.3. NESCAUM Standard Operating Practices for Thermo 1405 TEOM

2.4. NIST Monograph 175, Standard Limits of Error

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3. *Definitions*

3.1. Aquastat – A control device that opens or closes a circuit to control the rate of fuel consumption in response to the temperature of the heating media in the heating appliance.

3.2. Catch - any mass from the sample probe system other than the PM on the front filter.

3.3. Certification or audit test - a series of at least three test runs conducted for certification or audit purposes that meets specifications detailed in Section 8.

3.4. Delivered Efficiency – The percentage of heat available in a test fuel charge that the appliance delivers to a simulated heating load as specified in this test method.

3.5. Emission factor – the emission of a pollutant expressed in mass per unit of energy (typically) output from the appliance

3.6. Emission index – the emission of a pollutant expressed in mass per unit mass of fuel used

3.7. Emission rate – the emission of a pollutant expressed in mass per unit time

3.8. Firebox - the chamber in the appliance in which the test fuel charge is placed and combusted.

3.9. Heat output rate – The average rate of energy output from the appliance during a specific test period in Btu/hr (MJ/hr).

3.10. Hydronic Heating – A heating system in which a heat source supplies energy to a liquid heat exchange media such as water that is circulated to a heating load and returned to the heat source through pipes.

3.11. Manufacturer's Rated Heat Output Capacity –The value in Btu/hr (MJ/hr) that the manufacturer specifies that a particular model of hydronic heating appliance is capable of supplying at its design capacity as verified by testing during Phase 1 and Phase 5 of the test protocol.

3.12. NIST – National Institute of Standards and Technology

3.13. Relative humidity measurement with accuracy of 2% RH between 5 and 95% RH.

3.14. Secondary air supply - air supply that introduces air to the appliance such that the burn rate is not altered by more than 10 percent when the secondary air supply is adjusted during the test run. The appliance manufacturer or test facility can document this through design drawings that show the secondary air is introduced only into a mixing chamber or secondary chamber outside the firebox.

3.15. Test – means the data for all test runs conducted on the heating appliance.

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3.16. Test facility - the area in which the heating appliance is installed, operated, and sampled for emissions.

3.17. Test run - An individual emission test, which encompasses the time required to complete all specified phases of the test profile.

3.18. Thermopile - A device consisting of a number of thermocouples connected in series, used for measuring temperature differential.

3.19. Appliance - an enclosed, woodburning appliance capable of and intended for space heating or domestic water heating, as defined in the applicable regulation.

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4. *Summary of Test Method*

4.1. Dilution Tunnel. Emissions are determined using the "dilution tunnel" method specified in ASTM E2515-11 *Standard Test Method for Determination of Particulate Matter Emissions Collected in a Dilution Tunnel.* The flow rate in the dilution tunnel is maintained at a constant level throughout the test cycle and accurately measured. Samples of the dilution tunnel flow stream are extracted at a constant flow rate and drawn through high-efficiency filters. The filters are equilibrated and weighed before and after each test to determine the emissions catch, and this value is multiplied by the ratio of tunnel flow to filter flow to determine the total particulate emissions produced in the test cycle. The method also includes optional use of a real-time particulate matter measurement that allows for providing one-minute data, which can be used to provide one hour and test phase emissions information.

4.2. *Particulate Matter.* PM emissions are determined using a dilution tunnel method specified in ASTM 2515-11 *Standard Test Method for Determination of Particulate matter Emissions Collected in a Dilution Tunnel* with exceptions as defined in Section 8 and 9.4 of this test method. The flow rate in the dilution tunnel is maintained at a constant level throughout the test cycle and accurately measured. Two different particulate sampling methods are used in this test method.

4.2.1. Filter-based method. Samples of the dilution tunnel flow stream are extracted at a constant flow rate and drawn through high-efficiency filters as defined in ASTM E2515-11 using Teflon coated filters such as Pallflex Emfab (TX40) with a maximum diameter of 47 mm, without organic binder, exhibiting at least 99.95 percent efficiency. The filters are equilibrated and weighed before and after the test to determine the emissions collected and this value is multiplied by the ratio of tunnel flow to filter flow to determine the total particulate emissions produced in the test cycle.

4.2.2. Real-time PM Measurements. The second method is a real-time particulate measurement method based on a Tapered Element Oscillating Microbalance (TEOM) instrument, Thermo model 1405 TEOM or its equivalent, operated using the specifications detailed in the document titled, "*NESCAUM Standard Operating Procedures for Using TEOM 1405 in a Dilution Tunnel*" available at: https://www.nescaum.org/topics/test-methods.

4.3. *Carbon Monoxide.* The CO measured in the flue, before dilution, is used in the stack loss efficiency determination.

4.4. Combustion Efficiency. The efficiency determination involves determination of stack losses. The stack loss determination involves measurement of the flue gas temperature, CO_2, and CO. This is combined with measured fuel heating value and moisture content

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as well as assumed dry fuel ultimate analysis. The flue losses are then calculated as a percentage of the fuel input energy. This provides a stack loss efficiency.

4.5. *Operation.* Appliance operation is conducted on a cold-to-hot test cycle, meaning that the appliance starts the test run at room temperature and ends with the appliance in fully heated state. The appliance is operated at a variety of heat demand loads representing start-up emissions, high heat demand, low heat demand, cycling, idling, and recovery from night time set back. The appliance is operated through six heating phases during the test run. To complete the certification test, a minimum of three full test runs are averaged to determine the test results. For automatic feed systems, fuel is fed as determined by appliance delivery systems.

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5. *Significance and Use*

5.1. The measurement of particulate matter emission rates is an important test method widely used in the practice of air pollution control.

5.1.1. These measurements, when approved by state or federal agencies, are often required for the purpose of determining compliance with regulations and statutes.

5.1.2. The measurements made before and after design modifications are necessary to demonstrate the effectiveness of design changes in reducing emissions and make this standard an important tool in manufacturers' research and development programs.

5.2. Measurement of heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production

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6. ***Test Equipment and Supplies***. The following items are required for sample collection:

6.1. *Anemometer.* A device capable of detecting air velocities less than 0.10 m/sec (20 ft/min). for measuring air velocities near the test appliance.

6.2. *Barometer.* Aneroid or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg).

6.3. *Draft Gauge*. Electromanometer or other device for the determination of flue draft or static pressure readable to within 0.50 Pa (0.002 in. H2O)

6.4. *Dilution Tunnel temperature and relative humidity measurement.* A probe capable of measuring tunnel temperature to within 0.5 C and tunnel RH to within 2%, such as the Omega HX85-A.

6.5. *Flue Gas Temperature Measurement*. Must meet the requirements of CSA B415.1-2010, Clause 6.2.2.

6.6. *Flue Gas Composition Measurement*. Must meet the requirements of CSA B415.1-2010, Clauses 6.3.1 through 6.3.3.

6.7. *Heat Exchanger.* A water-to-water heat exchanger capable of dissipating the expected heat output from the system under test.

6.8. *Humidity Gauge*. Psychrometer or hygrometer for measuring room humidity.

6.9. *Insulated Solid Pack Chimney*. For installation of appliances. Solid pack insulated chimneys shall have a minimum of 2.5 cm (1 in.) solid-pack insulating material surrounding the entire flue and possess a label demonstrating conformance to U.L. 103 (incorporated by reference—see §60.17).

6.10. *Lab Scale*. For measuring the mass of the test fuel charges. Accuracy of ± 0.01 pounds (± 0.00045 kg).

6.11. *Optional Recirculation Pump*. Circulating pump used during the certification test to prevent temperature stratification, in the appliance, of liquid being heated.

6.12. *Platform Scale and Monitor*. A platform scale capable of weighing the appliance under test and associated parts and accessories when completely filled with water to an accuracy of ± 0.10 pound (± 0.045 kg) and a readout resolution of ± 0.01 pound (± 0.00045 kg).

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6.13. *Test Facility*. The test facility shall meet the following requirements during testing:

6.13.1. The test facility temperature shall be maintained between 18 and 32°C (65 and 90°F) during each test run.

6.13.2. Air velocities within 0.6 m (2 ft) of the test appliance and exhaust system shall be less than 0.25 m/sec (50 ft/min) without fire in the unit.

6.13.3. The flue shall discharge into the same space or into space freely communicating with the test facility. Any hood or similar device used to vent combustion products shall not induce a draft greater than 1.25 Pa (0.005 in. H_2O) on the appliance measured when the appliance is not operating.

6.13.4. For test facilities with artificially induced barometric pressures (e.g., pressurized chambers), the barometric pressure in the test facility shall not exceed 775 mm Hg (30.5 in. Hg) during any test run.

6.14. *Test Facility Temperature Monitor*. A thermistor, RTD, or other equivalent device, located centrally in a vertically oriented 150 mm (6 in.) long, 50 mm (2 in.) diameter pipe shield that is open at both ends, capable of measuring temperature to within 1-degree Fahrenheit of expected temperatures.

6.15. Appliance Flue.

6.15.1. Steel flue pipe extending to 2.6 ±0.15 m (8.5 ±0.5 ft) above the top of the platform scale, and above this level, insulated solid pack type chimney extending to 4.6 ±0.3 m (15 ±1 ft) above the platform scale, and of the size specified by the appliance manufacturer. This applies to both freestanding and inserts type appliances.

6.15.2. Other chimney types (e.g., solid pack insulated pipe) may be used in place of the steel flue pipe if the appliance manufacturer's written appliance specifications require such chimney for home installation (e.g., zero clearance appliance inserts). Such alternative chimney or flue pipe must remain and be sealed with the appliance following the certification test.

6.16. *Water Temperature Difference Measurement*. A Type –T 'special limits' thermopile with a minimum of 5 pairs of junctions shall be used to measure the temperature difference in water entering and leaving the heat exchanger. The temperature difference measurement uncertainty of this type of thermopile is equal to or less than ± 1.0 °F (± 0.5 °C). Other temperature measurement methods may be used if the temperature difference measurement uncertainty is equal to or less than ± 1.0 °F (± 0.50 °C). This measurement uncertainty shall include the temperature sensor, sensor well arrangement, piping arrangements, lead wire, and measurement / recording system. The response time of the temperature measurement system shall be less than half of the time interval at which temperature measurements are recorded.

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6.17. *Water Flow Meter.* A water flow meter shall be installed in the inlet to the load side of the heat exchanger. The flow meter shall have an accuracy of ± 1% of the measured flow.

6.17.1. Appliance Side Water Flow Meter (optional). A water flow meter with an accuracy of ± 1% of the flow rate is recommended to monitor the supply-side water flow rate.

6.18. *Water Temperature Measurement.* Thermocouples or other temperature sensors to measure the water temperature at the inlet and outlet of the load side of the heat exchanger must meet the calibration requirements specified in 10.1 of this method.

6.19. *Appliance Temperature Monitors.* Seven, each capable of measuring temperature with standard Type J or K thermocouple accuracy of +/- 0.75% of expected absolute temperatures.

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7. *Safety*

7.1. Disclaimer. This method may involve hazardous materials, operations, and equipment. This test method may not address all the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to performing this test method.

