MEMORANDUM

To: Ms. Melanie Magee, EPA Region 6
CC: Denise Rogers, Texas Gulf Terminals Inc.
From: Brian Burdorf, Trinity Consultants
Date: August 18, 2018
RE: Response to MACT questions on Marine Loading emission calculations and lightering analysis

Ms. Magee,

Texas Gulf Terminals Inc. (TGTI) submitted a *Case-by-Case MACT Permit Application (Appendix D)* to EPA Region 6 on July 9, 2018, as part of the TGTI project to obtain a license for the operation of a Deepwater Port (DWP) in Federal waters of the U.S. Gulf of Mexico. Additional information was requested regarding several topics including the marine loading emission calculations and lightering analysis during a phone conversation on July 27, 2018.[1] Additional information is provided for the following topics:

- Explanation for use of Equation 1 instead of Equations 2 and 3 of AP-42 Chapter 5.2 for marine loading calculations.
- Information on speciation of HAPs via a gas analysis of the crude vapors.
- Reason for the use of different molecular weight and true vapor pressure for condensate to calculate annual and hourly emissions.
- Clarification on the usage of control efficiency onshore in the calculations for the lightering alternative analysis.
- A detailed discussion of the impact of secondary emissions for the lightering alternative anlaysis.
- Applicability of RACT
- Feasibility of measurement of emissions.

The following attachments are provided in support of TGTI's responses to the requests for additional information:

Attachment 1 – Comparison of Crude/Condensate Emissions between Equations 1 and 2 of AP-42 Chapter 5.2
Attachment 2 – Reference for Equation 3 of AP-42 Chapter 5.2
Attachment 3 – TGTI Crude Composition Data
Attachment 4 – Detailed Emission Calculations for Crude Vapor Speciation
Attachment 5 – Alternative Emission Calculations and Comparison Approach

Detailed information related to the emission calculations and lightering alternative analysis are also contained in the *Air Quality Information for Environmental Impact Statement (Appendix A)* which was submitted to EPA on July 9, 2018, and in the MARAD Deepwater Port License Application for the Texas Gulf Terminals Project (Volume I Appendix V).

[1] Phone conversation; Ms. Melanie Magee (EPA Region 6), Mr. Brian Burdorf (Trinity Consultants), and Mr. AJ Hansborough (Trinity Consultants) on July 27, 2018.

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1. Explanation for using Equation 1 instead of Equations 2 and 3 of AP-42 Chapter 5.2

TGTI Response: The use of Equation 1 and saturation factor from Table 5.2-1 provides the worst-case emissions from the proposed source. A comparison of crude oil and condensate loading emissions between Equations 1 and 2 is provided in Attachment 1.

Additionally, TGTI reviewed the equations EPA suggested and determined them not to be applicable for estimating emissions from the loading of very large crude carriers (VLCCs). The reference that EPA cites for Equation 3 in AP-42 Chapter 5.2, (provided as Attachment 2) "*Atmospheric Hydrocarbon Emissions From Marine Vessel Transfer Operations, Publication 2514A, American Petroleum Institute, Washington, DC, 2009*" clearly states that the derived equation should not be used to estimate evaporative losses from VLCCs or ultra large crude carriers (ULCCs) unless the saturation factor K_S is determined. Further, TCEQ has requested the use of Equation 1 over Equation 2/3 in the past several years.

2. Speciation of HAPs via a gas analysis of the crude vapors.

TGTI Response: The crude composition data obtained from TGTI is provided in Attachment 3. Benzene and toluene are the two HAPs identified from these profiles. A summary of HAP speciation obtained from the crude profiles is shown in Table 1 below.

Table 1. TGTI Crude Assays
HAP Speciation (Liquid wt%)

Profiles	Benzene	Toluene
1	0.22	0.61
2	0.65	2.74
3	0.76	0.32
4	0.15	1.37
5	0.24	0.47

The HAP vapor weight percentages are calculated based on the following steps.

First, liquid mole fraction (l_i) is calculated using the maximum liquid weight percent (W_i) from the crude profiles provided in Attachment 3 using the following equation.

$$l_i = (W_i / M_i) / \Sigma (W_i / M_i)$$

where l_i = liquid mole fraction of component i
M_i = liquid molecular weight of component I, lb/lbmol
W_i = liquid weight percent of component i

Second, partial pressure of the individual components is estimated using Raoult's law. According to Raoult's Law, the partial pressure of a component is the product of its pure component vapor pressure and its liquid mole fraction. The sum of the partial pressures is equal to the total vapor pressure of the mixture.

The pure component vapor pressures are calculated using the Antoine's equation.

$$\text{Log } P = A - B / (T + C)$$

where P = vapor pressure, mmHg
T = temperature, °C
A, B, and C = component-specific constants

Using the Antoine's coefficients for benzene as an example, A = 6.905, B = 1211.033 and C = 220.790, the pure component vapor pressure comes out to be 1.68 psia at 23°C. In order to calculate the mixture vapor pressure, the partial pressures need to be calculated for each component. The partial pressure is the product of the pure component vapor pressure of each component (calculated above) and the mole fraction of each component in the liquid as calculated in step 1.

Third, the vapor mole fractions of the components are calculated. The vapor mole fraction, y_i, is equal to the partial pressure of the component divided by the total partial pressure of the mixture.

$$y_i = P_{partial} / P_{total}$$

where y_i = vapor mole fraction of component i
$P_{partial}$ = partial pressure of component i
P_{total} = total partial pressure of the mixture

Fourth, the molecular weight of the vapor, M_V is calculated. Molecular weight of the vapor depends upon the mole fractions of the individual components in the vapor.

$$M_{Vi} = \Sigma M_i y_i$$

where M_{vi} = vapor molecular weight of component i
M_i = liquid molecular weight of component i
y_i = vapor mole fraction of component i

Finally, vapor weight fraction (W_i) of the component is the product of the molecular weight of the component (M_i) and vapor mole fraction (y_i) divided by the summation of the products of the molecular weight of the components and their vapor mole fractions.

$$W_i = M_i y_i / \Sigma M_i y_i$$

Based on the approach explained above, the average vapor weight fractions of components in the crude profiles at 73.5 °F are calculated and the maximum HAP vapor speciation is summarized below. Detailed emission calculations for HAP vapor speciation are provided in Attachment 4.

Table 2. HAP Speciation based on Crude profiles provided by TGTI

HAP	Max Single HAP Vapor wt%	Max Total HAP Vapor wt%
Benzene	0.24%	0.53%
Toluene	0.30%	

A conservative approach was employed that assumed benzene and toluene were the only components present in the crude and by applying a 100% safety factor to the benzene and toluene liquid weight fraction from the TGTI crude profiles. The resulting vapor weight fractions for benzene and toluene used in the DWP license application are summarized in Table 3 below. Please note that the HAP vapor weight percentages used in the DWP application (Table 3) are conservative since they are significantly higher than the HAP vapor weight fractions calculated based on the TGTI crude profiles (Table 2).

Table 3. HAP Speciation used in the Application

HAP	Max Single HAP Vapor wt%	Max Total HAP Vapor wt%
Benzene	0.95%	1.93%
Toluene	0.98%	

3. A different molecular weight and TVP was used for annual and hourly emissions from condensate. Explain if intended.

TGTI Response: The properties of gasoline were used to represent condensate in the hourly and annual emission calculations. A maximum true vapor pressure (TVP) of 11 psia is used to calculate hourly emissions from condensate. The annual emissions from condensate are based on an annual average RVP of 13.5 psia, which is equivalent to a TVP of 9.25 psia. For crude oil, the hourly and annual emissions are based on a maximum TVP of 11 psia and an annual average TVP of 11 psia. The TVP values used in the calculations are based on conservative assumptions.

Different molecular weights for the hourly and annual condensate emissions are used due to the fact that the molecular weight of gasoline (which is used to represent condensate) varies with vapor pressure. Different Reid vapor pressure (RVP) gasolines have different molecular weights. This is consistent with Table 7.1-2 of AP-42 Chapter 7.1, where the molecular weight of gasoline ranges from 60 – 68 lb/lb-mole for gasoline RVPs ranging from 7 – 15 psia.

4. Additional details on the lightering analysis.

The alternative for loading VLCCs (compared to the proposed SPM buoy system) involves the current process of lightering which requires ship to ship (STS) transfers. The alternative analysis quantifies the

comparable air emissions generated from VLCC loading through complete lightering and partial lightering. Initial details for the emission calculations and lightering alternative analysis are contained in the *Air Quality Information for Environmental Impact Statement (Appendix A)* which was submitted to EPA on July 9, 2018, and in the MARAD Deepwater Port License Application for the TGTI project (Volume I Appendix V). Additional details on the lightering analysis are explained below and in Attachment 5:

Loading of VLCCs through lightering is performed in one of two ways:

- ***Complete Lightering*** - VLCC Completely Loaded Offshore
    - Three (3) Aframax carriers are loaded onshore, they travel 65 miles[2] to the lightering zone, and unload via ship-to-ship transfers into the VLCC;

- ***Partial Lightering*** - VLCC Partially Loaded Inland with Remainder Loaded by Lightering Offshore
    - VLCC travels inland, loads up to 50% capacity inland; VLCC travels to lightering zone, Suezmax vessels loaded onshore, Suezmax vessels travel 65 miles[1] to lightering zone and unloads via STS transfers into the VLCC filling the remaining 50% of the VLCC capacity offshore.[3]

Clarification on the usage of control efficiency onshore in the calculations

TGTI Response: While some of the ship loading that occurs during the lightering process takes place onshore where emissions can be captured and controlled, this does not represent a reduction in emissions compared to the proposed SPM buoy system. The process of fully loading a VLCC offshore through lightering via STS transfer creates emissions equivalent to the emissions generated by the loading of the VLCC from the proposed SPM buoy system. Emissions generated from the onshore loading of the smaller vessels used for lightering (even though the onshore loading process would be controlled) are additional to the emissions generated later offshore during the STS transfer to the VLCC. Therefore, even though vapors generated from marine loading of the lightering vessels onshore are assumed to be collected with a system that achieves a 99% capture efficiency and 99% control efficiency, all of these emissions (VOC and other pollutants) are additional emissions which would not be generated by the proposed SPM buoy system.[6]

TGTI reviewed monthly data on how VLCCs have been loaded in 2018. This review identified that over 90% of crude oil loaded into VLCCs was loaded completely via STS transfers through lightering. The remaining crude oil loaded into VLCCs was loaded using a combination of partial loading onshore, offshore lightering, and loading at LOOP.[7] The emissions estimated for complete and partial lightering are therefore aggregated based on these percentages (i.e., the annual emissions estimate for the alternative scenario assumes 90% of the crude throughput will occur through complete lightering and 10% will occur as partial loading onshore and offshore lightering).

Details on Secondary Emissions generated during the Lightering process

TGTI Response: The proposed SPM buoy system represents the most efficient and safe way to fully and directly load a VLCC. The proposed SPM buoy system eliminates the inefficiencies that are inherent in lightering operations and eliminates additional emissions that are generated from the operation of the

[2] Estimated distance travelled is 65 miles.
[3] Only one onshore terminal in the US has partially loaded a VLCC onshore before the remainder is filled via lightering.
[6] *Control efficiency as represented for other onshore terminals and also per current TCEQ policy. Capture efficiency was obtained from "Air Permits Division Marine Loading Collection Efficiency Guidance (September 21, 2016)."*
[7] It should be noted that from an emissions standpoint, loading emissions at LOOP are equivalent to loading emissions generated via STS transfers during lightering because emissions are not captured and controlled.

lightering vessels which are not required for the SPM buoy system operation. TGTI has conducted an alternatives analysis that compares the potential emissions of the proposed SPM buoy system with the emissions that would be generated from an equivalent throughput of lightering.

