Performance evaluation in land-based test facility

BAWAT BWMS

Treatment using pasteurization and in-tank de-oxygenation

BAWAT A/S

Final report

September 2014

The expert in **WATER ENVIRONMENTS**

This report has been prepared under the DHI Business Management System certified by DNV GL to comply with ISO 9001 (Quality Management)

QUALITY SYSTEM CERTIFICATION
DNV·GL
ISO 9001
DNV GL BUSINESS ASSURANCE DENMARK A/S

Approved by
17-09-2014 X Approved by Signed by: Jens Tørsløv

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Treatment using pasteurization and in-tank de-oxygenation

DHI Maritime Technology Evaluation Facility in Hundested, Denmark

Prepared for BAWAT A/S

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Project number	11812682
Approval date	2014.09.17
Revision	Final report
Classification	Confidential

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Abbreviations

Abbreviation	Description
AVG	Average
BE	Biological efficacy
BWMS	Ballast water management system
CFU	Colony-forming units
CMFDA	Chloromethylfluorescein diacetate
DOC	Dissolved organic carbon
FDA	Fluorescein diacetate
FR	Field replicate
IMO	International Maritime Organization
MEPC	Marine Environment Protection Committee
NTU	Nephelometric turbidity units
POC	Particulate organic carbon
PSU	Practical salinity units
QAPP	Quality assurance project plan
SOP	Standard operating procedure
SSI	Statens Serum Institut
STD	Standard deviation
T0	Day 0 samples
T5	Day 5 samples
T6	Day 6 samples
TSS	Total suspended solids
UV	Ultraviolet
UV-T	UV transmittance
WET	Whole effluent toxicity

1 Executive summary

DHI provides independent performance evaluation of ballast water management systems (BWMS) for the approval process. The purpose of the performance evaluation is to assure that BWMS approved by administrations are capable of meeting the ballast water discharge standard in Regulation D-2 /1/, also known as the IMO D-2 standard, in land-based and shipboard evaluations and do not cause unacceptable harm to the vessel, crew, environment or public health.

The objective of this project was to conduct a performance evaluation of the BAWAT BWMS in a land-based test facility with the aim to meet the testing requirements in Resolution MEPC.174(58) /2/.

From March 2013 through April 2014, DHI conducted a land-based test of the BAWAT BWMS with DNV GL as classification society.

The basic treatment principles with the BAWAT BWMS are pasteurization and in-tank de-oxygenation.

A total of 17 biological efficacy (BE) test cycles were performed. The BWMS was operated by BAWAT, and the operation was surveyed by DHI staff during all BE test cycles except test cycle M-1. BAWAT staff was present at the test facility during all BE test cycles. Seven BE test cycles were conducted with brackish water, six BE test cycles were conducted with marine water, and four BE test cycles were conducted with fresh water. During land-based testing the number of recirculations was increased from 4 to 5 for all test cycles conducted on 30 April 2013 and onwards. The cooling procedure was changed from ‘after treatment cooling’ to ‘in-line cooling’ for all test cycles conducted on 28 May 2013 and onwards.

The BAWAT BWMS was tested in salinities ranging from <1 PSU, 18 to 21 PSU and from 32 to 37 PSU with water temperatures ranging from approx. 1 to 21°C. The concentrations of total suspended solids (TSS), particulate organic carbon (POC) and dissolved organic carbon (DOC) were in accordance with the minimum water quality characteristics in the IMO G8 guidelines in all BE test cycles except for BE test cycle B-2 where the concentration of TSS was 38 mg/L instead of >50 mg/L.

The densities of viable organisms and the number of taxa and species identified in the inlet and control discharge water were in accordance with the IMO G8 guidelines in all test cycles. The average densities of viable organisms ≥50 µm ranged from approx. 190,000 to 1,100,000 organisms/m^3 in the inlet water, and from approx. 12,000 to 165,000 organisms/m^3 in the control discharge water. The average densities of viable organisms ≥10 and <50 µm determined by inverted microscopy varied from approx. 1,000 to 9,000 organisms/mL in the inlet water, and from approx. 150 to 1,500 organisms/mL in the control discharge water. Heterotrophic bacteria were present in concentrations from approx. 20,000 to approx. 550,000 CFU/mL in the inlet water and from approx. 11,000 to >200,000 CFU/mL in the control discharge water.

Table 1.1 summarizes the number of viable organisms in water treated with the BAWAT BWMS at discharge. The performance evaluation leads to the conclusion that the BAWAT BWMS complied with the ballast water discharge standard in five BE tests in brackish water, five BE tests in marine water and two BE tests in fresh water.