7.2. These tests involve combustion of wood, which releases substantial amounts of heat and combustion products. The heating system also produces large quantities of very hot water and the potential for steam production and system pressurization. Appropriate precautions must be taken to protect personnel from burn hazards and respiration of products of combustion. Exposure of personnel to unsafe levels of carbon monoxide must be avoided, and the use of continuous ambient carbon monoxide monitoring is strongly recommended.

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8. *Sampling, Test Specimens, and Test Appliances*

8.1. Particulate Matter Sampling. PM emissions allow the use of two options to obtain integrated results and one-hour emissions data.

8.1.1. **Option 1** - three ASTM E2515 trains will be used for this testing.

8.1.1.1. Proportionality shall be limited to ± 10%, using 10-minute data.

8.1.1.2. Train 1: Start-up Measurement. A measurement of the start-up phase will be reported using one ASTM 2515 train. This measurement will commence at the beginning of the test and ends sixty (60) minutes after commencing the test.

8.1.1.3. ASTM 2515 Trains 2 and 3: Integrated load measurement. Two, dual ASTM 2515 trains will measure particulate for the entire test run.

8.1.1.4.Option 3 use two ASTM 2515 trains, both pull one hour.

8.1.2. **Option 2** – 2 ASTM 2515 trains and TEOM.

8.1.2.1. ASTM 2515 Trains 1 and 2: Integrated load measurement. Two, dual ASTM 2515 trains will measure particulate for the entire test run.

8.1.2.2. TEOM data will be collected at 10-second intervals and averaged up to 1-minute intervals for reporting. TEOM operation shall follow the procedures listed in the TEOM SOP detailed in Appendix A. TEOM data shall be recorded on an excel spreadsheet following the minimum data reporting requirements. Emissions from the ASTM 2515 trains shall serve as the primary PM emission measurement. The TEOM data will be used to report emissions for the first, one-hour period.

8.2. Sample Collection. The following reagents are required for sample collection:

8.2.1. Teflon coated glass fiber filters such as Pallflex Emfab (TX40) with a maximum diameter of 47 mm, without organic binder, exhibiting at least 99.95 percent efficiency.

8.2.2. Same as Method 5, in Section 7.2.

8.2.3. Sample Analysis. Two reagents are required for the sample analysis:

8.2.4. Acetone. Same as Method 5, in Section 7.2.

8.2.5. Saturated salt solution of magnesium chloride, if weigh room RH will exceed 40%.

8.3. *Test Fuel.* This method can be used with wood pellet fuels.

8.3.1. Pelletized fuels

8.3.1.1. Fuel used must be PFI, CANplus, ENPlus certified, or other equivalent fuel certification standard.

8.3.1.2. Test fuel must undergo and report ultimate/proximate analysis by an independent lab.

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8.3.1.3. All fuels used for testing must have a temperature no greater than 75F when loaded into the appliance.

8.3.2. Wood chip fuels shall conform to the following requirements:

8.3.2.1. Fuel used for testing must undergo ultimate/proximate analysis by an independent lab.

8.3.2.2. Fuel used for testing must be characterized by ANSI/ASABE AD17225-4:2014 FEB2018 Solid biofuels — Fuel specifications and classes — Part 4: Graded wood chips

9. *Sample Collection, Preservation, Storage, and Transport*

9.1. *Test Specimens.* Appliances shall be supplied as complete appliances, including all controls and accessories necessary for installation at the test facility including thermal storage tank description and volume. A full set of specifications, designs, and assembly drawings shall be provided when the product is placed under certification of a third-party agency. The manufacturer shall provide a tank with the minimum volume needed for operation and any parts that are specific for operation, as shown in Method 28 WHH PTS. Examples of parts to be supplied by the manufacturer would be a thermostat or various sensors required for communicating tank temperature to the appliance, recirculation loops (if needed), specific pump (if needed), all fittings for coming off the tank, etc.

9.2. *User Guide.* The manufacturer must supply a one-page user guide that will direct certain portions of the test protocol. The User Guide must be provided to the lab and the consumer as a single sheet and documented in the test report. The user guide shall be the only directions provided and used by the testing facility for certification purposes; it shall address key user operations, and it shall conform to the following requirements. Manufacturers are not allowed to direct or inform any portion of testing or deviate from operations specified in the User Guide, as the User Guide is the only information that can be used to inform appliance operation during certification testing. User Guide Layout Requirements – the User Guide shall conform to the following design specifications:

9.2.1. Directions must be illustrated by text and pictures

9.2.1.1. Font size – minimum font size is 12.

9.2.1.2. Use of columns allowed

9.2.1.3. Margins – must have a minimum of ¾" inch margins

9.2.1.4. A minimum of 40% of the user guide must use graphics or photos to support text directions.

9.2.1.5. Must fit on a single side of an 8 x11.5-inch sheet of paper

9.2.1.6. Must be provided in a laminated form to the consumer.

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9.2.2. User Guide elements – The User Guide shall not include exact specifications for fuel piece size, fuel placement, fuel-spacing, nor shall it specify the number of pieces per row of fuel charge. The User Guide cannot contradict or deviate from user instructions provided in the appliance user manual. The User Guide shall include information on the following items.

9.2.2.1. Appliance preparation – what must be done to the appliance prior to starting a fire to include appliance setpoints and software settings. Settings must reflect use in high-temperature heating systems.

9.2.2.2. Fuel properties – what types of fuel and fuel moisture requirements are allowed for use in the appliance. The fuel properties detailed in the User Guide are for homeowner use, for certification testing, fuel requirements shall follow the protocols detailed in this method.

9.2.2.3. Start-up procedures – general guidelines for properly starting the appliance to include starting procedures and appliance settings to include software configurations.

9.2.2.4. Reloading procedures – If applicable, guidelines for properly reloading fuel once a fire has been started in the appliance.

9.3. *Pretest Recordkeeping.*

9.3.1. Record data and detailed information on all testing or burning completed on the appliance including all pre-test burns conducted at the testing facility or by the manufacturer at a maximum of 10-minute intervals. Aging conducted at the manufacturer shall conform to the same requirements as the test facility. This information shall include the amount of pellets burned, air settings, burn times and dates, appliance and stack temperature data.

9.4. Modifications to ASTM 2515 requirements.

9.4.1. Liquid water should not be present anywhere in the sampling system for a valid sample.

9.4.2. Dilution tunnel temperature and relative humidity shall be measured and logged near the sample probe to calculate tunnel dewpoint. Filter temperature shall be measured and logged using a measurement method with an accuracy of 0.5 degrees Celsius (C) or better.

9.4.3. For a valid test run the following conditions shall not exceed any of the following conditions for a period of more than five minutes in total:

9.4.3.1. Filter temperature shall remain between 80 and 90 deg. F (26.7 to 32.2 C)

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9.4.3.2. The dilution tunnel temperature shall be no more than 104 deg. F (40 C) for any rolling 10-minute average.

9.4.3.3. Tunnel relative humidity shall not exceed 95%.

9.4.3.4. Tunnel dew point temperature shall be at least 3.6 deg. F (2 deg. C) less than filter temperature.

9.4.3.5. If any parameter is exceeded, the test report should explicitly note the results of the sampling train liquid water inspection.

9.4.4. Proportionality shall be limited to ± 10%, using, at a minimum, 10-minute data.

9.5. Test Facility Conditions.

9.5.1. Locate the test facility temperature monitor on the horizontal plane that includes the primary air intake opening for the appliance. Locate the temperature monitor 1 to 2 m (3 to 6 ft) from the front of the appliance in the 90° sector in front of the appliance.

Use an anemometer to measure the air velocity. Measure and record the room air velocity before the pretest ignition period (Section 8.7) and once immediately following the test run completion .

9.5.2. Measure and record the test facility's ambient relative humidity, barometric pressure, and temperature before and after each test run.

Measure and record the flue draft or static pressure in the flue at a location no greater than 0.3 m (1ft) above the flue connector at the appliance exhaust during the test run at the recording intervals

9.6. Appliance Installation.

9.6.1. Appliances shall be supplied as complete appliances, as described in marketing materials, including all controls and accessories necessary for installation in the test facility. A full set of specifications, installation and operating instructions, and design and assembly drawings shall be provided. The manufacturer's written installation and operating instructions are to be used as a guide in the set-up and testing of the appliance and shall be part of the test record.

9.6.2. Assemble the appliance and parts in conformance with the manufacturer's written installation instructions. A representative of the manufacturer may assist in appliance installation.

9.6.3. Place the appliance centrally on the platform scale capable of weighing the appliance fully loaded with a resolution of ±0.10 lb (0.05 kg).

9.6.4. The appliance shall be fitted with the type of chimney recommended or provided by the manufacturer and extending to 15 ±0.5ft (4.6 ± 0.15m) from the upper surface of the scale. If no flue or chimney system is recommended or provided by the manufacturer, connect the appliance to a flue of a diameter equal to the flue outlet of the appliance. The flue section from the appliance flue collar to 8 ± 0.5 feet above the scale shall be a

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single wall stove pipe, and the remainder of the flue shall be double-wall insulated Class A chimney.

9.7. *Optional Equipment Use*

9.7.1. A recirculation pump may be installed between connections at the top and bottom of the appliance to minimize thermal stratification if specified by the manufacturer's instructions shipped with the unit. If specified by the manufacturer, the manufacturer shall provide all piping, pumps, and controls necessary for the recirculation system. The pump shall not be installed in such a way as to change or affect the flow rate between the appliance and the heat exchanger.

9.7.2. If the manufacturer's instructions shipped with the unit specify that a thermal control valve or other device be installed and set to control the return water temperature to a specific set point, the valve or other device shall be installed and set per the manufacturer's written instructions to reflect a high-temperature installation, unless the manufacturer specifies that the appliance is for use only in low-temperature installations.

9.8. *Starting Weight*. Prior to filling the appliance with water, weigh and record the appliance mass.

9.9. *Heat Exchanger*

9.9.1. Plumb the unit to a water-to-water heat exchanger with sufficient capacity to draw off heat at the maximum rate anticipated. Route hoses and electrical cables and instrument wires in a manner that does not influence the weighing accuracy of the scale as indicated by placing dead weights on the platform and verifying the scale's accuracy.

9.9.2. Locate temperature sensors to measure the water temperature at the inlet and outlet of the load side of the heat exchanger.

9.9.3. Install a thermopile (or equivalent instrumentation) meeting the requirements of Section 6.3 to measure the water temperature difference between the inlet and outlet of the load side of the heat exchanger.

9.9.4. Install a calibrated water flow meter in the heat exchanger load side supply line. The water flow meter is to be installed on the cooling water inlet side of the heat exchanger so that it will operate at the temperature at which it is calibrated.

9.9.5. Place the heat exchanger in a box with 2 in. (50 mm) of expanded polystyrene (EPS) foam insulation surrounding it to minimize heat losses from the heat exchanger.