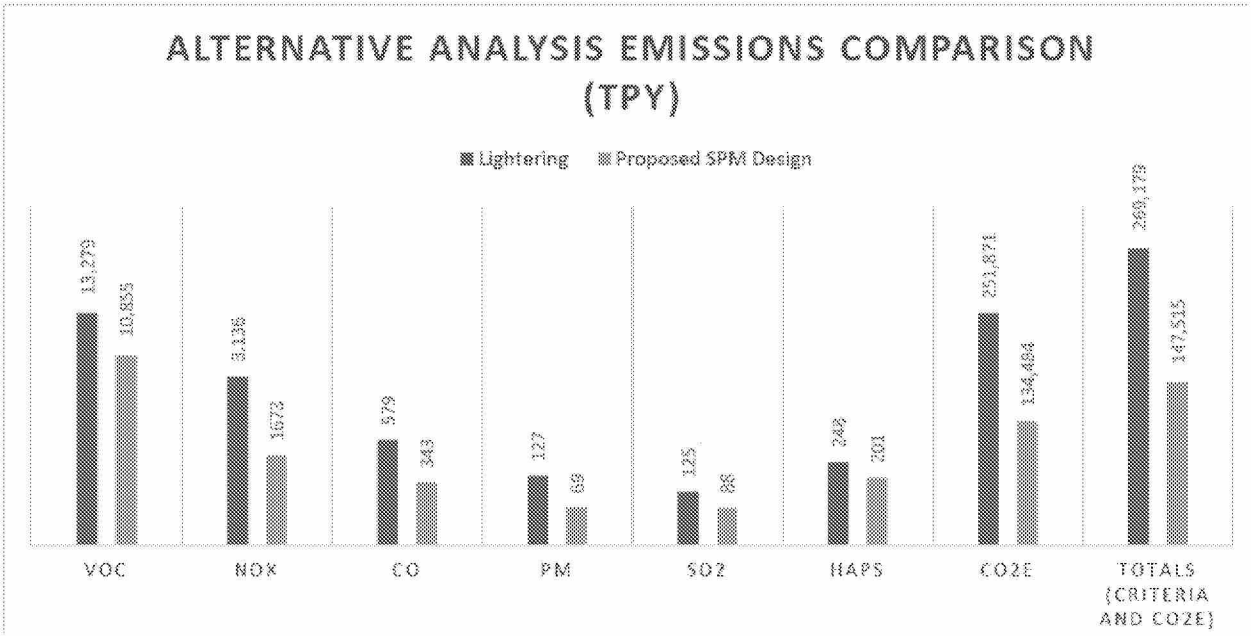
The emissions from lightering are based on loading of crude or condensate from Aframax or Suezmax vessels to the VLCC as described in the complete and partial loading operations above. As a conservative estimate, TGTI assumed 90% of lightering would be completed with complete lightering and 10% would be completed with partial lightering. Annual maximum loading rate of 192 million BBL/ year is used for emission estimation. Onshore VOC emissions are based on an aggregate of uncaptured fugitive emissions and controlled captured emissions. Emissions from combustion byproducts of the onshore control device are shown for NOx, CO, SO_2 and particulates. Total HAP emissions are calculated by multiplying the total VOC emissions with the HAP vapor weight fraction. The liquid composition of crude oil/condensate is obtained from crude profiles data provided by TGTI. A 100% safety factor is applied to the HAP liquid composition and used as an input to calculate the HAP vapor composition of crude oil/condensate.

The comparison of emissions for the proposed design to the Alternatives scenario are shown below based on the explanation provided above. Please note that this scenario shows separate emissions for Complete and Partial lightering and then it estimates the aggregate emissions. As demonstrated in the comparison table below,, the proposed SPM buoy system will not only have a lower environmental impact compared to lightering operations but it will also present a more efficient, logistically simplified, and safer approach to crude exports from the United States. Comparison of these emissions to the proposed design are represented in the following tables. Additional details on the emission calculations and comparison approach is included in Attachment 5.

Alternative Analysis Emissions Summary

Description of Activity	VOC tpy	NOx tpy	CO tpy	PM tpy	PM_{10} tpy	$PM_{2.5}$ tpy	SO_2 tpy	H_2SO_4 tpy	H_2S tpy	Total HAPs tpy	CO2e tpy
Proposed Project Design											
Crude Carrier, Support Vessels & Boats	47	1673	343	69.1	54.9	52.1	87.6	1.65	0.00	1.1	134484
Crude Carrier Loading	10808								0.24	200.0	
Proposed Project Design - Total	**10855**	**1673**	**343**	**69.1**	**54.9**	**52.1**	**87.6**	**1.65**	**0.24**	**201**	**134484**
Alternative Project Designs (Lightering) [1]											
VLCC completely loaded offshore - 3 AFRAMAX carriers load onshore, travel 65 miles [2] and then unload to VLCC											
Crude Carrier, Support Vessels & Boats	47	1,673	343	69.1	54.9	52.1	87.6	1.65	0.00	1.1	134484
Crude Carrier Loading	10808								0.24	200.0	
Lightering Loading	215	39	79	3.0	3.0	3.0	0.8		0.00	4.0	64737
Lightering Transit	2718								0.07	52.5	
Lightering Vessel Propulsion	28	1,410	128	53.4	53.4	49.1	32.8	1.03		0.5	50278
Additional Tugs/Support Ships [3]	5	94	41	5.1	3.0	2.9	5.5	0.17		0.1	8383
Complete Lightering	*13821*	*3,217*	*590*	*130.6*	*114.3*	*107.0*	*126.8*	*2.85*	*0.31*	*258*	*257903*
VLCC partially loaded inland and remaining loaded offshore - VLCC loads up to 50% capacity at shore; and Suezmax vessel fills the remaining 50% of the VLCC offshore [2].											
Crude carrier, Support Vessels & Boats	47	1,673	343	69.1	54.9	52.1	87.6	1.65	0.00	1.1	134,484
Crude Carrier Loading	5511								0.12	102.0	
Lightering Loading	108	20	39	1.5	1.5	1.5	0.4	0.00	0.00	2.0	32,378
Lightering Transit	2718								0.07	52.5	
Lightering Vessel Propulsion	13	627	57	23.7	23.7	21.8	14.6	0.46		0.2	22,346
Additional Tugs/Support Ships [3]	5	94	41	5.1	3.0	2.9	5.5	0.17	0.00	0.1	8,383
Partial Lightering	*8401*	*2,413*	*480*	*99.4*	*83.1*	*78.3*	*108.1*	*2.28*	*0.19*	*158*	*197,592*
Alternative Lightering Scenario Total [1]	**13279**	**3136**	**579**	**127.5**	**111.2**	**104.2**	**124.9**	**2.79**	**0.29**	**248**	**251871**
Emission Reduction (TPY) from Proposed SPM Design	2424	1463	236	58	56	52	37	1.1	0.1	47	117387

[1] Alternative Lightering scenario shown uses a combination of complete and partial lightering. Totals show a 90% emission contribution from 100% capacity loaded offshore "Complete Lightering" and 10% contribution from partially loaded capacity "Partial Lightering" for comparison purposes.
[2] The shortest distance between the shore and SPM location is 15 miles but the distance travelled is not straight and estimated to be 65 miles one way.
[3] The alternative lightering scenario assumes that one additional tug boat is needed for servicing the AFRAMAX, SUEZMAX and VLCCs with operating conditions similar to the tug boats proposed for normal operation. The emissions shown here are the sum of the emissions from the main and auxiliary engines. Please review the normal operation calculations for tug-boats for additional details.



5. Applicability of RACT

In the preamble of the 1995 promulgation of NESHAP Subpart Y, EPA stated the following:

> *The Agency also determined that offshore terminals loading 10 million barrels or more per year of gasoline or 200 million barrels or more of crude oil should not be required to control VOC or HAP emissions under section 183(f) RACT requirements. [...] Since most of the other comments noted the significantly higher costs and poor cost effectiveness shown by these sources (see previous paragraph) would make control requirements unreasonable for these offshore terminals, the Agency determined that requirement for controls at offshore RACT terminals would not be consistent with the requirements for the technology to be "reasonable."*

While NESHAP subpart Y is not applicable to the proposed SPM buoy system, the same logic that EPA applied to offshore loading terminals in the preamble to the original MACT Subpart Y rule in 1995 can be applied. The combination of high costs and technical complications for controlling the proposed SPM buoy system are such that technology to control the emissions beyond what has been proposed as MACT in the 112(g) Case-by-Case MACT application is not "reasonable."

6. Feasibility of Measurement of Emissions

Section 112(h)(2)(B) of the Clean Air Act states the following:

> *For the purpose of this subsection, the phrase "not feasible to prescribe or enforce an emission standard" means any situation in which the Administrator determines that –*
>
> *(B) The application of measurement methodology to a particular class or sources is not practical due to technological and economic limitations.*

In the case of the proposed SPM buoy system, the application of measurement of emissions from the VLCC being loaded is not practical due to logistical and technological limitations. TGTI proposed submerged loading and work practice standards as the MACT limit for the proposed SPM buoy system. A numerical emission standard was not proposed because it is not a technically feasible option. TGTI will not own or operate the VLCCs that utilize the SPM buoy system. As such, TGTI will not have access to the deck of the VLCC ships as they are foreign-flagged vessels which are controlled by the ship's Captain. It is not reasonable to expect TGTI to measure the emissions from each VLCC directly as this would present a significant logistical and operational challenge. Even if TGTI could secure access to the dock of each VLCC that utilized the SPM, measurement of the emissions would require extensive equipment to be brought onboard and would add significant time required to load the VLCCs. The proposal for work practice standards (and no emission standard) as the MACT limit is consistent with EPA's determination in both the 1995 and 2011 promulgations of MACT Subpart Y for offshore loading terminals.

ATTACHMENT 1 - COMPARISON OF CRUDE/CONDENSATE EMISSIONS BETWEEN EQUATIONS 1 AND 2 OF AP-42 CHAPTER 5.2

ATTACHMENT 1 - COMPARISON OF CRUDE/CONDENSATE EMISSIONS BETWEEN EQUATIONS 1 AND 2 OF AP-42 CHAPTER 5.2

A comparison of emissions between equations 1 and 2 of AP-42 Chapter 5.2 for crude oil and condensate is shown in the table below.

Liquid Loaded [1]	Loading Calculation	Compartment Condition Prior to Loadng	Saturation Factor [2]	Maximum Temp [3]		Vapor MW	Maximum True Vapor Pressure (TVP) [4]	Arrival Emission Factor [5]	Generated Emission Factor [6]	Uncontrolled Loading Loss [7]	TOC to VOC Factor	Hourly Loading Rate [8]	Uncontrolled VOC Hourly Emissions [9]
				(°F)	(°R)	(lb/lb mol)	(psia)	(lb/1,000 gal)	(lb/1,000 gal)	(lb/1,000 gal)		(bbl/hr)	(lb/hr)
Crude Oil	AP-42 Ch 5.2, Eq 1 - API	Volatile Uncleaned	0.2	73.5	533.2	50	11	--	--	2.57	1	60,000	6,478.07
Crude Oil	AP-42 Ch 5.2, Eq 2-3	Volatile Uncleaned	--	73.5	533.2	50	11	0.86	0.78	1.64	0.85	60,000	3,508.46
Condensate	AP-42 Ch 5.2, Eq 1 - API	Volatile Uncleaned	0.2	73.5	533.2	60	11	--	--	3.08	1	60,000	7,773.68
Condensate	AP-42 Ch 5.2, Eq 2-3	Volatile Uncleaned	--	73.5	533.2	60	11	0.86	0.93	1.79	0.85	60,000	3,841.73

[1] For hourly emission estimates, the worst-case marine loading commodity between Crude oil and Condensate will be utilized.
[2] Saturation factor for marine loading obtained from U.S. EPA 42, Section 5.2 (1/95), Table 5.2-1.
[3] Maximum of monthly average liquid surface temperature was used.
[4] Maximum true vapor pressure for Crude oil and Condensate obtained from information provided by Texas Gulf Terminals
[5] Arrival emission factor for crude/condensate loading obtained from U.S. EPA 42, Section 5.2 (1/95), Table 5.2-3.
[6] Generated emission factor is calculated using equation 3 from U.S. EPA 42, Section 5.2 (1/95).
[7] Uncontrolled Loading Loss (lb/1,000 gal) = 12.46 x Saturation Factor x Maximum TVP of Liquid Loaded (psia) x Vapor MW (lb/lbmol) / Maximum Temperature of Bulk Liquid Loaded (°R)
[8] Hourly Loading Rate obtained from information provided by TGTI Revised Design Parameters email from Ms. Denise Rogers (TGTI) to Mr. Brian Burdorf (Trinity Consultants) on February 25, 2018.
[9] Uncontrolled VOC Hourly Emissions (lb/hr) = Uncontrolled Loading Loss (lb/1,000 gal) x Hourly Loading Rate (bbl/hr) x 42 gal/bbl x TOC to VOC Factor x (1/1,000)

ATTACHMENT 2 - REFERENCE FOR EQUATION 3 OF AP-42 CHAPTER 5.2

API Manual of Petroleum Measurement Standards
Chapter 19.5
(Formerly, API Publication 2514A)

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HM 65

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Foreword

This publication was prepared jointly by the American Petroleum Institute Committee on Petroleum Measurement and the Energy Institute Hydrocarbon Management Committee. This standard supersedes API Publication 2514A, Second Edition, September 1981, which is withdrawn. See A.1 for more information on the previous editions of this document.