Table 1.1 Summary of the number of viable organisms in water treated with the BAWAT BWMS at discharge.

Test cycle	Organisms ≥50 µm per m³	Organisms ≥10 and <50 µm per mL	Organisms <10 µm Enterococci (CFU/100 mL)	Organisms <10 µm *E. coli* (CFU/100 mL)	Organisms <10 µm *V. cholerae* (CFU/100 mL)
B-1	0	11	1.5	<1.0	Absent
B-2	0	1.8	<1,0	<1.0	Absent
B-3	3.0	12	1.0	<1.0	Absent
B-4	0	1.9	1.0	<1.0	Absent
B-5	0.33	7.2	2.3	<1.0	Absent
B-6	1.0	2.1	<1.0	<1.0	Absent
B-7	7.0	0.67	<1.0	<1.0	Absent
M-1	0	1.8	3.0	<100	Absent
M-2	0	0.92	4.0	<1.0	Absent
M-3	0	20	1.3	<1.0	Absent
M-4	4.0	2.1	5.5	<1.0	Absent
M-5	5.0	3.2	<1.0	<1.0	Absent
M-6	2.3	4.2	<1.0	<1.0	Absent
F-1	0.33	5.8	7.0	<1.0	Absent
F-2	5.3	6.6	1.0	<1.0	Absent
F-3	142	37	1.5	19	Absent
F-4	66	14	1.7	<1.0	Absent
Requirements	<10	<10	<100	<250	<1

Colours:
Green Compliance with the ballast water discharge standard
Light green Compliance with the ballast water discharge standard with deviations in relation to abiotic quality characteristics of the inlet water. The concentration of TSS was 38 mg/L instead of >50 mg/L. This difference is considered negligible for the BAWAT BWMS and without any influence on the biological performance evaluation
Red No compliance with the ballast water standard
CFU Colony-forming unit

2 Introduction

DHI is an independent, international consulting and research organisation established in Denmark and today represented in all regions of the world with a total of more than 1,000 employees. Our objectives are to advance technological development, governance and competence in the fields of water, environment and health. DHI works with governmental agencies and authorities, contractors, consultants and numerous industries.

DHI provides independent performance evaluation of ballast water management systems (BWMS) for the approval process. DHI has no involvement, intellectual or financial, in the mechanics, design or marketing of the products and technologies that are being evaluated. To ensure that DHI's tests are uncompromised by any real or perceived individual or team bias relative to test outcomes, DHI's test activities are subject to

rigorous quality assurance (QA), quality control (QC) and documentation. DHI's quality management system is certified according to ISO 9001 by DNV-GL. The certification is facilitated by the implementation of the DHI Business Management System.

For an application for final approval, the IMO International Convention for the Control and Management of Ships' Ballast Water and Sediments /1/ requires a performance evaluation of BWMS according to the principles laid down in Resolution MEPC.174(58) /2/, generally referred to as the IMO G8 guidelines, and, for systems that make use of active substances, also Resolution MEPC.169(57) /3/, generally referred to as the IMO G9 guidelines. The purpose of the performance evaluation is to assure that BWMS approved by administrations are capable of meeting the ballast water discharge standard in Regulation D-2 /1/, also known as the IMO D-2 standard, in land-based and shipboard evaluations and do not cause unacceptable harm to the vessel, crew, environment or public health.

The objective of this project was to conduct a performance evaluation of the BAWAT BWMS at a land-based test facility with the aim to meet the testing requirements in Resolution MEPC.174(58) /2/.

The acting classification society for the land-based test of the BAWAT BWMS was DNV GL.

This report describes a series of 17 land-based test cycles conducted by DHI from March 2013 to April 2014 with the BAWAT BWMS.

3 Classification society

The classification society appointed by the client for inspection and certification of the project is:

DNV GL AS
Veritasveien 1
NO-1363 Høvik
Norway

4 Client

The client requesting the performance evaluation is:

BAWAT A/S
Lejrvej 25
DK-3500 Værløse
Denmark

The client is the manufacturer of the BAWAT BWMS.

5 Testing laboratory

DHI established a land-based test facility in Hundested, Denmark, in June 2010. A description of the test facility is available in the quality assurance project plan (QAPP) in Appendix 1.

DHI's Environmental Laboratory has an accreditation according to ISO 17025 which includes biological analyses related to performance evaluation of BWMS and

ecotoxicological studies. Furthermore, the laboratory is authorized to carry out ecotoxicological studies in compliance with the OECD Principles of Good Laboratory Practice (GLP) (Appendix 6).

DHI's Environmental Laboratory and staff normally analyse all samples collected during the performance evaluation of BWMS. If required, specialized chemical analyses of, e.g., active substances or disinfection by-products, are conducted by a subcontractor.