9.9.6. The reported heat output rate shall be based on measurements made on the load side of the heat exchanger.

9.9.7. Temperature instrumentation shall be installed in the appliance outlet and return lines. The average of the outlet and return water temperature on the supply side of the system

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shall be considered the average appliance temperature. Installation of a water flow meter in the supply side of the system is optional.

9.9.8. Fill the system with water. Determine the total weight of the water in the appliance when the water is circulating. Verify that the scale indicates a stable weight under operating conditions. Make sure air is purged properly.

10. Calibration, Standardization and Quality Control

10.1. *ASTM E2515-11.* Perform all calibrations required by ASTM E2515-11

10.2. *Water Temperature Sensors.* Temperature measuring equipment shall be calibrated before initial use and at least semi-annually thereafter. Calibrations shall follow NIST Monograph 175, Standard Limits of Error.

10.3. *Heat Exchanger Load Side Water Flow Meter.* The heat exchanger load side water flow meter shall be calibrated within the flow range used for the test run using NIST-traceable methods. Verify the calibration of the water flow meter before and after each test run and at least once during each test run by comparing the water flow rate indicated by the flow meter to the mass of water collected from the outlet of the heat exchanger over a timed interval. The volume of the collected water shall be determined based on the water density calculated from Section 13, Eq. 12, using the water temperature measured at the flow meter. The uncertainty in the verification procedure used shall be 1% or less. The water flow rate determined by the collection and weighing method shall be within 1% of the flow rate indicated by the water flow meter.

10.4. *Scales.* Perform a multipoint calibration (at least five points spanning the operational range) of the platform scale before its initial use. The scale manufacturer's calibration results are sufficient for this purpose. Before each certification test, audit the scale with the appliance in place by weighing at least one calibration weight (Class F) that corresponds to between 20 percent and 80 percent of the expected test fuel charge weight. If the scale cannot reproduce the value of the calibration weight within 0.0045 kg (0.01 lb.) or 1 percent of the expected test fuel charge weight, whichever is greater, recalibrate the scale before use with at least five calibration weights spanning the operational range of the scale. The scales used to weigh the appliance, and test fuel charge shall be calibrated using NIST-traceable methods at least once every 6 months.

10.5. *Balance (optional).* Calibrate as described in Section 10.1.

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10.6. *Anemometer*. Calibrate the anemometer as specified by the manufacturer's instructions before the first certification test and semiannually thereafter.

10.7. *Barometer*. Calibrate against a mercury barometer before the first certification test and semiannually thereafter.

10.8. *Draft Gauge*. Calibrate as per the manufacturer's instructions; a liquid manometer does not require calibration.

10.9. *Humidity Gauge*. Calibrate as per the manufacturer's instructions before the first certification test and semiannually thereafter

10.10. *Flue Gas Analyzers*. In accordance with CSA B415.1-2010, Clause 6.8.

10.11. *Weigh room conditions*. The following conditions shall be met:

10.11.1. The facility shall use an active ionizing air blower (or 210Polonium alpha sources) to neutralize charge associated with the filter. 210Polonium alpha sources must be replaced annually or more often.

10.11.2. Temperature range of 68 to 78 deg. F.

10.11.3. Relative humidity shall be no higher than 45%.

10.12. *Filter equilibration / conditioning post sample collection*. Use of desiccation is not allowed. Equilibrate filters at a relative humidity between 30 and 40% for at least 24 hours. A saturated salt solution of magnesium chloride (33% RH) can be used.

10.13. *Filter weight measurements*. Report the following filter measurements:

10.13.1. Day zero – initial filter measurement immediately after completing testing.

10.13.2. Final filter measurement or day seven measurement, whichever measurement comes first.

10.14. *Blanks*. Test reports shall measure and report data on blanks as follows:

10.14.1. Lab blank, which is removed from each filter batch, stored in a protective environment, and weighed during each weighing session.

10.14.2. Room blank collected during every test run. The blank shall be placed within 2 feet of the intake for the dilution air and shall be placed at a minimum of 10 feet away from any combustion activities.

10.15. Probe Catch: Report sampling system catch as a separate number from back filter catch.

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11. Conditioning

11.1. *Appliance Aging*. Prior to testing, the appliance shall be operated for a minimum of 50 hours using a variety of heat demands. The conditioning may take place at the manufacturer's facility prior to testing or at the certification facility.

11.2. *Appliance Aging Documentation.* A appliance of any type shall be aged before initiating a certification test. The aging procedure shall be conducted and documented by the manufacturer or the certified testing laboratory. All aging data must be reported and shall include the hours of operation, heat demands for aging.

11.3. *Appliance Aging operations.* Operate the appliance using manufacturer designated fuel. The appliance shall be operated at a variety of burn phases. The test report shall detail the amount of fuel burned, fuel parameters (species, heat demands, and fuel types), air and control settings used, and note the time spent in each air setting phase.

11.3.1. If the appliance uses a catalytic combustor, it must be engaged according to manufacturer's instructions and operate for at least 50 hours during the break-in period. Report hourly catalyst exit temperature data and the hours of operation.

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12. Procedure.

12.1. A representative of the manufacturer may observe testing but may not provide instructions to the certification lab, in any form, with testing staff or equipment once the certification tests begin. The names of testing witnesses cannot be withheld as confidential business information (CBI).

12.2. During certification testing, the unit cannot be connected for remote access. Nor can the appliance be operated remotely. For example, the unit cannot be connected to the internet unless remote access is to allow for remote witnessing or recording of the test. Remote access may only be granted by the certification laboratory. If remote access is granted, witness list shall reflect those who have been granted remote witness capacity and provide recordings of remote activities as part of the test report.

12.3. For certification testing, all system control settings shall be tested with all controls and software set as-the manufacturer will ship or install, often referred to as default settings. These default settings shall be defined by the manufacturer, communicated to the lab, documented in the test report, and match those communicated in owner's manual and installation instructions to the installer or end-user. These control settings and the documentation of the control settings as to be provided to the installer or end-user shall be part of the test record.

Informational note: these units typically have an operating limit at about 180 °F and a safety high limit at about 195 °F. If the unit reaches the safety limit, a manual reset is commonly required. As noted above, the actual settings shall be based on the manufacturer's default settings.

12.3.1. Where the manufacturer defines several operational control logic parameters and heat load settings, one shall be defined in the appliance documentation as the default or standard-setting. It is expected that this will be the configuration for use with a simple baseboard high-temperature heating system. This is the configuration to be followed for these tests. The manufacturer`s documentation shall define the other control settings as optional or alternative settings.

12.4. Sampling Equipment.

12.4.1. Prepare the sampling equipment as defined by ASTM E2515-11 with modifications defined in 9.4 of this method, and if using the TEOM, using the SOP referenced.

12.4.2. Sample Flow Corrections for Water Vapor: Corrections shall use the average of actual tunnel dew point measurements during a sample run, use of the assumed dew point value is prohibited.

12.5. Instructions

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12.5.1. Appliance Operation and Adjustments. Set the air inlet supply controls as designated in the User Guide, as defined in Section 9.2 of this test method. Record all adjustments made to the air supply controls, adjustments to and additions or subtractions of fuel, and any other changes to appliance operations that occur during the test period. Record fuel weight data and appliance temperature measurements at 1-minute intervals.

12.5.2. Before each test run, the firebox shall be vacuumed. Testing shall begin without any ash or other materials in the appliance.

12.6. Test Run Procedure. The table below summarizes the phases that encompass a complete test run. **Addition of cooling water during the testing is not allowed.** A complete test run requires completion of all five phases of the test protocol, as described below.

IDC Test Procedure Summary	
Start-up Phase	Startup per manufacturer's instructions. Pull off heat as needed when approaching operating temperature limit and ramp up to 100%
Phase 1	100% heat demand 60 minutes
Phase 2	13% heat demand (+/-2%) for 120 minutes or after one cycle, whichever comes first. If unit begins to cycle within 0-30 minutes of Phase 2, 6 cyles must be completed in Phase 4. If the unit begins to cycle within 31-60 minutes of Phase 2, 4 cycles must be completed in Phase 4. If the unit cycles within 61-90 minutes of Phase 2, 3 cycles must be completed in Phase 4. If the unit cycles within 91-12o minutes of Phase 2, 2 cycles must be completed in Phase 4. If the unit does not cycle during Phase 2, only 1 cycle must be completed in Phase 4.
Phase 3	No heat demand for 45 minutes
Phase 4	Forced cycling - Must complete 1-6 cycles, as determined by cycling time in Phase 2. • During on-cycle - cooling water is stopped, the system heats to maximum temperature limit • Off-cycle - Wait 30 minutes, then set cooling water at 100% heat demand until system reaches minimum operating temperature limit • Phase 4 ends after 2 cycles and concludes the second 30 minute off period
Phase 5	100% heat demand for 60 minutes • Stop cooling water if water jacked drops below minimum operating temperature limit and resume cooling water at 100% heat demand when water jacket reaches operating temperature setpoint

12.6.1. Start-up Phase

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12.6.1.1. Appliance operation – during this phase, the appliance shall start from a cold condition and ramp up until the heat demand is 100% of the appliances' maximum rated heat output [1] for a period of five minutes.

12.6.1.2. Definition for end of start-up phase – cold start phase shall end when the appliance is within the modulation setpoints, prescribed by manufacturer and maximum heat demand can be maintained for a period of at least five minutes without a rise in water and stack temperature (+/- 10°F).
Complete 60-minute average calculation to confirm as this will impact phase 2 setting.

12.6.1.3. Lockout access to thermal storage during the first 30 minutes of Phase 1.

12.6.2. The appliance shall remain at Phase 1 – 100% heat demand for a period of 60 minutes.

12.6.2.1.1. Appliance controls should target operation at the maximum firing rate. Following cold start, cooling water will not be turned on until after the appliance reaches appliance/storage setpoints , and storage is above operating conditions programmed by the manufacturer. After the burner has stabilized at maximum burn rate and the temperature has reached 160 °F, the cooling load shall be set to the nominal output rate.

12.6.2.1.2. The appliance shall fire at its maximum burn rate for the entire period. The appliance water temperature, however, may increase during this time period.

12.6.2.1.3. If at any time, the appliance temperature is rising and approaching the operating limit, the output rate shall be increased to prevent the appliance from cycling off or from modulating to a lower firing rate.

12.6.2.2. Appliance temperature: For Run #1, the appliance shall be at ambient room temperature, which cannot exceed 80 F must room temperature. Before each test run and IR photo shall be taken of the appliance and thermal storage. For the first run (Run #1), the appliance and buffer tank (or thermal storage) shall not exceed 120 F. No appliance temperature requirements for Run #2 or #3. Temperature measurements for the external and internal temperatures shall be taken 15 minutes before starting the test and shall be reported in the test report.

12.6.2.3. Record and report the weight of the appliance at the beginning and end of Phase 1.

12.6.2.4. End of Phase 1. The end of Phase 1 is defined by a period of 60 minutes of maximum heat demand placed on the appliance.

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1 If the maximum output is ± 10% of the manufacturers stated capacity, the appliance rating must be changed to reflect actual tested values.

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12.6.2.5. To determine average maximum heat output, all replicates shall be averaged and no individual run shall have a heat output rate +/- 10%.