The American Petroleum Institute Committee on Petroleum Measurement (COPM) and the Energy Institute's Hydrocarbon Management Committee (HMC) are responsible for the production and maintenance of standards and guides covering various aspects of static and dynamic measurement of petroleum. The API/EI Joint Committee on Hydrocarbon Management (JCHM), its sub-committees and work groups consist of technical specialists representing oil companies, equipment manufacturers, service companies, terminal and ship owners and operators. The API/EI JCHM encourages international participation and when producing publications its aim is to represent the best consensus of international technical expertise and good practice. This is the main reason behind the production of joint publications involving cooperation with experts from both the API and EI.

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Atmospheric hydrocarbon emissions from marine vessel transfer operations

1 Scope

This standard provides methods for estimating evaporative loss from marine vessel transfer operations. Specifically, this standard addresses:

1) loading stock into:

   a) ship or ocean barges, or

   b) shallow draft barges, and

2) loading ballast water into ship or ocean barges from which crude oil has been unloaded.

The emission estimates are for uncontrolled loading operations and do not apply to operations using vapor balance or vapor control systems or ballasting of ships with segregated ballast tanks.

This standard does not address evaporative loss for:

1) very large crude carriers (VLCCs) or ultra large crude carriers (ULCCs) (unless the saturation factor K_S is determined);

2) marine vessels employing crude oil washing (see 3.3.1);

3) marine vessel transit loss;

4) loading ballast water into marine vessels that, prior to dockside unloading, held anything other than crude oil (unless the saturation factor K_S is determined); or

5) unloading marine vessels.

This standard supersedes API 2514A, Second Edition, September 1981, which is withdrawn.

2 References

[1] American Petroleum Institute, *Recommended Practice for Specification of Evaporative Losses*, *Manual of Petroleum Measurement Standards*, Chapter 19, Section 4, Second Edition, September 2005

[2] American Petroleum Institute, Publication 2524, *Impact Assessment of New Data on the Validity of American Petroleum Institute Marine Transfer Operation Emission Factors*, July 1992

[3] American Petroleum Institute, Publication 2514A, *Atmospheric Hydrocarbon Emissions from Marine Vessel Transfer Operations*, Second Edition, September 1981

[4] Spectrasyne Ltd., "Studies of VOC Emissions from External Floating Roof Tanks and Barge Loading—November 1993," Spectrasyne Report No. TR9413, prepared for CONCAWE, Brussels, Belgium, June 13, 1994

[5] CONCAWE, "VOC Emissions from External Floating Roof Tanks: Comparison of Remote Measurements by Laser with Calculated Methods," CONCAWE Report No. 95/52, January 1995

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ATTACHMENT 3 - TGTI CRUDE COMPOSITION DATA

Reference: **Crude 1**
Crude: **Crude 1**

Crude Summary Report

General Information		Molecules (%wt on crude)		Whole Crude Properties	
Reference:	Crude 1	methane + ethane	0.02	Density @ 15°C (g/cc)	0.817
Name:	Crude 1	propane	0.21	API Gravity	41.60
Traded Crude:	Unknown	isobutane	0.20	Total Sulphur (% wt)	0.25
Origin:	United States of /	n-butane	1.15	Pour Point (°C)	-26.39
Sample Date:	-	isopentane	1.18	Viscosity @ 20°C (cSt)	8.82
Assay Date:	-	n-pentane	1.70	Viscosity @ 40°C (cSt)	4.89
Issue Date:	-	cyclopentane	0.08	Nickel (ppm)	0.5
Comments:	-	C_6 paraffins	1.06	Vanadium (ppm)	1.0
		C_6 naphthenes	0.24	Total Nitrogen (ppm)	177
		benzene	0.22	Total Acid Number (mgKOH/g)	0.03
		C_7 paraffins	2.21	Mercaptan Sulphur (ppm)	20.3
		C_7 naphthenes	0.87	Hydrogen Sulphide (ppm)	0.0
		toluene	0.61	Reid Vapour Pressure (psi)	8.8

Cut Data		Atmospheric Cuts									Vacuum Cuts			
Start (°C)	IBP	C5	65	100	150	200	250	300	350	370	370	450	500	550
End (°C)	FBP	65	100	150	200	250	300	350	370	FBP	450	500	550	FBP
Yield (% wt)		3.9	3.4	9.5	9.3	9.9	9.9	9.5	3.6	39.5	13.5	7.5	6.5	11.9
Yield (% vol)		4.9	3.9	10.4	9.9	10.1	9.8	9.2	3.5	36.0	12.8	6.9	5.9	10.4
Cumulative Yield (% wt)		1.6	5.4	8.8	18.4	27.7	37.6	47.5	56.9	60.5	60.5	74.1	81.5	88.1
Volume Average B.P. (°C)	308	39	91	128	175	225	275	325	360	500	409	474	524	616
Density @ 15°C (g/cc)	0.817	0.638	0.714	0.748	0.768	0.797	0.823	0.842	0.852	0.896	0.866	0.887	0.902	0.936
API Gravity	41.6	90.2	66.7	57.6	52.7	45.9	40.4	36.4	34.6	26.3	31.9	28.0	25.3	19.5
UOPK	12.4			12.0	12.1	12.1	12.1	12.2	12.3	12.5	12.4	12.4	12.5	12.5
Molecular Weight (g/mol)				117	149	184	224	271	309	460	364	446	511	627
Total Sulphur (% wt)	0.247	0.002	0.005	0.008	0.016	0.040	0.098	0.202	0.275	0.51	0.345	0.444	0.54	0.73
Mercaptan Sulphur (ppm)	20.3	2.1	15.8	22.0	27.8	26.8	18.8							
Total Nitrogen (ppm)	177					2	4	15	35	441	112	310	512	858
Basic Nitrogen (ppm)	119.61					0.7042	2.7875	8.4895	15.961	298.61	38.448	100.68	201.42	770.76
Total Acid Number (mgKOH/g)	0.03	0.00	0.00	0.00	0.01	0.02	0.02	0.04	0.04	0.06	0.06	0.07	0.07	0.06
Viscosity @ 20°C (cSt)	8.82				2.47									
Viscosity @ 40°C (cSt)	4.89				1.74	2.69	4.36	7.58	11.8					
Viscosity @ 50°C (cSt)	3.82					2.25	3.55	5.90	8.81	90.2	16.5	47.2	140	
Viscosity @ 60°C (cSt)										56.4	12.2	31.4	83.6	
Viscosity @ 100°C (cSt)										13.9	4.65	9.24	18.3	114
Viscosity @ 130°C (cSt)														35.7
RON (Clear)	24.9	77.7	51.0	52.6	39.0									
MON (Clear)	36.8	77.2	50.2	48.5	37.1									
Paraffins (% wt)	41.6	97.9	70.0	57.6	46.1									
Naphthenes (%wt)	35.1	2.1	23.6	25.5	30.9									
Aromatics (% wt)	23.3	0.0	6.4	16.9	23.1									
Pour Point (°C)	-26					-45	-22	1	12	15	28	43	51	26
Cloud Point (°C)						-42	-20	3						
Freeze Point (°C)					-61	-39	-16							
Smoke Point (mm)					27	21	16							
Cetane Index					50	56	62	70	77					
Naphthalenes (% vol)					0.0839	2.2615	7.2394	12.325						
Aniline Point (°C)				48.5	54.8	64.9	74.8	84.6	91.4		100.9	111.6	118.0	
Hydrogen (% wt)		16.6	15.2	14.5	14.4	13.9	13.5	13.2	13.1		12.9	12.8	12.7	
Wax (% wt)	10.7									19.6	23.5	24.6	21.1	11.2
C_7 Asphaltenes (% wt)	0.1									0.2		0.0	0.0	0.6
Micro Carbon Residue (% wt)	0.4									1.0		0.1	0.6	2.8
Rams. Carbon Residue (% wt)	0.3									0.9		0.1	0.5	2.5
Vanadium (ppm)	1.0									2.6		0.0	0.0	8.5
Nickel (ppm)	0.5									1.3		0.0	0.0	4.4
Iron (ppm)	51.0									129.2		0.0	0.0	427.3

Reference: **Crude 2**
Crude: **Crude 2**

Crude Summary Report

General Information		Molecules (%wt on crude)		Whole Crude Properties	
Reference:	Crude 2	methane + ethane	0.00	Density @ 15°C (g/cc)	0.735
Name:	Crude 2	propane	0.52	API Gravity	60.88
Traded Crude:	Unknown	isobutane	0.83	Total Sulphur (% wt)	0.01
Origin:	Unknown	n-butane	1.89	Pour Point (°C)	-19.71
Sample Date:	12 May 2017	isopentane	2.36	Viscosity @ 20°C (cSt)	1.05
Assay Date:	18 May 2017	n-pentane	3.38	Viscosity @ 40°C (cSt)	0.81
Issue Date:	-	cyclopentane	0.00	Nickel (ppm)	0.0
Comments:	-	C_6 paraffins	3.64	Vanadium (ppm)	0.0
		C_6 naphthenes	6.54	Total Nitrogen (ppm)	7
		benzene	0.65	Total Acid Number (mgKOH/g)	0.03
		C_7 paraffins	8.02	Mercaptan Sulphur (ppm)	8.0
		C_7 naphthenes	5.14	Hydrogen Sulphide (ppm)	0.0
		toluene	2.74	Reid Vapour Pressure (psi)	8.0

Cut Data		Atmospheric Cuts									Vacuum Cuts			
Start (°C)	IBP	C5	65	100	150	200	250	300	350	370	370	450	500	550
End (°C)	FBP	65	100	150	200	250	300	350	370	FBP	450	500	550	FBP
Yield (% wt)		7.4	19.4	27.1	15.2	9.8	6.8	4.6	1.4	5.0	3.4	0.9	0.4	0.3
Yield (% vol)		8.5	19.7	26.7	15.2	9.5	6.4	4.2	1.2	4.3	2.9	0.8	0.4	0.2
Cumulative Yield (% wt)		3.3	10.7	30.0	57.2	72.3	82.2	89.0	93.6	95.0	95.0	98.4	99.3	99.7
Volume Average B.P. (°C)	154	39	85	123	173	224	273	323	360	436	404	472	522	596
Density @ 15°C (g/cc)	0.735	0.636	0.723	0.747	0.731	0.762	0.788	0.810	0.826	0.860	0.845	0.877	0.902	0.944
API Gravity	60.9	91.1	64.1	57.9	61.9	54.1	48.1	43.0	39.8	32.9	36.0	29.8	25.2	18.3
UOPK	12.5			12.0	12.7	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.5	12.3
Molecular Weight (g/mol)				113	151	187	228	276	315	396	364	446	507	593
Total Sulphur (% wt)	0.010	0.000	0.001	0.002	0.003	0.007	0.015	0.031	0.049	0.105	0.077	0.129	0.175	0.248
Mercaptan Sulphur (ppm)	8.0	1.4	7.1	8.3	9.0	7.9	5.6							
Total Nitrogen (ppm)	7					3	8	13	19	112	46	130	242	625
Basic Nitrogen (ppm)	4.523					1.0709	3.6077	9.0155	15.216	69.956	27.152	60.412	117.89	525.24
Total Acid Number (mgKOH/g)	0.03	0.00	0.00	0.01	0.01	0.02	0.04	0.05	0.06	0.07	0.07	0.08	0.07	0.06
Viscosity @ 20°C (cSt)	1.05				1.53									
Viscosity @ 40°C (cSt)	0.81				1.13	1.81	3.06	5.41	8.71					
Viscosity @ 50°C (cSt)	0.73					1.56	2.55	4.35	6.72	22.0	12.4	43.2	156	
Viscosity @ 60°C (cSt)										15.9	9.32	29.2	92.8	
Viscosity @ 100°C (cSt)										5.74	3.90	8.90	20.0	114
Viscosity @ 130°C (cSt)														36.2
RON (Clear)	50.7	76.7	61.4	59.5	38.5									
MON (Clear)	51.1	76.5	58.9	56.3	36.8									
Paraffins (% wt)	52.8	100.0	51.8	53.3	49.2									
Naphthenes (%wt)	29.8	0.0	44.8	25.4	26.5									
Aromatics (% wt)	17.4	0.0	3.4	21.3	24.3									
Pour Point (°C)	-20					-41	-16	8	20	39	33	46	53	-4
Cloud Point (°C)						-38	-14	10						
Freeze Point (°C)					-61	-36	-11							
Smoke Point (mm)					28	24	20							
Cetane Index					72	77	83	88	94					
Naphthalenes (% vol)					0.176	1.336	3.5329	5.7802						
Aniline Point (°C)				46.6	53.1	65.1	76.7	87.8	95.3		103.5	113.9	119.5	
Hydrogen (% wt)		16.7	15.1	14.1	14.2	13.7	13.4	13.3	13.2		13.3	13.2	13.1	
Wax (% wt)	3.5									27.0	28.0	28.4	24.4	15.3
C_7 Asphaltenes (% wt)	0.0									0.1		0.0	0.0	1.2
Micro Carbon Residue (% wt)	0.0									0.5		0.3	1.6	6.1
Rams. Carbon Residue (% wt)	0.0									0.5		0.2	1.5	5.6
Vanadium (ppm)	0.0									0.2		0.0	0.0	3.1
Nickel (ppm)	0.0									0.5		0.0	0.0	8.8
Iron (ppm)	2.2									43.9		0.0	0.0	760.6