The performance evaluation of the BAWAT BWMS was conducted by DHI Denmark at the following facilities:

DHI Environmental Laboratory
Agern Allé 5
DK-2970 Hørsholm
Denmark

DHI Maritime Technology Evaluation Facility
Færgevejen 18
DK-3390 Hundested
Denmark

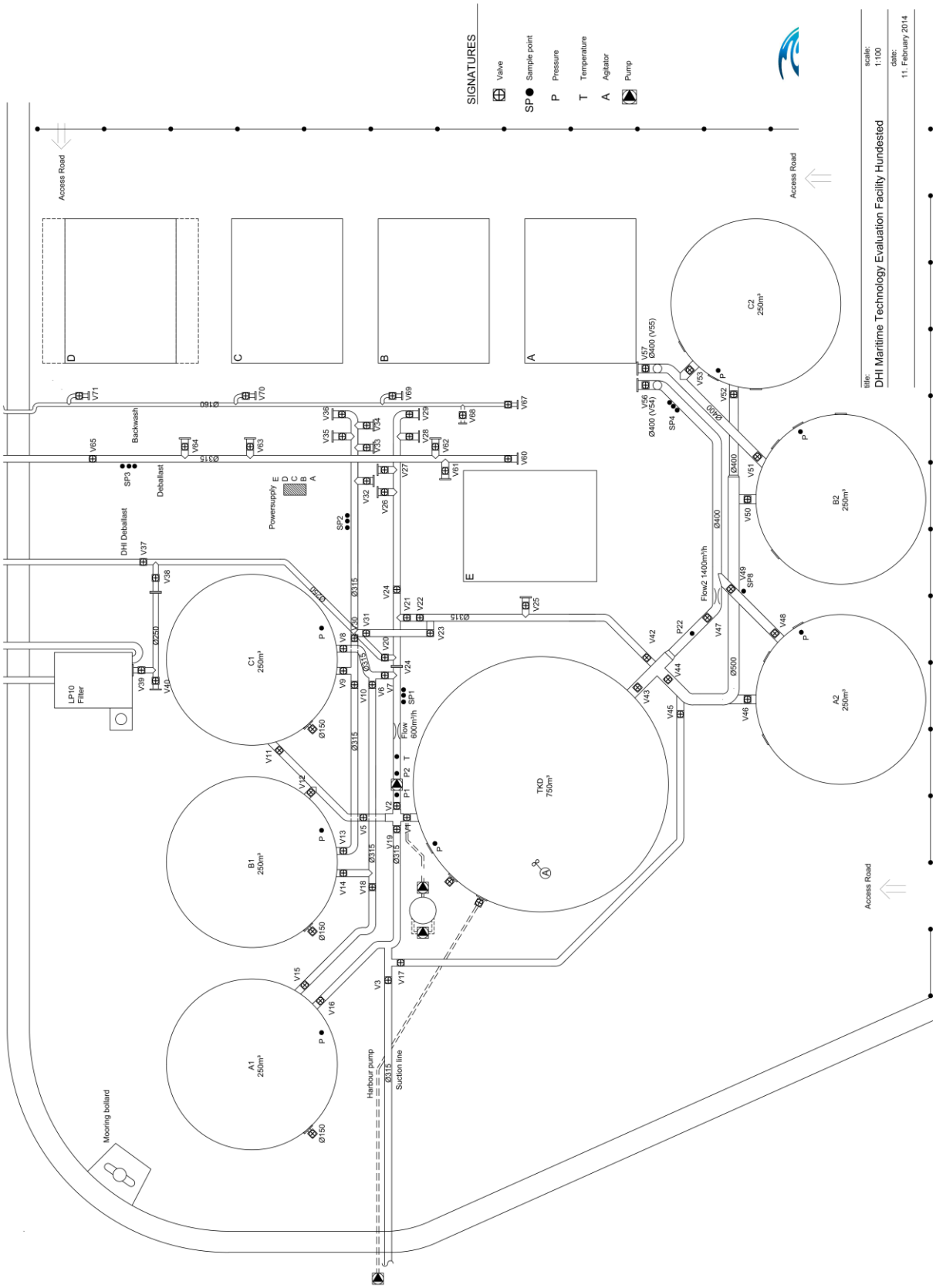

Figure 5.1 DHI Maritime Technology Evaluation Facility, Hundested, Denmark

6 Ballast water management system

The basic treatment principles with the BAWAT BWMS are pasteurization and in-tank deoxygenation. The BAWAT BWMS treatment process involves recirculation of the test water in the retention tank through a pasteurization unit. In the recirculation loop nitrogen is injected in the water.