12.6.2.6. Heat Output Capacity Validation. During Phase 1, the unit must produce an average heat output rate that is within ±10% of the manufacturer's rated heat output capacity. If average heat output is not within these limits, the manufacturer's rated heat output capacity is considered not validated and must be changed. In such cases, the testing may be redone using an adjusted heat output capacity if requested by the manufacturer. If the manufacturer's rated heat output capacity is increased as a result of this requirement, the tests done in Phases 2, 3, and 4 may still meet the requirements of Table 1, and a re-test may not be required.

12.6.3. Phase 2 – Low Heat Demand Phase. This phase commences immediately after Phase

12.6.3.1. Appliance operation – the appliance heat demand is reduced to 13%+ /- 2% of the appliance's maximum rated heat output. The appliance stays at this heat demand for a period of 120 minutes or one complete cycle, whichever comes first. Ramp down to this heat load must be made in a period of fewer than 10 minutes. The test report shall indicate the time period used for ramp down.

12.6.3.2. Record and report the weight of the appliance at the beginning and end of Phase 2.

12.6.3.3. Operational Parameters: Heat demand on the appliance is placed at 13% +/- 2% of maximum output as the unit is delivered to the customer.

12.6.3.4. End of Phase – the end of Phase 2 is defined by the appliance is defined by a period of 120 minutes at 13% +/-2% heat demand placed on the appliance or after one cycle, whichever comes first.

12.6.3.5. *The time at which the unit cycles in Phase 2 shall determine how many cycles must be completed in Phase 4.*

12.6.3.5.1. If unit begins to cycle within 0-30 minutes of Phase 2, 6 cycles must be completed in Phase 4.

12.6.3.5.2. If the unit begins to cycle within 31-60 minutes of Phase 2, 4 cycles must be completed in Phase 4.

12.6.3.5.3. If the unit cycles within 61-90 minutes of Phase 2, 3 cycles must be completed in Phase 4.

12.6.3.5.4. If the unit cycles within 91-120 minutes of Phase 2, 2 cycles must be completed in Phase 4. If the unit does not cycle during Phase 2, only 1 cycle must be completed in Phase 4.

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12.6.4. Phase 3 – No Heat Demand (Idling) Phase. This phase commences immediately after Phase 2.

12.6.4.1. Appliance operation – Appliance heat demand is 0%, and the appliance is turned off. The appliance stays at this heat demand for a period of 45 minutes. Ramp down to this heat load must be made in a period of fewer than 5 minutes. The test report shall indicate the time period used for ramp down.

12.6.4.2. No appliance temperature requirements for Phase 3.

12.6.4.3. Record and report the weight of the appliance at the beginning and end of Phase 3.

12.6.4.4. End of Phase. The end of Phase 3 occurs when the appliance spends a minimum of 45 minutes at no load ends and the boiler cools to a setpoint where the boiler will cycle on at the beginning of Phase 4. This may be completed by manual setting a cooling load.

12.6.5. Phase 4 – Cyclic Operations

12.6.5.1. Appliance operation - During Phase 4 the unit shall complete the number of cycles as determined in Phase 2, as defined in 12.6.3.5.

12.6.5.1.1. The appliance must complete the required number of on/off cycles. During on-cycle - cooling water is stopped, the appliance heats to maximum temperature limit. During the off-cycle – the appliance is turned off for a period of 30 minutes, then set cooling water 100% heat demand until appliance reaches minimum operating temperature limit, and the appliance's controls receive a call for heat.

12.6.5.2. This phase emulates the operation of the appliance, responding to a thermostat call at the start of this phase, power the appliance back on. The heater and storage temperature at the time it powers on will determine whether there is a call for heat or not. This will be indicated by the appliance firing back up, which can be indicated through control status, or starting of the combustion air/ induced draft fan or if it stays in an "idle" state, such as standby or slumber.

12.6.5.3. If there is a call for heat, the cooling water shall remain off until the appliance temperature rises to the operating limit, and the appliance controls act to minimize the burn rate in an "off" or "idle" state. The transition to this mode is determined either by the control status indication or the stopping of the combustion air / induced draft fan. This will indicate the end of the on-cycle and start of the off-cycle period. The time of the start of off-cycle will be recorded, and then the heater and storage will sit for 30 minutes. Following this, the cooling load shall be cycled on at 100%. This marks the end of the first cycle. Then allow cooling water flow to be adjusted for an output of 100% of nominal full load output. This pattern shall continue until the time at which

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the appliance operating controls act to restart the active combustion and reheat the appliance in an on-cycle. The transition to this active combustion mode is determined either by the control status indication or restarting of the combustion air/induced draft fan. This phase and the test ends when the appliance has again reached the operating limit temperature, and the appliance controls act to minimize the burn rate in an "off" or "idle" mode and then sat for a period of 30 minutes to complete the second cycle.

12.6.5.4.If, during this test, the appliance shuts down on the high-temperature safety control, requiring a manual reset, the test is a failed run.

12.6.5.5. Appliance temperature: no appliance temperature requirements for Phase 4.

12.6.5.6. Record the weight of the appliance at the beginning and end of Phase 4

12.6.5.7. Start of Phase – the cycling event begins in an off-cycle.

12.6.5.8. End of Phase – the end of Phase 4 occurs after the 30-minute period after the second cycling event is completed, and the appliance is in an off-cycle.

12.6.6. Phase 5 – Response to Setback Conditions

12.6.6.1. Appliance operation –. The cooling water shall be adjusted for an output of 100% of the nominal full-load output for 60 minutes. If the appliance system (heater and storage) drops below the minimum operating range, as specified by the manufacturer, cooling will stop temporarily until the heater returns to manufacturer specified operating temperature. Cooling water will then be adjusted to continue an output of 100%, or nominal load. The time at which cooling is stopped and continued shall be recorded.

12.6.6.2. Record the weight of the appliance at the beginning and end of the phase

12.6.6.3. End of Phase – the end of Phase 5 occurs when a period of 60 minutes of 100% heat demand has been placed on the appliance.

12.6.7. End of the Test Run. The test runs ends when all five phases of the test run have been completed in sequence.

12.6.7.1. Test Run Completion. At the end of the Phase 5 period, as prescribed in Section 8, stop the particulate sampling instruments and Overall Efficiency (SLM) measurements, and record the run time and all final measurement values.

12.6.7.2. At the end of the test run, continue to apply a thermal load to the heater to allow the remaining fuel to safely be consumed. No measurements are required during this period.

12.7. *Test run requirements.* The following are the pre-testing appliance use requirements for each test run.

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12.7.1. Run 1 – appliance must be at lab temperature and wait a minimum of 48 hours without combustion before starting Run 1.

12.7.2. Run 2 – shall not operate for a minimum of 8 hours from the conclusion of Run 1 before commencing Run 2. Appliance coals and ash can remain in the appliance until 1 hour before conducting Run 2. All coals and ash must be removed before commencing Run 2.

12.7.3. Run 3 – shall wait a minimum 8 hours from the conclusion of Run 2 before commencing Run 3. Appliance coals and ash can remain in the appliance until 1 hour before conducting Run 3. All coals and ash must be removed before commencing Run 3.

12.8. Before initiating the compliance test, clean the flue with an appropriately sized wire chimney brush before each certification test. Test documentation should include the date and time of flue cleaning.

12.9. *Failure to Operate at All Test Conditions*. If an appliance cannot operate in all of the test Phases without achieving an appliance temperature that causes the safety high limit to be activated, requiring a manual reset, the test is a failed run. After two failed test runs, the unit is deemed to have failed the test, and the unit cannot be certified with this test method.

12.10. *Consecutive Test Runs*. Consecutive test runs may be conducted, provided that the requirements of Section 12.6 of this method are met.

12.11. *Test Series completion*. A complete test series is defined as the successful completion of three full test runs, as specified in Section 12.6 of this method.

12.11.1. If the appliance fails more than the two test runs, the appliance has failed the certification test.

12.12. *Additional Test Runs*. The testing laboratory may conduct more than three test runs. If more than three test runs are conducted, the results from all valid test runs shall be used in calculating the average emission rate. The measurement data and results of all test runs shall be reported regardless of which values are used in calculating the emission rate. No test run data can be eliminated from the reporting requirements of this method.

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12.13. *Low Appliance Temperature.* If at any time, average water temperature falls below minimum operating temperatures set by the manufacturer, then cooling will be stopped until the water temperature averages reach temperature setpoint.

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13. Calculation of Results – Calculation of Results

13.1. Nomenclature

E_T – Total particulate emissions for the full test run as determined per ASTM E2515-11 in grams

$E_{g/MJ}$ – Emissions rate in grams per megajoule of heat output

$E_{lb/mmBtu\ output}$ – Emissions rate in pounds per million Btu of heat output

$E_{g/kg}$ – Emissions factor in grams per kilogram of dry fuel burned

$E_{g/hr}$ – Emissions factor in grams per hour

HHV – Higher heating value of fuel = 8600 Btu/lb (19.990 MJ/kg)

LHV – Lower heating value of fuel = 7988 Btu/lb (18.567 MJ/kg)

ΔT – Temperature difference between water entering and exiting the heat exchanger

Q_{out} – Total heat output in BTU's (megajoules)

Q_{in} – Total heat input available in test fuel charge in BTU (megajoules)

M – Mass flow rate of water in lb/min (kg/min)

V_i – Volume of water indicated by a totalizing flow meter at the ith reading in gallons (liters)

V_f – Volumetric flow rate of water in heat exchange system in gallons per minute (liters/min)

Θ – Total length of test run in hours

ti – Data sampling interval in minutes

η_{del} – Delivered heating efficiency in percent

F_i – Weighting factor for heat output category i

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T1 – Temperature of water at the inlet on the supply side of the heat exchanger

T2 – Temperature of the water at the outlet on the supply side of the heat exchanger

T3 – Temperature of water at the inlet to the load side of the heat exchanger

T4 – Temperature of cooling water at the outlet of the load side of the heat exchanger, °F.

T5 – Temperature of the hot water supply as it leaves the appliance/heater, °F.

T6 – Temperature of return water as it enters the appliance/heater, °F.

TI_{avg} – Average temperature of the appliance and water at start of the test

TI_{avg} – (T1 + T2)/2 at the start of the test, °F

TF_{avg} – Average temperature of the appliance and water at the end of the test

TFa_{vg} – (T1 + T2)/2 at the end of the test, °F

TIS1 – Temperature at the inlet to the storage system at the start of the test.

TIS2 – Temperature at the outlet from the storage system at the start of the test.

TFS1 – Temperature at the inlet to the storage system at the end of the test.

TFS2 – Temperature at the outlet from the storage system at the end of the test.

TISavg – Average temperature of the storage system at the start of the test.

TISavg – (TIS1 + TIS2)/2 at the end of the test.

TFSavg – Average temperature of the storage system at the end of the test.

TFSavg – (TFS1 + TFS2)/2.