Reference: **Crude 3**
Crude: **Crude 3**

Crude Summary Report

General Information		Molecules (%wt on crude)		Whole Crude Properties	
Reference:	Crude 3	methane + ethane	0.03	Density @ 15°C (g/cc)	0.811
Name:	Crude 3	propane	0.41	API Gravity	42.89
Traded Crude:	Unknown	isobutane	0.25	Total Sulphur (% wt)	0.16
Origin:	United States of /	n-butane	1.27	Pour Point (°C)	-23.84
Sample Date:	-	isopentane	1.08	Viscosity @ 20°C (cSt)	5.29
Assay Date:	-	n-pentane	1.63	Viscosity @ 40°C (cSt)	3.27
Issue Date:	-	cyclopentane	0.05	Nickel (ppm)	1.5
Comments:	-	C_6 paraffins	1.88	Vanadium (ppm)	1.7
		C_6 naphthenes	2.95	Total Nitrogen (ppm)	298
		benzene	0.76	Total Acid Number (mgKOH/g)	0.03
		C_7 paraffins	3.68	Mercaptan Sulphur (ppm)	77.0
		C_7 naphthenes	2.05	Hydrogen Sulphide (ppm)	0.0
		toluene	0.32	Reid Vapour Pressure (psi)	6.7

Cut Data		Atmospheric Cuts									Vacuum Cuts			
Start (°C)	IBP	C5	65	100	150	200	250	300	350	370	370	450	500	550
End (°C)	FBP	65	100	150	200	250	300	350	370	FBP	450	500	550	FBP
Yield (% wt)		3.9	9.3	10.7	8.8	9.1	8.7	8.0	3.0	36.5	11.0	5.6	4.3	15.6
Yield (% vol)		4.9	10.3	11.6	9.3	9.3	8.5	7.7	2.9	32.5	10.2	5.1	3.9	13.3
Cumulative Yield (% wt)		2.0	5.9	15.2	25.9	34.7	43.8	52.5	60.5	63.5	63.5	74.5	80.1	84.4
Volume Average B.P. (°C)	304	41	85	125	175	225	275	325	360	563	409	474	524	727
Density @ 15°C (g/cc)	0.811	0.639	0.733	0.743	0.768	0.797	0.821	0.842	0.854	0.911	0.870	0.889	0.896	0.955
API Gravity	42.9	89.8	61.5	59.0	52.8	46.0	40.7	36.5	34.0	23.8	31.0	27.5	26.3	16.6
UOPK	12.5			12.1	12.1	12.1	12.1	12.2	12.2	12.6	12.3	12.4	12.6	12.7
Molecular Weight (g/mol)				115	149	184	224	271	308	508	362	444	513	762
Total Sulphur (% wt)	0.162	0.002	0.003	0.005	0.010	0.025	0.062	0.134	0.188	0.373	0.244	0.314	0.365	0.487
Mercaptan Sulphur (ppm)	77.0	9.9	69.3	108.4	134.5	117.5	70.9							
Total Nitrogen (ppm)	298					2	7	29	66	803	197	517	838	1321
Basic Nitrogen (ppm)	165.3					0.8954	4.1393	13.634	26.062	446.08	58.147	144.05	263.67	876.91
Total Acid Number (mgKOH/g)	0.03	0.00	0.00	0.00	0.01	0.02	0.02	0.04	0.05	0.05	0.06	0.07	0.07	0.04
Viscosity @ 20°C (cSt)	5.29				2.49									
Viscosity @ 40°C (cSt)	3.27				1.74	2.70	4.43	7.86	12.5					
Viscosity @ 50°C (cSt)	2.67					2.25	3.59	6.07	9.20	237	17.4	47.0	110	
Viscosity @ 60°C (cSt)										132	12.7	31.1	66.8	
Viscosity @ 100°C (cSt)										24.2	4.71	8.94	15.2	373
Viscosity @ 130°C (cSt)														85.0
RON (Clear)	28.3	77.3	66.8	52.2	39.0									
MON (Clear)	42.7	77.0	63.9	49.9	37.1									
Paraffins (% wt)	42.4	98.7	47.5	61.5	46.5									
Naphthenes (%wt)	35.6	1.3	44.4	26.3	30.6									
Aromatics (% wt)	22.0	0.0	8.1	12.1	22.9									
Pour Point (°C)	-24					-44	-21	3	15	13	30	45	52	5
Cloud Point (°C)						-42	-19	4						
Freeze Point (°C)					-60	-37	-14							
Smoke Point (mm)					27	21	16							
Cetane Index					50	56	63	70	76					
Naphthalenes (% vol)					0.0423	1.3678	5.5322	10.193						
Aniline Point (°C)				49.2	55.8	66.0	76.1	86.1	93.0		102.5	113.4	119.6	
Hydrogen (% wt)		16.6	14.7	14.7	14.4	13.9	13.5	13.3	13.1		12.9	12.7	12.5	
Wax (% wt)	9.1									18.3	24.3	25.1	23.5	10.1
C_7 Asphaltenes (% wt)	0.2									0.6		0.0	0.0	1.4
Micro Carbon Residue (% wt)	0.7									1.8		0.1	0.6	4.1
Rams. Carbon Residue (% wt)	0.6									1.7		0.1	0.5	3.7
Vanadium (ppm)	1.7									4.6		0.0	0.0	10.8
Nickel (ppm)	1.5									4.0		0.0	0.0	9.4
Iron (ppm)	24.0									65.7		0.0	0.0	153.4

Reference: **Crude 4**
Crude: **Crude 4**

Crude Summary Report

General Information		Molecules (%wt on crude)		Whole Crude Properties	
Reference:	Crude 4	methane + ethane	0.02	Density @ 15°C (g/cc)	0.822
Name:	Crude 4	propane	0.43	API Gravity	40.60
Traded Crude:	Unknown	isobutane	0.39	Total Sulphur (% wt)	0.56
Origin:	Unknown	n-butane	1.49	Pour Point (°C)	-18.48
Sample Date:	05 March 2016	isopentane	1.08	Viscosity @ 20°C (cSt)	4.88
Assay Date:	07 March 2016	n-pentane	1.67	Viscosity @ 40°C (cSt)	3.31
Issue Date:	-	cyclopentane	0.22	Nickel (ppm)	5.6
Comments:	-	C_6 paraffins	2.83	Vanadium (ppm)	18.6
		C_6 naphthenes	2.81	Total Nitrogen (ppm)	953
		benzene	0.15	Total Acid Number (mgKOH/g)	0.05
		C_7 paraffins	3.74	Mercaptan Sulphur (ppm)	1.6
		C_7 naphthenes	2.24	Hydrogen Sulphide (ppm)	0.0
		toluene	1.37	Reid Vapour Pressure (psi)	7.7

Cut Data		Atmospheric Cuts									Vacuum Cuts			
Start (°C)	IBP	C5	65	100	150	200	250	300	350	370	370	450	500	550
End (°C)	FBP	65	100	150	200	250	300	350	370	FBP	450	500	550	FBP
Yield (% wt)		4.8	8.5	11.7	8.7	9.4	9.0	8.2	3.0	34.3	10.6	5.6	4.8	13.3
Yield (% vol)		6.1	9.8	12.5	9.2	9.5	8.9	7.8	2.8	29.8	9.8	5.0	4.2	10.8
Cumulative Yield (% wt)		2.4	7.1	15.7	27.4	36.1	45.5	54.5	62.7	65.7	65.7	76.3	81.9	86.7
Volume Average B.P. (°C)	281	44	84	124	175	225	275	324	360	528	408	474	524	662
Density @ 15°C (g/cc)	0.822	0.645	0.717	0.765	0.779	0.811	0.835	0.857	0.872	0.944	0.891	0.917	0.939	1.008
API Gravity	40.6	87.8	65.8	53.3	50.1	42.9	37.8	33.5	30.8	18.3	27.3	22.7	19.2	8.8
UOPK	12.2			11.7	11.9	11.9	11.9	11.9	12.0	12.0	12.0	12.0	12.0	11.8
Molecular Weight (g/mol)				111	148	182	222	268	304	467	356	433	493	633
Total Sulphur (% wt)	0.56	0.002	0.005	0.008	0.021	0.066	0.191	0.434	0.63	1.40	0.86	1.16	1.36	1.95
Mercaptan Sulphur (ppm)	1.6	8.9	5.7	1.8	1.8	1.7	1.2							
Total Nitrogen (ppm)	953					2	12	91	242	2732	579	1274	2033	5325
Basic Nitrogen (ppm)	226.23					2.0463	10.229	36.862	71.512	641.29	147.06	302.25	474.58	1240.9
Total Acid Number (mgKOH/g)	0.05	0.00	0.01	0.02	0.03	0.04	0.05	0.07	0.08	0.09	0.09	0.10	0.10	0.09
Viscosity @ 20°C (cSt)	4.88				1.56									
Viscosity @ 40°C (cSt)	3.31				1.14	1.79	3.10	5.91	10.1					
Viscosity @ 50°C (cSt)	2.80					1.53	2.56	4.66	7.63	293	16.5	60.6	219	
Viscosity @ 60°C (cSt)										159	12.1	38.8	122	
Viscosity @ 100°C (cSt)										26.8	4.48	10.3	22.5	838
Viscosity @ 130°C (cSt)														154
RON (Clear)	31.1	77.5	61.9	59.0	39.1									
MON (Clear)	43.0	76.8	59.7	55.0	37.4									
Paraffins (% wt)	37.8	95.4	55.7	42.4	49.2									
Naphthenes (%wt)	32.2	4.6	42.5	38.5	28.2									
Aromatics (% wt)	30.0	0.0	1.8	19.0	22.6									
Pour Point (°C)	-18					-41	-20	0	11	33	24	38	46	54
Cloud Point (°C)						-40	-18	2						
Freeze Point (°C)					-59	-37	-15							
Smoke Point (mm)					26	24	22							
Cetane Index					44	49	56	62	66					
Naphthalenes (% vol)					0.0929	1.5399	5.1773	9.1977						
Aniline Point (°C)				52.6	57.6	65.0	72.2	79.3	84.2		90.6	98.2	102.8	
Hydrogen (% wt)		16.5	15.2	14.0	14.6	14.1	13.7	13.3	13.1		12.7	12.3	12.1	
Wax (% wt)	8.2									16.4	21.8	21.1	18.6	9.2
C_7 Asphaltenes (% wt)	0.5									1.3		0.0	0.0	3.4
Micro Carbon Residue (% wt)	1.7									5.0		0.4	1.8	12.1
Rams. Carbon Residue (% wt)	1.5									4.5		0.4	1.6	10.9
Vanadium (ppm)	18.6									54.3		0.0	0.0	140.4
Nickel (ppm)	5.6									16.4		0.0	0.0	42.5
Iron (ppm)	5.1									14.8		0.0	0.0	38.3