The cooling procedure was changed from ‘after treatment cooling’ to ‘in-line cooling’ for all test cycles conducted on 28 May 2013 and onwards to better simulate the conditions in shipboard installations.

A detailed technology and process description of the BAWAT BWMS is enclosed in Appendix B of the QAPP (Appendix 1).

7 Experimental design

The BAWAT BWMS performance evaluation involved physical and biological characterisation of water upon ballasting (inlet water) and comparison of organisms in control versus treated water at discharge after approx. five days (Table 7.1). Biological characterisations supported comparison with the ballast water discharge standard /1/.

The interior design of ballast water tanks plays an integral role in the BAWAT BWMS treatment process. For the BAWAT BWMS performance evaluation, the retention tank C2 was modified with a central tower and tarpaulins to create appropriate barriers to resemble ballast water tanks installed in ships. The tarpaulins were fixed to the central tower and the wall of the retentions tank by use of wires. The detailed modifications are illustrated in Figure 7.1 – Figure 7.3.

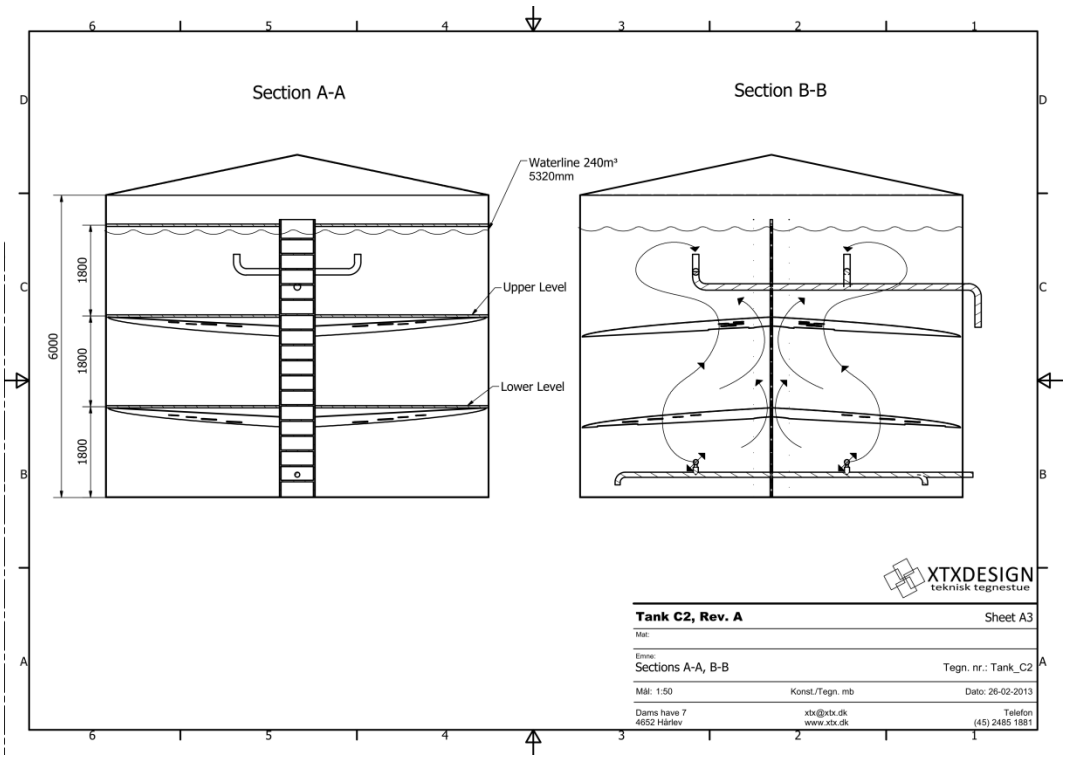

Figure 7.1 Cross sections of retention tank modifications

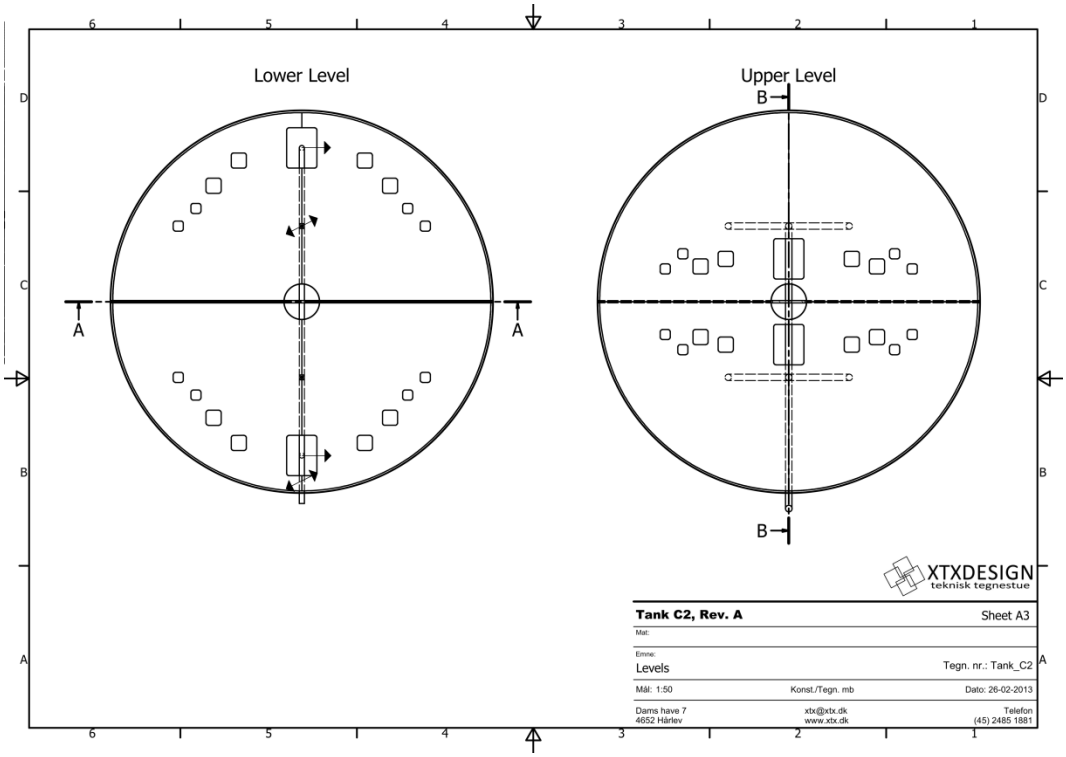

Figure 7.2 Tarpaulin design

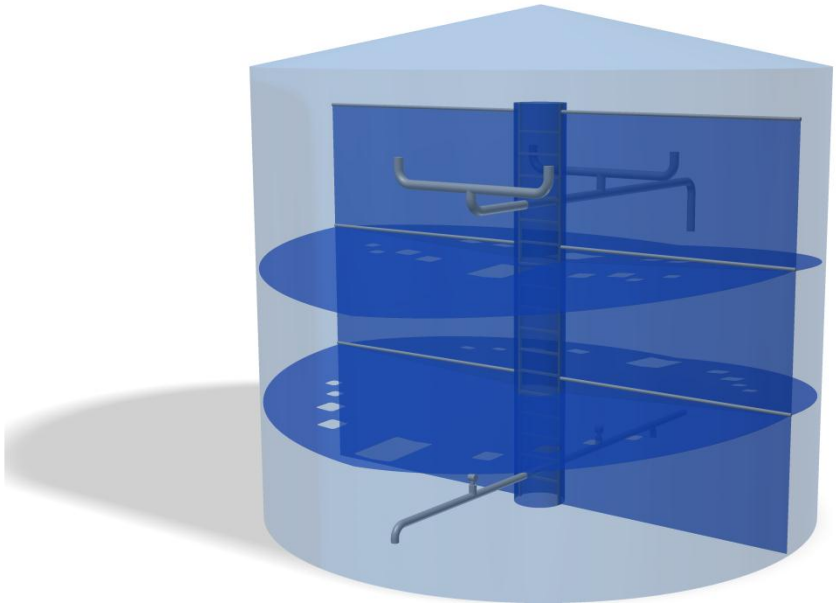

Figure 7.3 3D-view of retention tank modifications

7.1 Trial period and survey of the BAWAT BWMS

A total of 17 biological efficacy (BE) test cycles were conducted throughout the test period from March 2013 through April 2014. Seven BE test cycles were conducted in brackish water (B-1 to B-7), six BE test cycles were conducted in high saline marine water (M-1 to M-6), and four BE test cycles were conducted in fresh water (F-1 to F-4).

The treatment process of test cycle B-1 was surveyed by DNV GL, treatment processes of test cycles B-1 – B-7, M-1 – M-6 and F-1 – F-4 were surveyed by DHI.

7.2 Biological efficacy verification testing

7.2.1 BWMS treatment process

The BE test cycles were conducted by use of the source tank (Tank D), control tank (Tank A2 with the exception of BE test cycle F-4 in which Tank B1 was used) and one retention tank per test cycle (Tank C2) (Figure 5.1).