MC – Fuel moisture content in percent dry basis

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MC_t – Average moisture content as determined by ultimate/proximate analysis

σ – Density of water in pounds per gallon

C_p – Specific heat of water in Btu /lb, °F

C_{steel} – Specific heat of steel (0.1 Btu/ lb, °F)

W_{fuel} – Fuel charge weight in pounds (kg)

W_i – Weight of fuel in pounds (kg)

W_{app} – Weight of empty appliance in pounds

W_{wa} – Weight of water in the supply side of the system in pounds

WStorageTank – Weight of the storage tank empty in pounds (kg)

WWaterStorage – Weight of the water in the storage tank at TISavg in pounds (kg).

NOTE: For proportioning emission factors and rates per phase according to Appendix A, variables will have subscript added to determine the relevancy of phase i.e. $E_{T(P1)}$ indicates Total particulate emissions for Phase 1 and $E_{g/hr(P2)}$ indicates emissions factor in grams per hour for Phase 2.

13.2. *Test Run Reporting.*

13.2.1. Record all water temperatures, differential water temperatures, and water flow rates at time intervals of one minute or less. All data collected for regulatory purposes shall be reported at no time period shorter than one minute. Shorter collection times may be used for research but will not be considered for regulatory purposes.

13.2.2. Record data needed to determine Overall Efficiency (SLM) per the requirements of CSA B415.1-2010 Clauses 6.2.1, 6.2.2, 6.3, 8.5.7, 10.4.3 (a), 10.4.3(f), and 13.7.9.3

13.2.3. Measure and record the test room air temperature in accordance with the requirements of CSA B415.1-2010 Clauses 6.2.1, 8.5.7, and 10.4.3 (g).

13.2.4. Measure and record the flue gas temperature in accordance with the requirements of CSA B415.1-2010 Clauses 6.2.2, 8.5.7, and 10.4.3 (f).

13.2.5. Determine and record the Carbon Monoxide (CO) and Carbon Dioxide (CO_2) concentrations in the flue gas in accordance with CSA B415.1-2010 Clauses 6.3, 8.5.7, and 10.4.3 (i) and (j).

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13.2.6. Measure and record the test fuel weight per the requirements of CSA B415.1-2010 Clauses 8.5.7 and 10.4.3 (h).

13.2.7. CSA B415.1-2010 Record the test run time per the requirements of Clause 10.4.3

13.2.8. Record and document all settings and adjustments, if any, made to the appliance as recommended/required by manufacturers instruction manual for different combustion conditions or heat loads. These may include temperature setpoints, under and over-fire air adjustment, or other adjustments that could be made by an operator to optimize or alter combustion. All such settings shall be included in the report for each test run.

13.2.9. Monitor the average heat output rate on the load side of the heat exchanger based on water temperatures and flow. If the heat output rate over a 10-minute averaging period gets close to the limit of the target range, adjust the water flow through the heat exchanger to compensate. Make changes as infrequently as possible while maintaining the target heat output rate.

13.3. Measurements and Adjustments

13.3.1. Modification to measurement procedure and the standards referenced therein on Averaging Period for Determination of Efficiency by the Stack Loss Method. The methods currently defined in Method 28 WHH allow averaging over 10-minute time periods for flue gas temperature, flue gas CO_2, and flue gas CO for the determination of the efficiency with the Stack Loss Method. However, under some cycling conditions, the "on" period may be short relative to this 10-minute period. For this reason, during cycling operation the averaging period for these parameters may not be longer than the burner-on period divided by 10. The averaging period need not be shorter than one minute. During the off period, under cycling operation, averaging periods as specified in EPA Method 28 WHH and the standards referenced therein may be used. Where short averaging times are used; however, the averaging period for fuel consumption may still be at 10 minutes. This average wood consumption rate shall be applied to all of the smaller time intervals included.

13.4. *Emission Calculations.* Particulate matter, carbon dioxide, and carbon monoxide shall be calculated using the following methodology and reported in grams per hour, grams per kilogram and pounds per million British Therma Unit (Btu) per hour based on heat output:

13.4.1. Two PM measurements shall be reported

13.4.1.1. 60-minute reporting. Emissions from the first sixty minutes shall be reported. The 60 minute periods begins at match light. 60-minute data shall be collected and reported as a separate ASTM 2515-11 train or the TEOM data calculated per the SOP.

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13.4.1.2. Integrated Result. The results two, dual ASTM E2515-11 trains, shall integrate into a single result the appliance performance over the five phases of this test method's operational protocol.

13.4.2. Particulate Matter emissions.

13.4.2.1. During the test run, particulate emissions shall be measured per the requirements of ASTM E2515-11, with exceptions noted in 9.4 of this test method. This involves two sampling trains providing an integrated measurement over the entire test period, Phases 1 through 5, and

13.4.2.1.1.A third ASTM 2515-11 train to obtain 60-minute reporting data, or

13.4.2.1.2. Use of a Tapered Element Oscillating Microbalance (TEOM) instrument, or equivalent, as per Appendix A to this test method. Section 9 of Appendix A prescribes the methodology to determine the total PM emitted during each Phase and for the entire test run in grams.

13.5.*Particulate Matter Emissions Rates.* After the test is completed determine the particulate matter emissions rate E_r in accordance with ASTM E2515-11 for each test run. If using ASTM E2515-11 for one-hour data, prepare calculations for each first hour of operation.

13.6. *Average Fuel Load Content.* Determine average fuel load content using the results of the ultimate/proximate analysis.

13.7. *Determine Heat Input.*

$Q_{in} = (W_{fuel}/(1+(MC/100))) \times HHV$, BTU

$Q_{in\,LHV} = (W_{fuel}/(1+(MC/100))) \times LHV$, BTU

13.8. Determine Heat Output and Delivered Efficiency

$Q_{out} = \Sigma$ [Heat output determined for each sampling time interval]+ Change in heat stored in the appliance.

$Q_{out} = [\Sigma(C_{pi} \bullet \Delta T \bullet M \bullet t_i)]+(W_{app} \bullet C_{steel} + C_{pa}\, W_{water}) \bullet (TF_{avg} - Ti_{avg})$, BTU

Note: The subscript (i) indicates the parameter value for sampling time interval ti.

Mi = Mass flow rate = gal/min x density of water (lb/gal) = lb/min

Mi = Vfi · σi, lb/min

σi = (62.56 + (-.0003413 x T3i) + (-.00006225 x T3i 2)) 0.1337, lbs/gal

Cp = 1.0014 + (-.000003485 x T3i) Btu/lb, °F

Csteel = 0.1 Btu/lb, °F

Cpa = 1.0014 + (-.000003485 X (TIavg +TFavg)/2), Btu/lb-°F

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Vfi = (Vi –Vi-1)/(ti-ti-1), gal/min

Note: Vi is the total water volume at the end of interval i and Vi-1 is the total water volume at the beginning of the time interval. This calculation is necessary when a totalizing type water meter is used.

13.9. Determine Heat Output and Delivered Efficiency With External Thermal Storage

Qout = Σ [Heat output determined for each sampling time interval] + Change in heat stored in the appliance + Change in heat in storage tank.

Qout = Σ[Cpi · Δ Ti · Mi · ti] + (Wapp · Csteel + Wwater · Cpa) · (TFavg – Tlavg) + (WStorageTank · Csteel + WWaterStorage · Cpa) · (TFSavg – TISavg) Btu (MJ)

Note: The subscript (i) indicates the parameter value for sampling time interval ti.

13.9.1. Determine heat output rate as:

Heat Output Rate = Qout/Θ, BTU/hr

13.9.2. Determine emission rates and emission factors as:

$E_{g/MJ} = E_T/(Q_{out} \times 0.001055)$, g/MJ

$E_{lb/MM\ BTU\ output} = (E_T/453.59)/(Q_{output} \times 10^{-6})$, lb/mmBtu Out

$E_{g/kg} = E_T/(W_{fuel}/(1+MC/100))$, g/dry kg

$E_{g/hr} = E_T/\Theta$, g/hr

13.9.3. Determine delivered efficiency as:

$\eta_{del} = (Q_{out}/Q_{in}) \times 100$, %

$\eta_{del\ LHV} = (Q_{out}/Q_{in}\ LHV) \times 100$, %

13.9.4. Determine ηSLM - Overall Efficiency (SLM) using Stack Loss

13.9.4.1. For determination of the average overall thermal efficiency (ηSLM) for the test run, use the data collected over the full test run and the calculations in accordance with CSA B415.1-10, clause 13.7 except for 13.7.2 (e), (f), (g), and (h), use the following average fuel properties for oak: percent C = 50.0, percent H = 6.6, percent O = 43.2, percent ash = 0.2 percent. The averaging period for determination of efficiency by the stack loss method allows averaging over 10-minute time periods for flue gas temperature, flue gas CO_2, and flue gas CO for the determination of the efficiency. However, under some cycling conditions, the "on" period may be short relative to this 10-minute period. For this reason, during cycling operation the averaging period for these parameters may not be longer than the burner on period divided by 10. The averaging period need not be shorter than one minute. During the off

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period, under cycling operation, the averaging periods specified may be used. Where short averaging times are used; however, the averaging period for fuel consumption may still be at 10 minutes. This average wood consumption rate shall be applied to all of the smaller time intervals included.

13.9.4.2. Whenever the CSA B415.1-10 overall efficiency is found to be lower than the overall efficiency based on load side measurements, as determined by this method, the test report must include a discussion of the reasons for this result. Any result which finds efficiency greater than 5% shall result in a failed test run.

13.10. *Determine Steady-State Efficiency.* Determined delivered efficiency over the five phases is representative of annual efficiency. For Steady-State efficiency of high and low heat demands, determine the delivered efficiency of the individual steady-state phases, Phases 1,2, and 5.

$\eta_{del(p1)}$ Delivered Efficiency of Phase 1, percent

$\eta_{del(p2)}$ Delivered Efficiency of Phase 2, percent

$\eta_{del(p5)}$ Delivered Efficiency of Phase 5, percent

$\eta_{del(p1)} = Q_{out(p1)} / Q_{in(p1)} \times 100, \%$

$\eta_{del(p2)} = Q_{out(p2)} / Q_{in(p2)} \times 100, \%$

$\eta_{del(p5)} = Q_{out(p5)} / Q_{in(p5)} \times 100, \%$

13.11. Carbon Monoxide Emissions.

For each minute of the test period, the carbon monoxide emission rate shall be calculated as:

$$CO_{g/min} = Q_{std} \cdot CO_s \cdot 3.30 \times 10^{-5}$$

Total CO emissions for each of the five test phases ($CO_{\_1}$, $CO_{\_2}$, $CO_{\_3}$, $CO_{\_4}$, $CO_{\_5}$) shall be calculated as the sum of the emission rates for each of the 1-minute intervals. Total CO emission for the test run, COT, shall be calculated as the sum of $CO_{\_1}$, $CO_{\_2}$, $CO_{\_3}$, $CO_{\_4}$, and $CO_{\_5}$. 10-minute averages can be used in place of 1-minute intervals if appropriate as 13.8.4.1.