Reference: **Crude 5**
Crude: **Crude 5**

Crude Summary Report

General Information		Molecules (%wt on crude)		Whole Crude Properties	
Reference:	Crude 5	methane + ethane	0.13	Density @ 15°C (g/cc)	0.783
Name:	Crude 5.	propane	0.64	API Gravity	49.18
Traded Crude:	Unknown	isobutane	0.42	Total Sulphur (% wt)	0.03
Origin:	United States of /	n-butane	1.26	Pour Point (°C)	-26.83
Sample Date:	-	isopentane	0.55	Viscosity @ 20°C (cSt)	2.22
Assay Date:	-	n-pentane	0.61	Viscosity @ 40°C (cSt)	1.67
Issue Date:	-	cyclopentane	0.18	Nickel (ppm)	0.1
Comments:	-	C_6 paraffins	1.60	Vanadium (ppm)	0.0
		C_6 naphthenes	3.20	Total Nitrogen (ppm)	88
		benzene	0.24	Total Acid Number (mgKOH/g)	0.03
		C_7 paraffins	6.21	Mercaptan Sulphur (ppm)	9.7
		C_7 naphthenes	1.49	Hydrogen Sulphide (ppm)	0.0
		toluene	0.47	Reid Vapour Pressure (psi)	8.0

Cut Data		Atmospheric Cuts									Vacuum Cuts			
Start (°C)	IBP	C5	65	100	150	200	250	300	350	370	370	450	500	550
End (°C)	FBP	65	100	150	200	250	300	350	370	FBP	450	500	550	FBP
Yield (% wt)		2.9	11.1	17.4	13.2	11.4	10.2	8.4	2.9	20.0	9.8	4.5	3.0	2.7
Yield (% vol)		3.5	12.0	18.4	13.5	11.1	9.7	7.8	2.7	17.7	8.8	4.0	2.6	2.3
Cumulative Yield (% wt)		2.5	5.4	16.5	33.9	47.0	58.4	68.6	77.1	80.0	80.0	89.8	94.3	97.3
Volume Average B.P. (°C)	227	48	89	125	173	225	274	324	360	464	408	474	523	599
Density @ 15°C (g/cc)	0.783	0.653	0.723	0.740	0.764	0.797	0.823	0.845	0.858	0.885	0.871	0.883	0.896	0.930
API Gravity	49.2	85.3	64.2	59.6	53.6	45.9	40.3	35.8	33.3	28.3	30.9	28.7	26.3	20.6
UOPK	12.3			12.1	12.2	12.1	12.1	12.1	12.2	12.4	12.3	12.5	12.6	12.5
Molecular Weight (g/mol)				116	148	183	223	270	307	420	361	446	512	607
Total Sulphur (% wt)	0.026	0.002	0.002	0.003	0.004	0.007	0.013	0.028	0.043	0.092	0.059	0.089	0.123	0.185
Mercaptan Sulphur (ppm)	9.7	1.2	5.0	7.9	11.5	12.7	10.3							
Total Nitrogen (ppm)	88					1	3	13	32	428	95	298	630	1641
Basic Nitrogen (ppm)	35.95					0.6897	2.3182	6.0011	10.711	173.83	24.95	75.812	193	861.8
Total Acid Number (mgKOH/g)	0.03	0.00	0.00	0.00	0.01	0.02	0.02	0.04	0.04	0.06	0.06	0.06	0.07	0.06
Viscosity @ 20°C (cSt)	2.22				2.42									
Viscosity @ 40°C (cSt)	1.67				1.74	2.68	4.21	6.99	10.4					
Viscosity @ 50°C (cSt)	1.48					2.26	3.48	5.56	8.03	32.4	13.8	35.6	93.2	
Viscosity @ 60°C (cSt)										22.9	10.5	24.9	59.7	
Viscosity @ 100°C (cSt)										7.82	4.39	8.31	15.6	60.1
Viscosity @ 130°C (cSt)														23.0
RON (Clear)	37.9	78.7	59.1	57.3	38.8									
MON (Clear)	43.1	77.7	56.6	54.5	36.9									
Paraffins (% wt)	46.9	93.9	56.2	64.8	46.6									
Naphthenes (%wt)	33.3	6.1	41.7	22.4	29.3									
Aromatics (% wt)	19.7	0.0	2.1	12.8	24.1									
Pour Point (°C)	-27					-42	-18	6	18	14	31	45	52	-6
Cloud Point (°C)						-40	-16	7						
Freeze Point (°C)					-60	-35	-12							
Smoke Point (mm)					27	21	16							
Cetane Index					51	56	62	68	74					
Naphthalenes (% vol)					0.1157	1.6315	4.8638	8.1883						
Aniline Point (°C)				48.1	55.7	68.2	80.2	92.2	100.7		112.0	124.6	131.2	
Hydrogen (% wt)		16.4	15.2	14.7	14.0	13.7	13.4	13.2	13.2		13.2	13.1	13.0	
Wax (% wt)	8.2									25.9	28.0	29.3	24.5	13.7
C_7 Asphaltenes (% wt)	0.0									0.2		0.0	0.0	1.4
Micro Carbon Residue (% wt)	0.1									0.6		0.1	0.7	3.5
Rams. Carbon Residue (% wt)	0.1									0.5		0.1	0.6	2.9
Vanadium (ppm)	0.0									0.2		0.0	0.0	1.5
Nickel (ppm)	0.1									0.6		0.0	0.0	4.4
Iron (ppm)	3.0									15.0		0.0	0.0	111.8

ATTACHMENT 4 - DETAILED EMISSION CALCULATIONS FOR CRUDE VAPOR SPECIATION

Crude Vapor Speciation - Crude Profile 1

Component	Liquid Molecular Weight (M_l)	Liquid Weight Percent (W_i)	Liquid Moles [1] (W_i/M_l)	Liquid Mole Fraction [2] $X_i = W_i/(M_t x M_l)$	Temp (°F) 73.50 Temp (°C) 23.06 Antoine's Constants (deg. C)			Vapor Pressure [3] P_i*	Partial Pressure [4] $P_i = (P_i^*)(X_i)$	Vapor Mole Fraction [5] $Y_i = (P_i/P_t)$	Vapor Molecular Weight (M_v)	$(Y_i)(M_v)$	Vapor Weight Percent [6] Yi (Mv/Mt)	Max Total HAP Vapor Weight
	(lb/lb-mole)	(wt%)		(mole frac.)	A	B	C	(psia)	(psia)	(mole frac.)	(lb/lb-mole)		(wt%)	(wt%)
methane + ethane	16.00	0.02%	1.10E-05	2.05E-03	7.10	516.70	284.37	5031.02	10.34	0.45	16.00	7.21	20.22%	--
propane	44.10	0.21%	4.79E-05	0.0089	6.86	819.30	248.73	134.86	1.20	0.05	44.10	2.31	6.48%	--
isobutane	58.12	0.20%	3.44E-05	0.0064	6.82	912.10	243.34	48.03	0.31	0.01	58.12	0.78	2.18%	--
n-butane	58.12	1.15%	1.98E-04	0.0369	6.73	909.70	237.00	32.61	1.20	0.05	58.12	3.05	8.54%	--
isopentane	72.15	1.18%	1.64E-04	0.0305	6.79	1020.00	233.10	12.43	0.38	0.02	72.15	1.19	3.34%	--
n-pentane	72.15	1.70%	2.35E-04	0.0438	6.86	1070.60	232.70	9.21	0.40	0.02	72.15	1.27	3.56%	--
cyclopentane	70.10	0.08%	1.18E-05	2.19E-03	6.88	1119.20	230.74	5.68	1.25E-02	5.44E-04	70.10	3.81E-02	0.11%	--
benzene	78.11	0.22%	2.77E-05	0.0052	6.91	1211.00	220.79	1.68	0.01	3.79E-04	78.11	0.03	0.08%	0.15%
toluene	92.14	0.61%	6.65E-05	0.0124	7.02	1377.60	222.64	0.50	0.01	2.69E-04	92.14	0.02	0.07%	
crude oil	207.00	94.63%	4.57E-03	0.8517				10.64	9.06	0.40	50.00	19.77	55.41%	--
Total		M_t =	0.005					P_t =	22.92		M_t =	35.68	100.00%	

Sample Calcs for Benzene

[1] Liquid Moles (W_i/M_l) = Benzene Liquid Weight Percent (W_i) (wt%) / Benzene Liquid Molecular Weight (M_l)(lb/lb-mole)

$$\text{Liquid Moles } (W_i/M_l) = \frac{0.22\%}{} \left| \frac{\text{lb-mole}}{78.11 \text{ lb}} \right. = 2.77\text{E-}05$$

[2] Liquid Mole Fraction (X_i) (mole frac.) = Liquid Moles of Benzene (W_i/M_l) / Total Liquid Moles (Mt)

$$\text{Liquid Mole Fraction } (X_i) \text{ (mole frac.)} = \frac{2.77\text{E-}05}{0.005} = 0.0052$$

[3] Vapor Pressure (P_i*) (psia) = 10^(A - (B/(C+Temp (deg. C))) x 14.7 psia / 760 mmHg

[4] Benzene Partial Pressure (P_i) (psia) = Benzene Vapor Pressure (P_i*) (psia) * Benzene Liquid Mole Fraction (X_i) (mole frac)

$$\text{Benzene Partial Pressure } (P_i) \text{ (psia)} = \frac{1.68 \text{ psia}}{} \left| \frac{0.0052}{} \right. = 0.01 \text{ psia}$$

[5] Benzene Vapor Mole Fraction (Y_i) (mole frac) = Benzene Partial Pressure (P_i) (psia) / Total Partial Pressure (P_t) (psia)

$$\text{Benzene Vapor Mole Fraction } (Y_i) \text{ (mole frac)} = \frac{0.01 \text{ psia}}{22.92 \text{ psia}} = 3.79\text{E-}04$$

[6] Benzene Vapor Weight Percent (wt%) = Vapor Mole Fraction (Yi) (mole frac.) x Vapor Molecular Weight (Mv) (lb/lb-mole) / Σ (Yi)(Mv)

$$\text{Vapor Weight Percent (wt\%)} = \frac{3.79\text{E-}04}{} \left| \frac{78.11 \text{ lb}}{\text{lb-mole}} \right| \frac{1}{35.68} = 0.08\%$$

Crude Vapor Speciation - Crude Profile 2

Component	Liquid Molecular Weight (M_l)	Liquid Weight Percent (W_i)	Liquid Moles [1] (W_i/M_l)	Liquid Mole Fraction [2] $X_i = W_i/(M_t x M_l)$	Temp (°F) 73.50 Temp (°C) 23.06 Antoine's Constants (deg. C)			Vapor Pressure [3] P_i*	Partial Pressure [4] $P_i = (P_i^*)(X_i)$	Vapor Mole Fraction [5] $Y_i = (P_i/P_t)$	Vapor Molecular Weight (M_v)	$(Y_i)(M_v)$	Vapor Weight Percent [6] Yi (Mv/Mt)	Max Total HAP Vapor Weight
	(lb/lb-mole)	(wt%)		(mole frac.)	A	B	C	(psia)	(psia)	(mole frac.)	(lb/lb-mole)		(wt%)	(wt%)
methane + ethane	16.00	0.00%	2.10E-07	3.50E-05	7.10	516.70	284.37	5031.02	0.18	0.01	16.00	0.19	0.37%	--
propane	44.10	0.52%	1.18E-04	0.0198	6.86	819.30	248.73	134.86	2.66	0.18	44.10	7.99	15.26%	--
isobutane	58.12	0.83%	1.43E-04	0.0238	6.82	912.10	243.34	48.03	1.14	0.08	58.12	4.51	8.62%	--
n-butane	58.12	1.89%	3.25E-04	0.0542	6.73	909.70	237.00	32.61	1.77	0.12	58.12	6.98	13.33%	--
isopentane	72.15	2.36%	3.28E-04	0.0546	6.79	1020.00	233.10	12.43	0.68	0.05	72.15	3.33	6.36%	--
n-pentane	72.15	3.38%	4.68E-04	0.0780	6.86	1070.60	232.70	9.21	0.72	0.05	72.15	3.53	6.73%	--
cyclopentane	70.10	0.00%	6.53E-14	1.09E-11	6.88	1119.20	230.74	5.68	6.19E-11	4.21E-12	70.10	2.95E-10	0.00%	--
benzene	78.11	0.65%	8.31E-05	0.0139	6.91	1211.00	220.79	1.68	0.02	1.59E-03	78.11	0.12	0.24%	0.53%
toluene	92.14	2.74%	2.98E-04	0.0497	7.02	1377.60	222.64	0.50	0.02	1.68E-03	92.14	0.15	0.30%	
crude oil	207.00	87.63%	4.23E-03	0.7060				10.64	7.51	0.51	50.00	25.54	48.79%	--
Total		M_t =	0.006					P_t =	14.71		M_t =	52.35	100.00%	