Test water (400-500 m^3) contained in the source tank was transferred to the retention tank and the control tank simultaneously by pumping and treated by the BWMS using pasteurization and in-tank de-oxygenation.

During ballasting, the flow, pressure, temperature, dissolved oxygen, pH, salinity, turbidity and water levels in the tanks were recorded automatically (DHI SOP 30/1764).

Samples were collected before treatment by use of the relevant sample ports. Sampling was initiated at the start of operation (DHI SOPs 30/1738 and 30/1762). The samples were labelled according to procedures described in DHI SOP 30/1750.

7.2.2 Storage of treated and untreated test water

Following the transfer of test water to the retention tank and the control tank the water in the retention tank was treated with the BAWAT BWMS using pasteurization and in-tank de-oxygenation. After approx. 5 days (Table 7.1) the treated water and control water were discharged into the harbour.

7.2.3 Discharge of test water

1. The retention tanks, piping system and sample ports were cleaned (DHI SOP 30/1763).
2. Treated water contained in the retention tank was discharged into the harbour (treated discharge water).
3. Control water contained in the control tank was discharged into the harbour (control discharge water).

During de-ballasting, the flow, pressure, water temperature, dissolved oxygen, pH, salinity, turbidity and water levels in the tanks were recorded automatically (DHI SOP 30/1764).

Both samples of the treated discharge water and the control water were collected by use of the sampling ports on the test facility discharge line. Isokinetic sampling methodology with fixed sample volumes was applied according to the principles described in MEPC.173(58) (G2) /6/

7.2.4 Biological efficacy test cycles

An overview of dates, time periods, treated volumes, and test details for all 17 BE test cycles is presented in the table below. During the land-based testing the number of recirculations was increased from 4 to 5 for all test cycles conducted on 30 April 2013 and onwards. The cooling procedure was changed from ‘after treatment cooling’ to ‘in-line cooling’ for all test cycles conducted on 28 May 2013 and onwards.

Table 7.1 Details for inlet and discharge operations for biological efficacy test cycles.

Test cycle	Type	Inlet		Discharge	Test details
		Date & time	Volume (m^3)	Date & time	
B-1	BWMS	2013.04.10 09:15 – 10:10	250	2013.04.15 08:45 – 09:28	4 recirculations, after treatment cooling
	Control		205	2013.04.15 09:45 – 10:23	
B-2	BWMS	2013.04.16 08:58 – 09:57	245	2013.04.22 08:45 – 09:27	4 recirculations, after treatment cooling
	Control		201	2013.04.22 09:57 – 10:36	
B-3	BWMS	2013.04.23 08:48 – 09:43	235	2013.04.29 08:55 – 09:40	4 recirculations, after treatment cooling
	Control		200	2013.04.29 10:00 – 10:39	
B-4	BWMS	2013.04.30 08:57 – 09:51	246	2013.05.06 08:57 – 09:42	5 recirculations, after treatment cooling
	Control		201	2013.05.06 10:10 – 10:49	
B-5	BWMS	2013.08.06 09:01 – 10:00	238	2013.08.12 08:42 – 09:24	5 recirculations, in-line cooling
	Control		206	2013.08.12 09:53 – 10:32	
B-6	BWMS	2014.03.18 09:13 – 10:06	242	2014.03.24 09:10 – 09:56	5 recirculations, in-line cooling
	Control		200	2014.03.24 10:20 – 10:58	
B-7	BWMS	2014.03.27 09:12– 10:05	242	2014.04.02 09:08– 09:54	5 recirculations, in-line cooling
	Control		202	2014.04.02 10:26 – 11:05	
M-1	BWMS	2013.03.20 09:35 – 10:36	246	2013.03.25 10:03 – 10:49	4 recirculations, after treatment cooling
	Control		205	2013.03.25 11:23 – 12:04	
M-2	BWMS	2013.05.08 08:55 – 09:48	250	2013.05.14 08:44 – 09:27	5 recirculations, after treatment cooling
	Control		198	2013.05.14 09:54 – 10:30	
M-3	BWMS	2013.05.28 09:06 – 10:01	239	2013.06.03 08:24 – 09:10	5 recirculations, in-line cooling
	Control		203	2013.06.03 09:36 – 10:17	
M-4	BWMS	2013.06.04 09:05 – 09:59	242	2013.06.10 09:40 – 10:26	5 recirculations, in-line cooling
	Control		202	2013.06.10 10:53 – 11:29	
M-5	BWMS	2013.06.18 08:59 – 09:51	243	2013.06.24 09:25 – 09:59	5 recirculations, in-line cooling
	Control		210	2013.06.24 10:31 – 11:02	
M-6	BWMS	2013.06.25 09:05 – 09:59	241	2013.07.01 09:13 – 09:58	5 recirculations, in-line cooling
	Control		205	2013.07.01 10:25 – 11:06	
F-1	BWMS	2013.08.13 08:37 – 09:35	234	2013.08.19 09:24 – 10:06	5 recirculations, in-line cooling
	Control		194	2013.08.19 10:54 – 11:31	