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14. Reporting Requirements. The report shall include the following:

14.1. Introduction - no portion of the introduction may be claimed as CBI.

14.1.1. Purpose of test: certification, audit, efficiency, research, and development

14.1.2. Name and location of the laboratory conducting the test.

14.1.3. Wood appliance identification – manufacturer, model number/name, design type, description of the appliance tested, appliance condition, and date of receipt.

14.1.4. Test information – location of testing, date of tests, sampling methods used, number of test runs, a statement detailing any previous testing completed on the wood appliance.

14.1.5. A list of participants, their roles, and any observers present for the tests. The list shall include the participant's name, title, company, contact information and the purpose of their participation.

14.1.6. A statement that the test results apply only to the specific appliance tested.

14.2. Summary and Discussion of Results - no portion of the introduction may be claimed as CBI.

14.2.1. Table of results to include test run number, average burn rate for entire run, particulate emission rate for full run, particulate emission rate for start-up, carbon monoxide emission rate for a full run, carbon monoxide for startup, efficiency, burn time – total and by phase.

14.2.2. If the TEOM is used, the report shall contain the following:

14.2.2.1. For each test run use the TEOM to apportion filter PM data and use real-time analyzer data for other emissions to report: Θ_1,Θ_2, Θ_3, CO, CO_2, PM, and efficiency for (1) the start-up phase and (2) high-, (3) maintenance-, and (4) overnight-fire phases. Calculated results for the emissions reported as total emissions in grams, pounds per million Btu output, grams per MJ, grams per kilogram of dry fuel and grams per hour, and pounds per hour.

14.2.2.2. A statement of the estimated uncertainty of measurement of the emissions and efficiency test results.

14.2.2.3. A plot of CO emission rate in grams/minute vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.2.4. A plot of CO_2 emission rate in grams/minute vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.2.5. A plot of PM emission rate in grams/hour vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per

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hour on a rolling basis for the test run.

14.2.2.6. Summary of other data – test facility conditions, surface temperature averages, catalyst averages, pretest fuel weights, test fuel charge weights – total and by phase.

14.3. *Emission Calculations*. Particulate matter, carbon dioxide, and carbon monoxide shall be calculated using the following methodology and reported in grams per hour, grams per kilogram and pounds per million British Therma Unit (Btu) per hour based on heat output:

14.3.1. Two measurements shall be reported

14.3.1.1. Start-up. Emissions from match light until the end of the start-up phase shall be collected and reported as a separate element using two ASTM 2515-11 trains. One-hour data shall be reported by a third ASTM 2515-11 train or the TEOM data calculated per the SOP.

14.3.1.2. Integrated Result. The results two, dual ASTM E2515-11 trains shall integrate into a single result the appliance performance over the five phases of this test methods operational protocol.

14.3.2. Particulate Matter emissions.

14.3.2.1. During the test run, particulate emissions shall be measured per the requirements of ASTM E2515-11 with exceptions noted in 9.4 of this test method. This involves two sampling trains providing an integrated measurement over the entire test period, Phases 1 through 5.

14.3.2.2. During the entire test run, particulate concentration in the dilution tunnel shall also be measured in real time using a Tapered Element Oscillating Microbalance (TEOM) instrument, or equivalent, as per Appendix A to this test method. Section 9 of Appendix A prescribes the methodology to determine the total PM emitted during each Phase and for the entire test run in grams.

14.4. Discussion. - no portion of the discussion may be claimed as CBI.

14.4.1. Discussion shall include detailed information describing each test conducted on the appliance:

14.4.1.1. How the test was run

14.4.1.2. Specific test run problems and solutions

14.4.1.3. Test run result

14.5. Process description:

14.5.1. Data and drawings indicating the fire box size and location of the fuel charge.

14.5.2. Drawings and calculations used to determine firebox volume to include volume, height, width, and lengths, weight and volume adjustments. No portion of this section can be CBI.

14.5.3. Firebox configuration – At a minimum to include air supply locations and operation,

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air supply introduction location, refractory location and dimensions, catalyst location, baffle and by-pass location and operation (include line drawings or photographs)

14.5.4. Process operation during test – shall supply details on air supply settings and adjustments. No portion of this section can be CBI.

14.5.5. Test fuel properties – species, density, fuel moisture, fuel temperature, and load details. No portion of this section can be CBI.

14.5.6. Sampling. No portion of this section can be CBI.

14.5.6.1. A description of the test procedures and test equipment including a schematic or other drawing showing the location of all required test equipment. Also, a description of test fuel sourcing, handling and storage practices shall be included.

14.5.6.2. Describe sampling location relative to appliance, include drawing or photographs.

14.5.6.3. Provide data on sampling blanks.

14.6. Quality Control and Assurance Procedures. No portion of this section can be CBI.

14.6.1. Calibration procedures and results certification procedures, sample and analysis procedures.

14.6.2. Test method quality control procedures to include leak-checks, volume meter checks, stratification (velocity) checks, proportionality results.

14.7. Appendices – No data contained in the appendices can be claimed as CBI.

14.7.1. Results and Example Calculations. Complete summary tables and accompanying calculations.

14.7.2. Raw data. Copies of all files or sheets for sampling measurement, temperatures records, and sample recovery data.

14.7.3. Sampling and Analytical procedures. Detailed description of procedures followed by laboratory personnel in conducting the certification test.

14.7.4. Calibration Results. Summary of all calibrations, check and audits pertinent to the certification.

14.7.5. Sampling and Operation Records. Copies of all uncorrected records of activities not included in raw data sheets (e.g. appliance door open, times and durations).

14.7.6. User Guide. Appliance instructions for operating the device during the test following the User Guide specifications detailed in Section 8.1.1.

14.7.7. Test Facility Information. Report test facility temperature, air velocity, and humidity information.

14.7.8. Test Equipment Calibration and Audit Information. Report calibration and audit results for the platform scale test fuel balance, test fuel moisture meter, and sampling equipment, including volume metering systems and gaseous analyzers.

14.7.9. Pre-test procedures. Report all pretest procedures conduct at the lab on the appliance

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to burns, rates, and amounts.

14.7.10. Details of deviations from, additions to or exclusions from the test method, and their data quality implications on the test results (if any), as well as information on specific test conditions, such as environmental conditions. An explanation of the deviations, additions, or exclusions shall be provided along with an analysis as to why these elements had no impact.

14.7.11. All required data and applicable blanks for each test run shall be provided in spreadsheet format both in the printed report and in a computer file such that the data can be easily analyzed and calculations easily verified. Formulas used for all calculations shall be accessible for review.

14.7.12. For each test run: report TEOM flow and temperature and verification of all TEOM parameters presented in the TEOM 1405 SOP.

14.7.13. Raw data, calibration records, and other relevant documentation shall be retained by the laboratory for a minimum of 7 years.

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Table 1A – Must complete a table for each test run, minimum of three

Data Summary Part A - Run 1

Phase	Target Load	Actual Load	Phase Duration	Wood Consumed	Stack Loss Efficiency	Thermal Efficiency	Min Water Return Temp.
	Btu/hr	Btu/hr	hours	lbs	%	%	°F
1							
2							
3							
4							
5							
Total Run							

Data Summary Part A - Run 2

Phase	Target Load	Actual Load	Phase Duration	Wood Consumed	Stack Loss Efficiency	Thermal Efficiency	Min Water Return Temp.
	Btu/hr	Btu/hr	hours	lbs	%	%	°F
1							
2							
3							
4							
5							
Total Run							

Data Summary Part A - Run 3

Phase	Target Load	Actual Load	Phase Duration	Wood Consumed	Stack Loss Efficiency	Thermal Efficiency	Min Water Return Temp.
	Btu/hr	Btu/hr	hours	lbs	%	%	°F
1							
2							
3							
4							
5							
Total Run							

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Table 1B – Must complete a table for each test run, minimum of three

Data Summary Part B – 60-minute test results

Phase	EFco	EIco	ERco	EFpm	EIpm	ERpm	E_i	Ert_i		
	Lb/MMBtu output	g/kg fuel	g/hr	Lb/MMBtu output	g/kg fuel	g/hr	g	g		
Run 1										
Run 2										
Run 3										
Average of all runs										

Table 1C Data Summary – Averages

	EFAco	EIAco	ERAco	EFApm	EIApm	ERApm	Thermal Efficiency ηTA
	Lb/MMBtu output	g/kg fuel	Lb/hr	Lb/MMBtu output	g/kg fuel	Lb/hr	%
Test 1							
Test 2							
Test 3							
Average of three tests							

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Appendix A
Standard Operation Procedures for Thermo 1405 TEOM®
for use in a dilution tunnel or with an extractive dilution system
Version 1.0a, May 17, 2019

Section 1. Introduction

This document covers operation concepts and procedures for use of the TEOM model 1405 to measure and report continuous particulate matter (PM) measurements in EPA Method 5G dilution tunnel or equivalent dilution method. The Thermo-Scientific model 1405 TEOM is designed for ambient real-time PM measurements. It is an inertial microbalance - a true continuous mass measurement method with resolution of 0.01 µg (0.00001 mg). The TEOM is highly configurable, allowing the instrument to be "tuned" to best meet the needs of a specific application. The version of the TEOM used here is the simplest, without any sample conditioning options such as "SES" or "FDMS". For dilution tunnel PM measurements, the TEOM flows, temperatures, and timing settings are changed from the normal ambient settings. There are no hardware modifications needed. Instrument manuals, software, and related support information are available from the NESCAUM TEOM document collection.[2]

Flow Setting
Recommended flow setting is 0.5 liters per minute (lpm) at EPA STP. If very low PM concentrations consistently less than 5 mg/m^3 are expected, higher settings of 1 to 3 lpm can be used. Higher flow gives better sensitivity but shorter filter life. The flow settings should be set to provide the needed sensitivity but also ensure reasonable filter life. For appliances where heavy loading is anticipated, a setting of 0.5 lpm shall be used. Appliances with lighter PM loading can use a setting of 1 or 2 lpm depending on the intended use of the data; high time resolution (10 seconds instead of 1 minute) requires higher flows to achieve the same sensitivity. The TEOM flow must be constant during a test run – it can not be changed while sampling.

Filter Temperature Zones Settings
The three TEOM filter temperature zones are normally set to 30 C (86 F). Temperatures can be set somewhat higher if laboratory temperature is expected to be over 80 F, but no higher than 33C (91F). Temperatures can not be changed during a sampling run. The TEOM filter temperature setting is always a trade-off between stability during highly dynamic burn

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2 The TEOM manual is referenced in this SOP, and is available here:
https://www.thermofisher.com/order/catalog/product/TEOM1405
Additional support documents are at https://drive.google.com/open?id=0B4duMFtoHVUENk9uemxsbHRJczA

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conditions, minimizing loss of semi-volatile organic carbon mass, and avoiding condensing conditions at the filter temperature. Water is considered a semi-volatile mass (SVM) component, but standard practice is to minimize the amount of water measured as part of the PM. Based on current data, 30 C represents an appropriate setting.