Sample Calcs for Benzene

[1] Liquid Moles (W_i/M_l) = Benzene Liquid Weight Percent (W_i) (wt%) / Benzene Liquid Molecular Weight (M_l)(lb/lb-mole)

$$\text{Liquid Moles } (W_i/M_l) = \frac{0.65\%}{} \left| \frac{\text{lb-mole}}{78.11 \text{ lb}} \right. = 8.31\text{E-}05$$

[2] Liquid Mole Fraction (X_i) (mole frac.) = Liquid Moles of Benzene (W_i/M_l) / Total Liquid Moles (Mt)

$$\text{Liquid Mole Fraction } (X_i) \text{ (mole frac.)} = \frac{8.31\text{E-}05}{0.006} = 0.0139$$

[3] Vapor Pressure (P_i*) (psia) = 10^(A - (B/(C+Temp (deg. C))) x 14.7 psia / 760 mmHg

[4] Benzene Partial Pressure (P_i) (psia) = Benzene Vapor Pressure (P_i*) (psia) * Benzene Liquid Mole Fraction (X_i) (mole frac)

$$\text{Benzene Partial Pressure } (P_i) \text{ (psia)} = \frac{1.68 \text{ psia}}{} \left| \frac{0.0139}{} \right. = 0.02 \text{ psia}$$

[5] Benzene Vapor Mole Fraction (Y_i) (mole frac) = Benzene Partial Pressure (P_i) (psia) / Total Partial Pressure (P_t) (psia)

$$\text{Benzene Vapor Mole Fraction } (Y_i) \text{ (mole frac)} = \frac{0.02 \text{ psia}}{14.71 \text{ psia}} = 1.59\text{E-}03$$

[6] Benzene Vapor Weight Percent (wt%) = Vapor Mole Fraction (Yi) (mole frac.) x Vapor Molecular Weight (Mv) (lb/lb-mole) / Σ (Yi)(Mv)

$$\text{Vapor Weight Percent (wt\%)} = \frac{1.59\text{E-}03}{} \left| \frac{78.11 \text{ lb}}{\text{lb-mole}} \right| \frac{1}{52.35} = 0.24\%$$

Crude Vapor Speciation - Crude Profile 3

Component	Liquid Molecular Weight (M_l)	Liquid Weight Percent (W_i)	Liquid Moles [1] (W_i/M_l)	Liquid Mole Fraction [2] $X_i = W_i/(M_t x M_l)$	Temp (°F) 73.50 Temp (°C) 23.06 Antoine's Constants (deg. C)			Vapor Pressure [3] P_i*	Partial Pressure [4] $P_i = (P_i^*)(X_i)$	Vapor Mole Fraction [5] $Y_i = (P_i/P_t)$	Vapor Molecular Weight (M_v)	$(Y_i)(M_v)$	Vapor Weight Percent [6] Yi (Mv/Mt)	Max Total HAP Vapor Weight
	(lb/lb-mole)	(wt%)		(mole frac.)	A	B	C	(psia)	(psia)	(mole frac.)	(lb/lb-mole)		(wt%)	(wt%)
methane + ethane	16.00	0.03%	1.93E-05	3.54E-03	7.10	516.70	284.37	5031.02	17.82	0.57	16.00	9.05	28.89%	--
propane	44.10	0.41%	9.37E-05	0.0172	6.86	819.30	248.73	134.86	2.32	0.07	44.10	3.25	10.38%	--
isobutane	58.12	0.25%	4.38E-05	0.0081	6.82	912.10	243.34	48.03	0.39	0.01	58.12	0.71	2.28%	--
n-butane	58.12	1.27%	2.18E-04	0.0401	6.73	909.70	237.00	32.61	1.31	0.04	58.12	2.41	7.70%	--
isopentane	72.15	1.08%	1.50E-04	0.0276	6.79	1020.00	233.10	12.43	0.34	0.01	72.15	0.79	2.51%	--
n-pentane	72.15	1.63%	2.26E-04	0.0416	6.86	1070.60	232.70	9.21	0.38	0.01	72.15	0.88	2.80%	--
cyclopentane	70.10	0.05%	7.29E-06	1.34E-03	6.88	1119.20	230.74	5.68	7.62E-03	2.42E-04	70.10	1.70E-02	0.05%	--
benzene	78.11	0.76%	9.68E-05	0.0178	6.91	1211.00	220.79	1.68	0.03	9.50E-04	78.11	0.07	0.24%	0.27%
toluene	92.14	0.32%	3.42E-05	0.0063	7.02	1377.60	222.64	0.50	0.00	9.92E-05	92.14	0.01	0.03%	
crude oil	207.00	94.20%	4.55E-03	0.8365				10.64	8.90	0.28	50.00	14.13	45.12%	--
Total		M_t =	0.005					P_t =	31.50		M_t =	31.32	100.00%	

Sample Calcs for Benzene

[1] Liquid Moles (W_i/M_l) = Benzene Liquid Weight Percent (W_i) (wt%) / Benzene Liquid Molecular Weight (M_l)(lb/lb-mole)

$$\text{Liquid Moles } (W_i/M_l) = \frac{0.76\% \;\; \text{lb-mole}}{78.11 \text{ lb}} = 9.68\text{E-}05$$

[2] Liquid Mole Fraction (X_i) (mole frac.) = Liquid Moles of Benzene (W_i/M_l) / Total Liquid Moles (Mt)

$$\text{Liquid Mole Fraction } (X_i) \text{ (mole frac.)} = \frac{9.68\text{E-}05}{0.005} = 0.0178$$

[3] Vapor Pressure (P_i*) (psia) = 10^(A - (B/(C+Temp (deg. C))) x 14.7 psia / 760 mmHg

[4] Benzene Partial Pressure (P_i) (psia) = Benzene Vapor Pressure (P_i*) (psia) * Benzene Liquid Mole Fraction (X_i) (mole frac)

$$\text{Benzene Partial Pressure } (P_i) \text{ (psia)} = \frac{1.68 \text{ psia} \;\; 0.0178}{} = 0.03 \text{ psia}$$

[5] Benzene Vapor Mole Fraction (Y_i) (mole frac) = Benzene Partial Pressure (P_i) (psia) / Total Partial Pressure (P_t) (psia)

$$\text{Benzene Vapor Mole Fraction } (Y_i) \text{ (mole frac)} = \frac{0.03 \text{ psia}}{31.50 \text{ psia}} = 9.50\text{E-}04$$

[6] Benzene Vapor Weight Percent (wt%) = Vapor Mole Fraction (Yi) (mole frac.) x Vapor Molecular Weight (Mv) (lb/lb-mole) / Σ (Yi)(Mv)

$$\text{Vapor Weight Percent (wt\%)} = \frac{9.50\text{E-}04 \;\; 78.11 \text{ lb}}{\text{lb-mole}} \cdot \frac{1}{31.32} = 0.24\%$$

Crude Vapor Speciation - Crude Profile 4

Component	Liquid Molecular Weight (M_l)	Liquid Weight Percent (W_i)	Liquid Moles [1] (W_i/M_l)	Liquid Mole Fraction [2] $X_i = W_i/(M_t x M_l)$	Temp (°F) 73.50 Temp (°C) 23.06 Antoine's Constants (deg. C)			Vapor Pressure [3] P_i*	Partial Pressure [4] $P_i = (P_i^*)(X_i)$	Vapor Mole Fraction [5] $Y_i = (P_i/P_t)$	Vapor Molecular Weight (M_v)	$(Y_i)(M_v)$	Vapor Weight Percent [6] Yi (Mv/Mt)	Max Total HAP Vapor Weight
	(lb/lb-mole)	(wt%)		(mole frac.)	A	B	C	(psia)	(psia)	(mole frac.)	(lb/lb-mole)		(wt%)	(wt%)
methane + ethane	16.00	0.02%	1.26E-05	2.29E-03	7.10	516.70	284.37	5031.02	11.50	0.45	16.00	7.24	20.42%	--
propane	44.10	0.43%	9.65E-05	0.0175	6.86	819.30	248.73	134.86	2.36	0.09	44.10	4.09	11.55%	--
isobutane	58.12	0.39%	6.73E-05	0.0122	6.82	912.10	243.34	48.03	0.59	0.02	58.12	1.34	3.78%	--
n-butane	58.12	1.49%	2.57E-04	0.0466	6.73	909.70	237.00	32.61	1.52	0.06	58.12	3.47	9.80%	--
isopentane	72.15	1.08%	1.50E-04	0.0272	6.79	1020.00	233.10	12.43	0.34	0.01	72.15	0.96	2.71%	--
n-pentane	72.15	1.67%	2.32E-04	0.0420	6.86	1070.60	232.70	9.21	0.39	0.02	72.15	1.10	3.10%	--
cyclopentane	70.10	0.22%	3.13E-05	5.67E-03	6.88	1119.20	230.74	5.68	3.22E-02	1.27E-03	70.10	8.88E-02	0.25%	--
benzene	78.11	0.15%	1.96E-05	0.0035	6.91	1211.00	220.79	1.68	0.01	2.35E-04	78.11	0.02	0.05%	0.19%
toluene	92.14	1.37%	1.49E-04	0.0269	7.02	1377.60	222.64	0.50	0.01	5.27E-04	92.14	0.05	0.14%	
crude oil	207.00	93.17%	4.50E-03	0.8161				10.64	8.69	0.34	50.00	17.08	48.21%	--
Total		M_t =	0.006					P_t =	25.42		M_t =	35.44	100.00%	

Sample Calcs for Benzene

[1] Liquid Moles (W_i/M_l) = Benzene Liquid Weight Percent (W_i) (wt%) / Benzene Liquid Molecular Weight (M_l)(lb/lb-mole)

$$\text{Liquid Moles } (W_i/M_l) = \frac{0.15\% \;\; \text{lb-mole}}{78.11 \text{ lb}} = 1.96\text{E-05}$$

[2] Liquid Mole Fraction (X_i) (mole frac.) = Liquid Moles of Benzene (W_i/M_l) / Total Liquid Moles (Mt)

$$\text{Liquid Mole Fraction } (X_i) \text{ (mole frac.)} = \frac{1.96\text{E-05}}{0.006} = 0.0035$$

[3] Vapor Pressure (P_i*) (psia) = 10^(A - (B/(C+Temp (deg. C))) x 14.7 psia / 760 mmHg

[4] Benzene Partial Pressure (P_i) (psia) = Benzene Vapor Pressure (P_i*) (psia) * Benzene Liquid Mole Fraction (X_i) (mole frac)

$$\text{Benzene Partial Pressure } (P_i) \text{ (psia)} = 1.68 \text{ psia} \;\; 0.0035 = 0.01 \text{ psia}$$

[5] Benzene Vapor Mole Fraction (Y_i) (mole frac) = Benzene Partial Pressure (P_i) (psia) / Total Partial Pressure (P_t) (psia)

$$\text{Benzene Vapor Mole Fraction } (Y_i) \text{ (mole frac)} = \frac{0.01 \text{ psia}}{25.42 \text{ psia}} = 2.35\text{E-04}$$