Test cycle	Type	Inlet		Discharge	Test details
		Date & time	Volume (m^3)	Date & time	
F-2	BWMS	2013.08.20 08:23 – 09:19	235	2013.08.26 08:59 – 09:45	5 recirculations, in-line cooling
	Control		200	2013.08.26 10:07 – 10:46	
F-3	BWMS	2013.09.03 08:24 – 09:19	235	2013.09.09 08:57 – 09:38	5 recirculations, in-line cooling
	Control		190	2013.09.09 10:24 – 11:01	
F-4	BWMS	2013.11.12 09:17 – 10:15	232	2013.11.18 09:19 – 10:02	5 recirculations, in-line cooling
	Control		196	2013.11.18 10:30 – 11:07	

Table 7.2 Selected parameters determined during the BAWAT treatment process (Provided by BAWAT).

Test cycle	Energy consumption (kJ/m^3)*	Recirculations	Holding time (s)	Pasteurization Temperature (°C)	Average N_2 flow during pasteurization		Average O_2 level in N_2 during pasteurization (%)**	Dissolved O_2 in flow – end of treatment (mg/L) ***	
					N_2 Flow (L/min)	% of water flow		AVG	STD
B-1	114,270	4	72.4	72.3	148	7.1	2.1	0.6	0.24
B-2	118,300	4	71.4	72.6	150	7.2	2.0	0.5	0.23
B-3	118,076	4	71.6	72.6	148	7.1	2.0	0.7	0.13
B-4	131,674	5	70.9	72.6	150	7.1	2.0	0.6	0.11
B-5	109,797	5	75.8	71.7	152	7.7	2.0	1.0	0.32
B-6	193,035	5	75.1	73.5	160	8.0	2.0	1.2	0.32
B-7	204,429	5	75.6	73.2	158	8.0	2.1	1.0	0.40
M-1	111,943	4	73.1	72.3	154	7.5	-	0.5	0.25
M-2	126,904	5	71.5	72.3	154	7.4	2.0	0.5	0.12
M-3	163,397	5	76.5	72.3	150	7.7	2.0	1.0	0.23
M-4	176,997	5	76.3	72.3	149	7.6	2.0	0.8	0.17
M-5	189,542	5	76.6	72.2	152	7.7	2.1	0.7	0.21
M-6	179,910	5	76.9	71.8	152	7.8	2.1	0.6	0.23
F-1	121,723	5	75.6	71.9	153	7.7	2.0	1.1	0.17
F-2	130,628	5	75.6	71.9	151	7.6	2.0	1.1	0.20
F-3	133,003	5	75.6	72.1	151	7.6	2.0	1.3	0.17
F-4	218,664	5	81.7	73.1	150	8.2	2.1	1.4	0.12

* Details on energy consumption calculation are given in Appendix 3
** Average O_2 level in N_2 during pasteurization
*** Average of all dissolved oxygen sensors in tank and sensor in flow

For each BE test cycle, additional details regarding number of recirculations, cooling, addition of organisms, recordings of power consumption etc. are available in the data logging in Appendix 2. Data logged by BAWAT and logs from the DHI survey during treatment is enclosed in Appendix 3.

Samples for whole effluent toxicity (WET) testing were taken during test cycle B-5. A separate report was prepared for the WET testing /5/ and enclosed in Appendix 5.

7.3 Test water and challenge conditions in BE verification testing

Source water means the body of water, from which water is drawn for the land-based test. The IMO G8 guideline /2/ describes three distinct water types that may be applied in the land-based test:

- Fresh water (salinity <3 PSU)
- Brackish water (salinity 3-32 PSU)
- Marine water (salinity >32 PSU)

The BE test cycles with the BAWAT BWMS were performed with fresh, brackish and marine water.

For BE test cycles with fresh water, the source water was collected from the Arresø Canal (DHI SOP 30/1736). Organism densities in the collected fresh water often exceed the minimum criteria for live organisms in test water with an order of magnitude allowing for dilution of the natural fresh water with potable water.

For BE test cycles with brackish water, the source water was collected immediately south of the pier adjacent to the test facility (DHI SOP 30/1735); under normal conditions, the natural salinity of the source water is 15-20 PSU.