TEOM Filter Dynamics

Rapid changes in the sample matrix (PM, gases, water vapor) may result in transient TEOM PM (positive or negative) concentration excursions. This is not an instrument malfunction; it is a result of the mass dynamics occurring on both the TEOM and filter pull filters. The TEOM filter material (Emfab TX40), temperature (30 C), and filter loading are similar to the gravimetric sample train rate (the TEOM filter face velocity is 6.3 cm/sec at 0.5 lpm). Thus, the filter pull PM and TEOM PM measurements should be in agreement and highly correlated if both sampling systems are working properly.

While TEOM PM transients from filter dynamics are usually no longer than 1 or 2 minutes, there can be situations where these filter dynamics can result in data quality issues for an extended period of time. One example is a very rapid transition (a few minutes) from a very dirty burn (as much as 300 mg/m^3 in the tunnel) to a very clean burn (a few mg/m^3 or less), as experienced with some devices during startup or fuel reloads. For that scenario, it may be necessary to change the TEOM filter after a high loading phase to avoid a prolonged period of a large negative bias to the TEOM PM due to loss of SVM off of the filter from the high loading phase. See Section 6 for more information on when to do pre-emptive filter changes (filter changes done to prevent or minimize negative TEOM data).

The TEOM configuration used here allows for fast filter changes with minimal data loss (typically a few minutes) and does not require flows and temperatures to be within predefined instrument limits for valid data for PM concentrations to be reported. Critical instrument parameters are stored with the concentration data and can be used to invalidate data during review and processing as needed.

Instrument Software

RPComm (serial port interface) is the legacy TEOM program and can be used to display the last 15 minutes of data on a graph, download data, and read all key operating parameters easily. The ePort program (ethernet interface) is used to control the instrument remotely and to download data. Both programs can be used at the same time.

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Section 2. Overview of Routine Operation Procedures for Thermo 1405 TEOM

This section is a summary of routine operating procedures.

A. Quality Assurance checks to be completed after initial installation, and routinely every 6 months:

1. Modify system settings as detailed in Section 10
2. Perform KO check detailed in Section 5
3. Perform leak check detailed in Section 5

B. Routine procedures before every test run to be conducted 2-3 hours prior to testing.

1. Set TEOM filter temperature for the run. Changing this setting requires at least one hour before valid data can be collected. Detailed instructions on this element can be found in Section 3.
    a. The TEOM filter temperature must be at least 1 C above the hottest lab temperature expected during the test. The normal setting is 30 C (84 F) but may be set as high as 33 C (91 F).
    b. All three (3) temperatures zones - cap, air, case – must be set to the same value.

2. Set TEOM flow settings for the run. Changing this setting requires at least one hour before valid data can be collected. Detailed instructions on this element can be found in Section 4. TEOM flow can only be changed before a test run – it can not be changed during a run when the TEOM is sampling.
    a. Set flow
        i. Anticipated concentrations >5 mg/m^3: 0.5 lpm
        ii. Anticipated concentrations <5 mg/m^3: 1-3 lpm
    b. Calibrate TEOM flows. This step must be completed whenever the flow is changed. An external mass flow meter such as the TSI 4140 is used for flow calibrations.

3. Check the TEOM time and set as needed.
    Changing the time causes an instrument reboot and loss of up to an hour of data. See note below.

4. Initial filter change
    a. Install a clean filter before each run.
    b. Use the "Advanced" filter change mode.
    c. Perform an external flow check with the clean filter or before the start of a run.
    d. The net flow reading shall be within 2% of the TEOM flow setpoint.

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C. *One hour before testing*

Check TEOM settings for appropriate temperature, flow and time settings. Perform an external flow check as detailed in Section 4 and record the results. For valid results the flow check should be within 2% of the TEOM flow setpoint.

D. *Testing Operations*

1. Before initiating the test, run the TEOM while sampling dilution tunnel or diluter air for at least 5 minutes. The change of pressure can cause a transient TEOM response.

2. Filter Changes are done pre-emptively as described in Section 6 and whenever the TEOM filter loading reaches 130%, as reported on the TEOM, or when the sample flow starts to drop. The 1405 does NOT have any clear visual warning that the filter needs changing, but it is possible to use the TEOM digital outputs (relay contact closures) to trigger an external alarm at any desired filter loading.

   The "Advanced" filter change wizard mode shall be used to eliminate long equilibration period after the change; this stops the tapered element oscillation, resets the filter mass measurement, and simplifies filter changes. Detailed information on performing filter changes during testing is provided in Section 6 of this document.

3. At the end of the test perform an external flow check as detailed in Section 4 and record the result. For valid results flow check should be within 2% of the TEOM flow setpoint.

4. Download the test data using either the Thermo ePort software (preferred), RPComm, or to a USB thumb drive. Note: the data format may be different depending on how the data is downloaded.

<u>Notes:</u>

- It is normal for there to be "Warnings" present for the ambient T/RH sensors (not used). This is the only allowable warning once the system is warmed up and is in use for testing.

- When the TEOM is first turned on or rebooted, <u>no data are recorded</u> until the top of the next hour. As long as the TEOM is not rebooted, data will be recorded regardless of instrument status.

- When the time is changed, the instrument reboots (after many seconds of being hung, with no information on the screen). When it reboots, <u>no data are recorded</u> until after the top of the next hour (see above).

- TEOM PM concentrations are in micrograms per cubic meter, at EPA STP (25C and 1 atmosphere) unless the instrument configuration is changed. Filter mass loading is

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reported in micrograms, with a resolution of 0.01 micrograms (10^{-8} grams).

Section 3. Filter Temperature Adjustment SOP for 1405 TEOM

The TEOM filter temperature has the capacity to be set between 30 and 55 degrees C, however for testing purposes the filter temperature should be set to between 30 and 33 C. If the temperature is too low (less than 1 C above room temperature), the instrument may not be able to maintain the temperature set-point, possibly resulting in loss of data. Temperatures higher than necessary may result in excessive loss of semi-volatile PM during sampling. There are three temperature settings - cap, air, case – that shall all be set to the same value.

Temperature Change Procedure.
The TEOM temperatures are set in the Instrument Conditions, Temperatures menu. Temperatures can not be changed during a sampling run.

Note: The **T-Air** temperature zone may take a very long time (30 minutes or more) to stabilize, especially when the temperature is higher than the setpoint. If the "Case" temperature is within 0.1 C of the setpoint, data are usually valid.

Section 4. Sample Flow Check and Adjustment for the Thermo 1405 TEOM

Checking the Sample Flow.
The TEOM should be warmed up for at least 30 minutes before checking or adjusting the sample flow. The sample flow can not be changed during a test run. The sample flow should be checked at the sensor inlet with an external mass flow meter that reads in STP; that flow should be within 2 % of the flow on the TEOM display. Flow checks must be done:

A. at the start of every sampling day (with a clean filter),
B. at the end of the run (with the dirty filter), and
C. whenever the flow setting is changed.

Record the external flowmeter reading without flow as the zero and subtract that value from the flowmeter reading with flow to get the measured flow value.

If the post-test flow check (with a loaded filter) is lower than the initial flow check (with a clean filter), that is an indication of a possible leak. A leak test should also be performed whenever the flow check difference (between the TEOM display flow and the external flow meter flow) changes.

If the external flow (at EPA STP, with zero offset correction) is more than 5% off from the TEOM display flow, measure the flow without a filter in the TEOM. If the external flow check result is low with a filter but higher or correct without a filter, that is an indication of a leak.

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If the flow is the same with and without a filter and out of spec, the flow calibration routine should be performed. This routine should also be performed whenever the sample flow setting is changed.

Flow settings.
The TEOM sample flow can be set to between 0.5 and 3.0 LPM (all flows are at EPA STP of 1 atm. and 25 C). Lower flow gives longer filter lifetime and less sensitivity. Higher flow gives shorter filter lifetime and more sensitivity. The flow should be set to provide reasonable filter lifetime (typically at least 30 minutes) for any given test scenario, since about 4 minutes of data are lost when the filter is changed.

For most cases, the flow should be set to 0.5 LPM. If a high loading burn (PM greater than 20 mg/m^3) is anticipated, the flow must be set to 0.5 LPM. Flows higher than 1 LPM shall only be used when very light loading is expected (PM consistently below 2 to 3 mg/m^3).

The sample flow is set in Instrument Conditions, Flows, Flow Rates. Flow is calibrated using the wizard at Service, Calibration, Flow Calibration (page 5-39 of the TEOM manual).

NOTE: The TEOM sample flow cannot be changed during a test run.

Section 5. Leak Test and KO Check Procedure for 1405 TEOM

The Leak Test and K0 Checks described here do not need to be done on a routine basis. They should be done at least every 6 months, or as needed for troubleshooting.

Leak Check
A leak test measures the flow as reported by the TEOM's flow sensor with the inlet closed off. The TEOM leak test flow measurement must be corrected for the TEOM flowmeter's zero offset. To conduct a flow check, follow the procedures below:

1. With the TEOM warmed up for at least 30 minutes, read the TEOM reported flow with the pump turned off. This is the flowmeter zero reading.
2. Close off the inlet to the TEOM with a brass swage cap.
3. Turn on the TEOM pump.
4. Wait one minute and read the TEOM flow.
5. The leak test value is the difference between the reading without and with the pump on.
6. The leak test should be no greater than 0.05 lpm (net value).
7. Turn the pump off and remove the brass swage cap from the TEOM inlet.

K0 Check
In addition to routine pre- and post-sampling flow checks, a K0 check is another test that shall be completed to validate proper operation of the TEOM. K0 checks confirm the calibration factor for the tapered element mass transducer. It is done once per year and as needed. See page 5-50 of the manual.

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Section 6. Filter Change Procedure for 1405 TEOM

The TEOM measures the pressure drop across the filter as % of maximum (~ 100 to 130 %), shown on the instrument=s display. A clean filter has a loading of about 5% at 0.5 LPM and ~ 7% at 1 LPM. Filter lifetime will vary widely depending on the PM concentrations being sampled. At very high PM concentrations (several hundred mg/m^3), filter lifetime may be only 10 to 15 minutes. Under typical sampling conditions, lifetime is at least 30 minutes and up to an hour or more with concentrations in the 20 to 50 mg/m3 range. With care, filter changes can be done such that only a few minutes of data are lost.

The TEOM filter must always be changed before the filter mass loading becomes too high and the filter plugs and the sample flow drops. TEOM filters can also be changed before they overload to minimize negative data.

When TEOM data are the primary data source, The Teom filter gets changed whenever ANY of the following conditions are met. This minimizes negative or negatively biased Teom PM measurements.
2a. Filter plugs
2b. Filter mass loading exceeds 1000 ug AND the filter has been in use for at least 30 minutes. [both conditions have to be met]
2c. Persistent (at least several minutes) negative data of at least -2 mg/m^3 is observed that is not due to instrument noise when concentrations are very clean.
For this purpose, negative Teom data should be set to 0 in the final data set.

<u>Filter change procedure.</u>

The following are filter handling procedures that shall be followed:

A. Unused clean filters should be stored in the original box, with the silica gel desiccant.
B. Two clean filters should be stored in the mass transducer.
C. Filters should only be handled with the filter change tool that is stored inside the TEOM cabinet.