[6] Benzene Vapor Weight Percent (wt%) = Vapor Mole Fraction (Yi) (mole frac.) x Vapor Molecular Weight (Mv) (lb/lb-mole) / Σ (Yi)(Mv)

$$\text{Vapor Weight Percent (wt\%)} = 2.35\text{E-04} \;\; \frac{78.11 \text{ lb}}{\text{lb-mole}} \;\; \frac{1}{35.44} = 0.05\%$$

Crude Vapor Speciation - Crude Profile 5

Component	Liquid Molecular Weight (M_l)	Liquid Weight Percent (W_i)	Liquid Moles [1] (W_i/M_l)	Liquid Mole Fraction [2] $X_i = W_i/(M_t x M_l)$	Temp (°F) 73.50 Temp (°C) 23.06 Antoine's Constants (deg. C)			Vapor Pressure [3] P_i*	Partial Pressure [4] $P_i = (P_i^*)(X_i)$	Vapor Mole Fraction [5] $Y_i = (P_i/P_t)$	Vapor Molecular Weight (M_v)	$(Y_i)(M_v)$	Vapor Weight Percent [6] Yi (Mv/Mt)	Max Total HAP Vapor Weight
	(lb/lb-mole)	(wt%)		(mole frac.)	A	B	C	(psia)	(psia)	(mole frac.)	(lb/lb-mole)		(wt%)	(wt%)
methane + ethane	16.00	0.13%	8.06E-05	1.49E-02	7.10	516.70	284.37	5031.02	75.15	0.83	16.00	13.33	61.44%	--
propane	44.10	0.64%	1.45E-04	0.0269	6.86	819.30	248.73	134.86	3.63	0.04	44.10	1.77	8.17%	--
isobutane	58.12	0.42%	7.25E-05	0.0134	6.82	912.10	243.34	48.03	0.65	0.01	58.12	0.42	1.92%	--
n-butane	58.12	1.26%	2.16E-04	0.0401	6.73	909.70	237.00	32.61	1.31	0.01	58.12	0.84	3.88%	--
isopentane	72.15	0.55%	7.62E-05	0.0141	6.79	1020.00	233.10	12.43	0.18	0.00	72.15	0.14	0.65%	--
n-pentane	72.15	0.61%	8.49E-05	0.0157	6.86	1070.60	232.70	9.21	0.14	0.00	72.15	0.12	0.53%	--
cyclopentane	70.10	0.18%	2.54E-05	4.71E-03	6.88	1119.20	230.74	5.68	2.67E-02	2.96E-04	70.10	2.08E-02	0.10%	--
benzene	78.11	0.24%	3.04E-05	0.0056	6.91	1211.00	220.79	1.68	0.01	1.05E-04	78.11	0.01	0.04%	0.06%
toluene	92.14	0.47%	5.15E-05	0.0096	7.02	1377.60	222.64	0.50	0.00	5.26E-05	92.14	0.00	0.02%	
crude oil	207.00	95.50%	4.61E-03	0.8549				10.64	9.10	0.10	50.00	5.04	23.25%	--
Total		M_t =	0.005					P_t =	90.19		M_t =	21.70	100.00%	

Sample Calcs for Benzene

[1] Liquid Moles (W_i/M_l) = Benzene Liquid Weight Percent (W_i) (wt%) / Benzene Liquid Molecular Weight (M_l)(lb/lb-mole)

$$\text{Liquid Moles } (W_i/M_l) = \frac{0.24\%}{} \left| \frac{\text{lb-mole}}{78.11 \text{ lb}} \right. = 3.04\text{E-}05$$

[2] Liquid Mole Fraction (X_i) (mole frac.) = Liquid Moles of Benzene (W_i/M_l) / Total Liquid Moles (Mt)

$$\text{Liquid Mole Fraction } (X_i) \text{ (mole frac.)} = \frac{3.04\text{E-}05}{0.005} = 0.0056$$

[3] Vapor Pressure (P_i*) (psia) = 10^(A - (B/(C+Temp (deg. C))) x 14.7 psia / 760 mmHg

[4] Benzene Partial Pressure (P_i) (psia) = Benzene Vapor Pressure (P_i*) (psia) * Benzene Liquid Mole Fraction (X_i) (mole frac)

$$\text{Benzene Partial Pressure } (P_i) \text{ (psia)} = \frac{1.68 \text{ psia}}{} \left| \frac{0.0056}{} \right. = 0.01 \text{ psia}$$

[5] Benzene Vapor Mole Fraction (Y_i) (mole frac) = Benzene Partial Pressure (P_i) (psia) / Total Partial Pressure (P_t) (psia)

$$\text{Benzene Vapor Mole Fraction } (Y_i) \text{ (mole frac)} = \frac{0.01 \text{ psia}}{90.19 \text{ psia}} = 1.05\text{E-}04$$

[6] Benzene Vapor Weight Percent (wt%) = Vapor Mole Fraction (Yi) (mole frac.) x Vapor Molecular Weight (Mv) (lb/lb-mole) / Σ (Yi)(Mv)

$$\text{Vapor Weight Percent (wt\%)} = \frac{1.05\text{E-}04}{} \left| \frac{78.11 \text{ lb}}{\text{lb-mole}} \right| \frac{1}{21.70} = 0.04\%$$

Crude Vapor Speciation - Used In Application

Component	Liquid Molecular Weight (M_l)	Liquid Weight Percent (W_i)	Liquid Moles [1] (W_i/M_l)	Liquid Mole Fraction [2] $X_i = W_i/(M_t x M_l)$	Temp (°F) 73.50 Temp (°C) 23.06 Antoine's Constants (deg. C)			Vapor Pressure [3] P_i*	Partial Pressure [4] $P_i = (P_i^*)(X_i)$	Vapor Mole Fraction [5] $Y_i = (P_i/P_t)$	Vapor Molecular Weight (M_v)	$(Y_i)(M_v)$	Vapor Weight Percent [6] Yi (Mv/Mt)	Max Total HAP Vapor Weight
	(lb/lb-mole)	(wt%)		(mole frac.)	A	B	C	(psia)	(psia)	(mole frac.)	(lb/lb-mole)		(wt%)	(wt%)
benzene	78.11	1.50%	1.92E-04	0.0366	6.91	1211.00	220.79	1.68	0.06	6.43E-03	78.11	0.50	0.95%	1.93%
toluene	92.14	5.00%	5.43E-04	0.1033	7.02	1377.60	222.64	0.50	0.05	5.37E-03	92.14	0.49	0.98%	
crude oil	207.00	93.50%	4.52E-03	0.8601				11.00	9.46	0.99	50.00	49.41	98.07%	--
Total		M_t =	0.005					P_t =	9.57		M_t =	50.41	100.00%	

Sample Calcs for Benzene

[1] Liquid Moles (W_i/M_l) = Benzene Liquid Weight Percent (W_i) (wt%) / Benzene Liquid Molecular Weight (M_l)(lb/lb-mole)

$$\text{Liquid Moles } (W_i/M_l) = \frac{1.50\% \;\; \text{lb-mole}}{78.11 \text{ lb}} = 1.92\text{E-}04$$

[2] Liquid Mole Fraction (X_i) (mole frac.) = Liquid Moles of Benzene (W_i/M_l) / Total Liquid Moles (Mt)

$$\text{Liquid Mole Fraction } (X_i) \text{ (mole frac.)} = \frac{1.92\text{E-}04}{0.005} = 0.0366$$

[3] Vapor Pressure (P_i*) (psia) = 10^(A - (B/(C+Temp (deg. C))) x 14.7 psia / 760 mmHg

[4] Benzene Partial Pressure (P_i) (psia) = Benzene Vapor Pressure (P_i*) (psia) * Benzene Liquid Mole Fraction (X_i) (mole frac)

$$\text{Benzene Partial Pressure } (P_i) \text{ (psia)} = \frac{1.68 \text{ psia} \;\; 0.0366}{} = 0.06 \text{ psia}$$

[5] Benzene Vapor Mole Fraction (Y_i) (mole frac) = Benzene Partial Pressure (P_i) (psia) / Total Partial Pressure (P_t) (psia)

$$\text{Benzene Vapor Mole Fraction } (Y_i) \text{ (mole frac)} = \frac{0.06 \text{ psia}}{9.57 \text{ psia}} = 6.43\text{E-}03$$

[6] Benzene Vapor Weight Percent (wt%) = Vapor Mole Fraction (Yi) (mole frac.) x Vapor Molecular Weight (Mv) (lb/lb-mole) / Σ (Yi)(Mv)

$$\text{Vapor Weight Percent (wt\%)} = \frac{6.43\text{E-}03 \;\; 78.11 \text{ lb}}{\text{lb-mole}} \cdot \frac{1}{50.41} = 0.95\%$$

ATTACHMENT 5 - ALTERNATIVE EMISSION CALCULATIONS AND COMPARISON APPROACH

Emission Calculation and Comparison Approach

This section includes additional detail on the calculation methodology. Please note that the emission sources considered for the alternatives analysis are listed below:

1. Crude carrier, Support Vessels & Boats
2. Lightering Vessel Loading
3. Lightering Vessel Transfer/Transit
4. Lightering Vessel Propulsion
5. Tugs/Support Ships

This section provides additional details on the calculation methodology for items 2 and 3 above. Item 1 emissions are estimated to be the same as in the proposed design for all sources except for crude carrier loading. Therefore no background details are presented here for such emission sources.

For complete lightering, crude carrier loading emissions are the same as in the proposed design as the VLCC is loaded under similar conditions as in the proposed design. For partial loading, 50% of these emissions during the STS are similar to the proposed SPM design but the remaining 50% is controlled and therefore, these are estimated as the summation of (a) Loading Emissions for the proposed SPM design / 2 plus (b) Controlled VOC emissions during loading of 96 M BBL/YR. For VOC, this equals 10,808 tpy / 2 + 107.5 tpy. Calculations for HAPs and H_2S are calculated in a similar manner.

Emission calculation methodology for item 4 is explained in Appendix A of the permit application submission under the alternatives analysis section while the tug/support ship emissions methodology is the same as shown in the proposed design and equals the sum of the emissions from the main and auxiliary engines.

Lightering Vessel Loading

Details around emission calculations for Complete and Partial Lightering are explained below.

Emission Factors and Constants

Annual NO_X, CO, and PM Emissions Estimates for Loading of Crude Oil and Condensate				
Parameters			**Value**	**Unit**
NO_X Emission Factor [1]			0.10	lb/MMBtu
CO Emission Factor [1]			0.20	lb/MMBtu
$PM/PM_{10}/PM_{2.5}$ Emission Factor (Natural Gas)			7.60	lb/MMscf
$PM/PM_{10}/PM_{2.5}$ Emission Factor (Crude oil) [2]			17.57	lb/MMscf
$PM/PM_{10}/PM_{2.5}$ Emission Factor (Condensate) [2]			22.17	lb/MMscf
Molar Volume			389.18	acf/lbmole
Crude Oil Heat of Combustion [3]			18352	Btu/lb
Condensate Heat of Combustion [3]			18,679	Btu/lb

[1] NO_X and CO emission factors are assumed for conservatism
[2] PM Emission Factor for Crude oil/Condensate = PM Emission Factor for Natural Gas Combustion (lb/MMscf) x (1/Natural Gas Heat of Combustion (Btu/scf)) x Crude oil/Condensate Heat of Combustion (Btu/lb) x Crude Oil/Condensate Vapor MW (lb/lbmole) x (1/Molar Volume (scf/lbmole@68.33°F))

[3] Product Heat of Combustion based on representations in other permit applications.

Hourly and Annual GHG Emissions Estimates for Loading of Products		
Emission Factor	**Value**	**Unit**
CO_2 Emission Factor [1]	74.54	kg/MMBtu
CH_4 Emission Factor [1]	0.0030	kg/MMBtu
N_2O Emission Factor [1]	0.0006	kg/MMBtu
CO_2 Global Warming Potential [2]	1	
CH_4 Global Warming Potential [2]	25	
N_2O Global Warming Potential [2]	298	

[1] Emission factors are from 40 CFR Part 98, Subpart C, Tables C-1 and C-2 for Crude Oil.
[2] Per 40 CFR 98 - Mandatory Greenhouse Gas Reporting, Subpart A, Table A-1.