The TEOM manual has illustrated procedures for filter changes starting on page 5-6. Try to minimize the time the mass transducer is open to minimize the time needed to re-stabilize after the filter change.

1. The filter change menu can be located by pushing the Service, Maintenance, Replace Filter. Select Advanced option, and then Next to proceed.

2. Open the TEOM cabinet door, open the box of clean filters, and open the mass transducer. Remove the old filter by sliding the filter tool onto the filter and pulling straight out. Do not twist the tool (to prevent damage to the glass tapered element).

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3. Pick up a new filter (stored inside the mass transducer) with the tool. Position it directly over the tapered element and push the filter on gently. Once the filter is on, remove the tool from the filter and fully seat the filter by pushing firmly straight down on the filter with the bottom of the tool (see section 3 of the manual for more information). Store another new filter in the mass transducer.

4. Close the mass transducer, replace the filter box cover, and close the cabinet. Restart the TEOM by completing the filter change wizard.

5. If the PM concentration as read on the RPComm graph hasn't stabilized within 5 minutes, or if the Frequency is close to 0 (~10 instead of a few hundred Hz) the filter may need to be reseated or is defective, or the sensor latch is not closed properly. Repeat the filter change "advanced" procedure and take the filter off and re-seat it. Push it on firmly with the back of the filter tool and make sure the sensor is properly closed and latched. After two attempts, restart the procedure with another new filter.

Note: the PM concentration on the TEOM display will read 0 after a filter change until the top of the next hour. When valid data are being collected, the RPComm graph will indicate the concentration, and the "Total Mass" on the TEOM display will read something other than "0.00".

► There is one exception to this: after an instrument reboot for any reason (including setting the time), data are not stored until after the top of the next hour, even if the RPComm graph is showing data and the Total Mass is not 0.

Section 7: Reserved for future use

Section 8: Data Storage and Download

The TEOM shall be set to store data every 10 seconds. There is storage for several days of data at this storage interval. Data can be downloaded while the TEOM is running.

Data are usually downloaded with the ePort software but if needed can also be downloaded to a USB thumb drive or with the RPComm TEOM software. The data file is in .CSV format for importing into a spreadsheet.

Data parameters are saved as follows:

1. Date, Time
2. PM-2.5 raw MC
3. PM-2.5 MC
4. PM-2.5 total mass
5. PM-2.5 30-Min MC
6. Operating mode
7. System status
8. PM-2.5 flow rate

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9. PM-2.5 TEOM filter load
10. PM-2.5 TEOM filter pressure
11. Case temperature
12. Cap temperature
13. PM-2.5 air tube temperature
14. Enclosure temperature (temperature on the main TEOM circuit board)
15. PM-2.5 TEOM noise
16. PM-2.5 TEOM frequency
17. Vacuum pump pressure

The key parameters for data validation and analysis are:

1. Date and Time – reported as the end of the average interval
2. PM2.5 raw - PM2.5 raw is the same as PM2.5 MC except it is always reported even when the instrument status is invalid. This minimizes loss of data but also requires manual editing of the data file to remove invalid PM concentrations based on review of the data and critical parameters such as flow and temperatures. Concentration is in $\mu g/m^3$. A zero value for Mass Conc indicates no data.
3. PM2.5 total mass - the mass loading on the TEOM filter in µg.
4. PM2.5 flow rate - Flow is SLPM unless something else is used in the instrument configuration.
5. PM2.5 TEOM filter load - filter loading as % of maximum.
6. Case temperature, in degrees C.
7. Noise is a data stability metric and should normally be less than 0.10 when pm concentrations are low or zero.

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Section 9. Data Validation and Calculations

TEOM data are recorded every 10 seconds to minimize data loss during filter changes. Data validation is performed on the 10 second data and then usually averaged up to 1-minute intervals for reporting use.

TEOM data are valid when all flows and temperatures are within the defined operating ranges specified below.

1. "Case" temperature is stable and within 0.1 deg C of set-point. Other temperatures can be off as long as the Case temperature is stable and close to the set-point.
2. Flow reported by the instrument should be within 5% of the flow setpoint.

Because of the way the Teom is run here [with a wait time of 0], it never invalidates any data. Thus the data must always be reviewed and cleaned up manually. The wait time is set to 0 to minimize data loss during a filter change, or when the "Cap" temperature is out of range but the data are ok. The Teom reports a concentration of 0 or repeating values when there are no valid data.

The "Raw MC" PM concentration parameter is reported regardless of instrument conditions and thus includes invalid data that need to be removed during data validation. Normally the only data that need to be removed are during a filter change that occurs during a run. When a filter is changed, the last valid concentration value is repeated until new valid data are available. These repeating data are removed manually during validation and considered as "missing" data.

Note: For cumulative PM emission measurements (total grams of PM emitted during a burn phase or run), missing data shall be filled in with best-estimates based on the 1-minute PM concentrations immediately before and after the filter change. Otherwise, the effective emissions for the period with missing data are zero, creating a negative bias in the measurement.

It is common for the TEOM PM concentration to be somewhat negative during some burn phases. This happens when the TEOM filter mass loading is large and PM emissions are relatively low (e.g., for a clean burn phase that follows a dirty burn phase), and the TEOM filter loses mass. This can be controlled by pre-emptive filter changes as described in Section 6. Small negative concentration up to a few mg/m^3 can still occur however. To minimize measurement bias, these small negative concentrations should always be set to 0 during data processing. Large and rapid negative data swings in concentration may indicate a problem with the instrument and should normally be considered invalid or missing data (not set to 0).

The output of the TEOM is PM concentration in $\mu g/m^3$ at 25 C and 1 Atmosphere (29.92 inches Hg) pressure. To correct TEOM data to the test or reporting conditions use the following:

$$\text{PM at local T and P} = \text{PM at STP} * (298/T) * (P/29.92)$$

The 1-minute TEOM PM concentration is converted into grams/hour using the stack flow as follows.

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Stack flow from the vane anemometer (in m/s at stack temperature) is converted to cubic meters per minute at STP (25 C and 1 ATM.) using the stack diameter and temperature. Flow is then multiplied by Teom PM concentration (at STP) in grams per cubic meter to get PM emission rate in grams per minute. Multiply that by 60 to get grams per hour at 1-minute intervals. The average of all 1-minute PM emission rate measurements is the run-average grams per hour value.

Note: Proportionality with stack flow is not needed for PM emission rates from Teom PM data, since all of the data (stack flow, stack temperature, and PM concentration) are processed into PM emission rates using 1-minute data.

TEOM data can be used to apportion the PM emission rate (g/h) measured by a Method 5G or E2515 regulatory sample train to multiple burn phases by applying a correction factor to the 1-minute Teom data. The correction factor is the ratio of filter pull full run g/h to TEOM full run g/h. The 1-minute TEOM data is then adjusted by this correction factor.

For calculation of lbs/mmbtu, total grams PM emitted is calculated by multiplying the average g/h rate for the test period of interest times the number of hours of that test period. Grams are converted to lbs by multiplying grams by 453.6.

Section 10: TEOM Configuration Changes for Fast Response and High PM Concentrations, and List of TEOM Parameter Configuration Values.

These settings are for the 1405 TEOM as used in this application that are different from instrument default settings. See the 1405 manual for detailed information on how to change these values.

1. Remove the A and B factors [+3 and x1.03] that are used for PM10 FEM status. "Mass Constant A" is set to zero, and "Mass Constant B" is set to 1.00.

2. Change system filtering and wait time settings:
TM (Total Mass Avg time) from 300 to 15 seconds
MR-MC (Mass Rate/Mass Conc Avg time) from 300 to 15 seconds
Wait Time from 1800 to 0 seconds (disabled)

3. Change the sample flow from 3.0 to 0.5 lpm. The bypass flow is set to 0.

4. Change all 3 temperature zones [Case, Air, Cap] to 30 C.

5. Set both the "Avg" and "Std" T/P to 25 C / 1 atm - this is the default for systems without the external temperature sensor. Select Passive and Standard as shown below.

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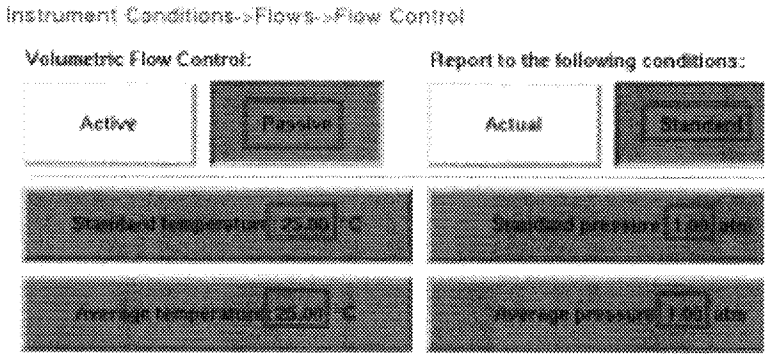

6. Change the Data Storage interval to 10 seconds.

A complete list of 1405 TEOM Settings that are modified from instrument defaults are listed below:

PRC	Description	Config Value	Unit	
12	storage interval	10	sec	
28	system wait time	0	sec	
35	mass average time	15	sec	See also PRC392 -- MRMC
48	case temperature set point	30	Deg C or higher as needed to maintain a stable case T	See also PRC 115 -- air tub
59	cap temperature set point	30	Deg C or higher as needed to maintain a stable case T	
74	average temperature set point	25	C	These are for reporting PM at EPA STP
75	standard temperature set point	25	C	These are for reporting PM at EPA STP
76	average pressure set point	1	atm	These are for reporting PM at EPA STP
77	standard pressure set point	1	atm	These are for reporting PM at EPA STP
91	bypass flow mass set point	0		Can be used as a baseline param for rpcomm plots.
115	TEOMA air tube set point	30	Deg C, or higher as needed to maintain a stable filter T; see also PRC 48 and 59.	
136	analog output1 minimum	-5000	optional -- ug/m3 as needed for RPComm plot scaling	
144	analog output1 maximum	50000	optional -- ug/m3 as needed for RPComm plot scaling	
227	TEOMA flow set point	1	lpm; or 0.5 to 2 lpm as needed; flow must be recalibrated if changed!	
392	MRMC average time	15	sec	
407	TEOMA mass constant A	0		
408	TEOMA mass constant B	1		

Note: all 3 temperatures must be set to the same value.

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Data Logging Parameters.

prc	description	var name in data file	Unit
244	raw mass conc	TEOMAMCRaw	ug/m3
245	mass conc	TEOMAMC	ug/m3
243	total filter mass loading	TEOMATotalMass	ug/m3
7	operating mode	OperatingMode	#
8	system status	StatusCondition	#
225	flow rate (STP)	TEOMAFlowMass	lpm
241	filter pressure	TEOMAFilterPressure	raw
242	filter load %	TEOMAFilterLoad	% of max
47	case temperature	CaseHeatTemp	C
58	cap temperature	CapHeatTemp	C
237	air tube temperature	TEOMAAirTubeHeatTemp	C
258	noise	TEOMANoise	ug
257	frequency	TEOMAFrequency	Hz

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