Criteria Pollutant Emission Calculations (NOx, CO, PM)

Summary of emission calculations is shown in the tables below with explanation on calculation methodology in the table footnotes.

Complete Lightering							
Liquid Loaded [1]	Annual Loading Rate [2]	Heat Input from Loading [3]	Annual Heat Input from Assist and Pilot Gas	Total Annual Heat Input	NO_X Annual Emissions [4]	CO Annual Emissions [4]	$PM/PM_{10}/PM_{2.5}$ Annual Emissions [5]
	(bbl/yr)	MMBtu/yr	(MMBtu/yr)	(MMBtu/yr)	(tons/yr)	(tons/yr)	(tons/yr)
Crude Oil	192,000,000	376,629	376,629	753,259	37.66	75.33	2.82
Condensate	192,000,000	392,722	392,722	785,443	39.27	78.54	2.97

Partial Lightering							
Liquid Loaded [1]	Annual Loading Rate [2]	Heat Input from Loading [3]	Annual Heat Input from Assist and Pilot Gas	Total Annual Heat Input	NO_X Annual Emissions [4]	CO Annual Emissions [4]	$PM/PM_{10}/PM_{2.5}$ Annual Emissions [5]
	(bbl/yr)	MMBtu/yr	(MMBtu/yr)	(MMBtu/yr)	(tons/yr)	(tons/yr)	(tons/yr)
Crude Oil	96,000,000	188,315	188,315	376,629	18.83	37.66	1.41
Condensate	96,000,000	196,361	196,361	392,722	19.64	39.27	1.48

[1] For hourly and annual emission estimates, the worst-case marine loading commodity between Crude oil and Condensate will be utilized.
[2] Annual Loading Rate obtained from information provided by TGTI.
[3] Heat Input from Loading (MMBtu/yr) = Annual Loading Rate (bbl/yr) x Product Heat of Combustion (Btu/lb) x Uncontrolled Loading Loss (lb/1,000 gal) x Capture Efficiency (%) x 42 gal/bbl x (1/1,000) x (1/1,000,000)
[4] NOX and CO, Annual Emissions (tpy) = Heat Input Rate from Loading (MMBtu/yr) x Emission Factor (lb/MMBtu) x (1 ton/2,000 lb)
[5] PM Annual Emissions (tpy) = Annual Loading Rate (bbl/yr) x Uncontrolled Loading Loss (lb/1,000 gal) x 42 gal/bbl x (1/Vapor MW (lb/lbmole)) x Molar Volume (scf/lbmole @ 68.33 F) x Emission Factor (lb/MMscf) x (1/1,000) x (1/1,000,000) x (1 ton/2,000 lb)
[6] Assumes a 1:1 overall ratio of assist and pilot gas heat input for operation of the VCU

Criteria Pollutant Emission Calculations (H_2S and SO_2)

Summary of emission calculations is shown in the tables below with explanation on calculation methodology in the table footnotes.

Complete Lightering						
Liquid Loaded [1]	H_2S Vapor Fraction [2]	Average TVP [3]	Mass Ratio of H_2S [4]	VOC Annual Emissions	H_2S Annual Emissions [5]	SO_2 Annual Emissions [4]
		(psia)	lb H_2S/lb VOC	(tpy)	(tpy)	(tpy)
Crude Oil	2.40E-05	11.00	2.19E-05	206	0.00	0.85
Condensate	2.40E-05	9.25	2.10E-05	215	0.00	0.85

Partial Lightering						
Liquid Loaded [1]	H_2S Vapor Fraction [2]	Average TVP [3]	Mass Ratio of H_2S [4]	VOC Annual Emissions	H_2S Annual Emissions [5]	SO_2 Annual Emissions [4]
		(psia)	lb H_2S/lb VOC	(tpy)	(tpy)	(tpy)
Crude Oil	2.40E-05	11.00	2.19E-05	103	0.00	0.42
Condensate	2.40E-05	9.25	2.10E-05	108	0.00	0.42

[1] For hourly and annual emission estimates, the worst-case marine loading commodity between Crude oil and Condensate will be utilized.
[2] Maximum H_2S vapor fraction is assumed to be 24 ppmv for sweet crude.
[3] True vapor pressure for Crude oil and Condensate obtained from information provided by TGTI.
[4] H_2S Mass Ratio in Crude Oil/Condensate (lb H_2S/lb VOC) = H_2S Vapor Fraction in Crude Oil/Condensate x H_2S MW (lb/lbmole)/Crude Oil/Condensate Vapor MW (lb/lbmole) x 14.7 psia/Vapor Pressure of Crude Oil/Condensate (psia)
[5] H_2S Annual Emissions (tpy) = Max H_2S Mass Ratio in Crude/Condensate (lb H_2S/lb VOC) x Uncontrolled VOC Annual Emissions (tpy)

GHG Emission Calculations

Summary of emission calculations is shown in the tables below with explanation on calculation methodology in the table footnotes.

Loading Vessel	Liquid Loaded	Annual Heat Input from Vapors	Annual Heat Input from Assist and Pilot Gas [3]	Total Annual Heat Input	CO_2 Annual Emissions [1]	CH_4 Annual Emissions [1]	N_2O Annual Emissions [1]	CO_2e Annual Emissions [2]
	(bbl/yr)	(MMBtu/yr)	(MMBtu/yr)	(MMBtu/yr)	(tpy)	(tpy)	(tpy)	(tpy)
Complete Lightering								
Crude Oil	192,000,000	376,629	376,629	753,259	61,892	2.49	0.50	62,103
Condensate	192,000,000	392,722	392,722	785,443	64,537	2.60	0.52	64,757
Partial Lightering								
Crude Oil	96,000,000	188,315	188,315	376,629	30,946	1.25	0.25	31,052
Condensate	96,000,000	196,361	196,361	392,722	32,268	1.30	0.26	32,378

[1] CO_2, N_2O and CH_4 Annual Emissions (tpy) = Emission Factor (kg/MMBtu) x Heat Input from Loading (MMBtu/yr) x (1 ton/2,000 lb) x (2.20462 lb/1 kg)
[2] CO_2e emissions are calculated based on the Global Warming Potentials (GWP)
*CO_2e = CO_2 Emission Rate * CO_2 GWP + CH_4 Emission Rate * CH_4 GWP + N_2O Emission Rate * N_2O GWP*
[3] Assumes a 1:1 overall ratio of assist and pilot gas heat input for operation of the VCU.

Lightering Transit

In addition to loading losses, losses occur while the cargo is in transit. Emissions are uncontrolled. HAP emissions are based on the product of the crude speciation profile wt. percent and VOC emissions.

Complete Loading

Transit losses are similar to breathing losses associated with petroleum storage. Transit time is estimated at 14.5 hrs or 0.60 days one way.

Partial Loading

VLCCs come inland and load to 50% (partial) capacity and then travel offshore to have the remaining product loaded via STS transfer at an offshore lightering location. One (1) Suezmax vessel loads inland and then travels to the lightering location to fill the remaining 50% of the VLCC via STS transfer offshore. Transit time is assumed to be 14.5 hrs or 0.60 days one way.

Criteria and HAP Emission Calculations

Emissions for STS transfer lightering are uncontrolled. HAP emissions are based on the product of the crude speciation profile wt. percent and the VOC emissions.

VOC Emissions

Annual VOC Emissions Estimates for Transit of Crude Oil and Condensate (Complete Lightering)							
Product in Transit [1]	Condensed Vapor Density	Average True Vapor Pressure (TVP) [2]	Uncontrolled Transit Loss [3]	No. of days for Transit [4] [6]	Control Destruction Efficiency	Annual Transit Rate [4]	Controlled VOC Annual Emissions [5]
	(lb/gal)	(psia)	(lb/1,000 gal-day)	(days)	(%)	(bbl/yr)	(tpy)
Crude Oil	7.1	11.00	1.12	0.60	0%	192,000,000	2,718
Condensate	5.6	9.25	0.74	0.60	0%	192,000,000	1,803

Annual VOC Emissions Estimates for Transit of Crude Oil and Condensate (Partial Lightering)							
Product in Transit [1]	Condensed Vapor Density	Average True Vapor Pressure (TVP) [2]	Uncontrolled Transit Loss [3]	No. of days for Transit [4] [6]	Control Destruction Efficiency	Annual Transit Rate [4]	Controlled VOC Annual Emissions [5]
	(lb/gal)	(psia)	(lb/1,000 gal-day)	(days)	(%)	(bbl/yr)	(tpy)
Crude Oil	7.1	11.00	1.12	0.60	0%	192,000,000	2,718
Condensate	5.6	9.25	0.74	0.60	0%	192,000,000	1,803

[1] For annual emission estimates, the worst-case marine loading commodity between Crude oil and Condensate will be utilized.
[2] Vapor pressures are retained consistent with those used for the Tank Farm.
[3] Uncontrolled loading loss during transfer operations is calculated using equation 5 from U.S. EPA 42, Section 5.2 (6/08).
[4] Note that the shortest distance between the shore and SPM location is 15 miles but the distance travelled is not straight and estimated to be 65 miles one way. Transit time is conservatively estimated at 14.5 hrs or 0.60 days one way.
[5] Controlled VOC Loading Emissions (tpy) = Uncontrolled Loading Loss (lb/1,000 gal) x Annual Loading Rate (bbl/yr) x 42 gal/bbl x (1/1,000) x (1 ton/2,000 lb) x (1- Control Efficiency (%))
[6] Capacities of various ships and tankers per http://alloiltank.com/oil-tanker-ship/

H_2S Emissions

Annual H_2S Emissions Estimates for Transfer of Crude Oil and Condensate are shown in the table below.

Liquid Loaded [1]	H_2S Vapor Fraction [2]	Average TVP [3]	Mass Ratio of H_2S [4]	Complete Lightering VOC Annual Emissions	Complete Lightering H_2S Annual Emissions [5]	Partial Lightering VOC Annual Emissions	Partial Lightering H_2S Annual Emissions [5]
		(psia)	lb H_2S/lb VOC	(tpy)	(tpy)	(tpy)	(tpy)
Crude Oil	2.40E-05	11.00	2.19E-05	2,718	0.06	2,718	0.06
Condensate	2.40E-05	9.25	2.10E-05	1,803	0.04	1,803	0.04

[1] For hourly and annual emission estimates, the worst-case marine loading commodity between Crude oil and Condensate will be utilized.
[2] Maximum H_2S vapor fraction is assumed to be 24 ppmv for sweet crude.
[3] Vapor pressures are retained consistent with those used for the Tank Farm.
[4] H_2S Mass Ratio in Crude Oil/Condensate (lb H_2S/lb VOC) = H_2S Vapor Fraction in Crude Oil/Condensate x H_2S MW (lb/lbmole)/Crude Oil/Condensate Vapor MW (lb/lbmole) x 14.7 psia/Vapor Pressure of Crude Oil/Condensate (psia)
[5] H_2S Annual Emissions (tpy) = Max H_2S Mass Ratio in Crude/Condensate (lb H_2S/lb VOC) x Uncontrolled VOC Annual Emissions (tpy)

HAP Emissions

Total HAP emissions are calculated as the total VOC emissions X Composition.

Complete Lightering			
Pollutant	Liquid Loaded [1]	Uncontrolled VOC Annual Emissions	Annual Emissions [2]
		(tpy)	(tpy)
Benzene	Crude Oil	2,718	25.82
	Condensate	1,803	7.75
Toluene	Crude Oil	2,718	26.64
	Condensate	1,803	6.67

Partial Lightering			
Pollutant	Liquid Loaded [1]	Uncontrolled VOC Annual Emissions	Annual Emissions [2]
		(tpy)	(tpy)
Benzene	Crude Oil	2,718	25.82
	Condensate	1,803	7.75
Toluene	Crude Oil	2,718	26.64
	Condensate	1,803	6.67

[1] For hourly and annual emission estimates, the worst-case marine loading commodity between Crude oil and Condensate will be utilized.
[2] Benzene Annual Emissions (tpy) = Max Benzene % in Crude/Condensate Vapors x Uncontrolled VOC Annual Emissions (tpy)
[3] Emissions are based on the total VOC emissions for transfer of Crude Oil and Condensate calculated previously.