For BE test cycles with marine water, the source water was collected immediately south of the pier adjacent to the test facility (DHI SOP 30/1735), and brine was added to achieve the required salinity (DHI SOP 30/1737) except test M-1 where the water immediately south of the pier had a natural salinity of 32 PSU.

7.3.1 Test water – water quality characteristics

Test water means the inlet water as contained in the source tank immediately prior to treatment. In land-based tests, source water may be adjusted to achieve the required challenge conditions. The test water was adjusted to meet the water quality parameters in Table 7.3.

Table 7.3 Minimum water quality characteristics according to the IMO G8 guidelines /2/

Parameter	Test water		
	Fresh <3 PSU	Brackish 3-32 PSU	Marine >32 PSU
Dissolved organic carbon (DOC)	>5 mg/L	>5 mg/L	>1 mg/L
Particulate organic carbon (POC)	>5 mg/L	>5 mg/L	>1 mg/L
Total suspended solid (TSS)	>50 mg/L	>50 mg/L	>1 mg/L

If necessary to obtain the stated water quality parameters, the concentrations of dissolved organic carbon (DOC), particulate organic carbon (POC) and total suspended solids were increased by additions of lignin sulphonate (DOC), starch (POC and TSS) and kaolin clay (TSS) (DHI SOP 30/1737).

7.3.2 Test water – biological organism conditions

The test water was prepared to meet the densities of live organisms in Table 7.4.

Table 7.4 Minimum criteria for densities of live organisms in the test water according to the IMO G8 guidelines /2/.

Organism size class	Total concentration	Diversity
≥50 µm	10^5 organisms/m^3	5 species across 3 phyla
≥10 µm and <50 µm	10^3 organisms/mL	5 species across 3 phyla
<10 µm	10^4/mL as culturable aerobic heterotrophic bacteria	Not applicable

If necessary to obtain the stated minimum criteria, the densities of live organisms were increased by addition of harvested indigenous organisms and/or cultured species (DHI SOP 30/1734). Addition of harvested and/or cultured species was recorded in the data logging in Appendix 2. Heterotrophic bacteria were present in the test water in densities exceeding the minimum criteria described in Table 7.4.

The minimum densities of live organisms in the control discharge water are presented in Table 7.5.

Table 7.5 Minimum criteria for densities of live organisms in the control discharge water according to the IMO G8 guidelines /2/

Organism size class	Total concentration
≥ 50 µm	100 organisms/m^3
≥10 µm and < 50 µm	100 organisms/mL

8 Sampling and analyses in BE verification testing

8.1 Sample overview

Table 8.1 Overview of sampling and purpose of samples

Parameter	Inlet water to BWMS and control tank	Treated discharge water	Control discharge water	Sample collection	Sample volume
Ballast and de-ballast operations					
Volume	×	×	×	Continuous	Online
Pressure	×	×	×	Continuous	Online
Flow	×	×	×	Continuous	Online
Other parameters*	×	×	×	Continuous	Online
Water quality conditions					
Temperature, salinity, turbidity, pH, dissolved oxygen	×	×	×	Continuous	Online
TSS, DOC, POC and UV-T**	×	×	×	Discrete grab (3 replicates; start, middle, end)	Approx. 0.5 L
Concentrations of viable organisms					
Viable organisms ≥50 µm/m^3	×	×	×	Discrete (Inlet: 5 – 6 replicates, Discharge: 3 replicates; time integrated)	Inlet: 20 L Discharge: 1 m^3
Viable organisms ≥10 and <50 µm/mL	×	×	×	Discrete 3 replicates; each representing approx. ⅓ of the operation period)	Approx. 10 L
Viable organisms <10 µm/mL	×	×	×	Discrete grab (3 replicates; start, middle, end)	Approx. 0.5 L
Whole effluent toxicity (WET)	-	×***	×***	Discrete (time integrated)	Approx. 25 L

* Operational parameters to ensure that the systems have been operated correctly and in accordance with the Operation and Maintenance manual
** UV transmittance at 254 nm, 1 cm, measured in inlet samples
*** Only in BE test cycle B-5

An overview of sample collection and purpose is given in Table 8.1. The samples were stored in thermo boxes with cooler bricks in the dark from the time of collection until handling of the samples at the DHI Environmental Laboratory.

8.2 Inlet water

Table 8.2 Sampling and analysis of inlet water to BWMS and control tank

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Microscopy	30/1701	DHI
Organisms <10 µm		
Heterotrophic aerobic bacteria	30/1706	DHI
E. coli and enterococci	30/1708	DHI
Physical/chemical properties		
Temperature, pH, O_2, salinity and turbidity	30/1764	DHI
TSS, DOC and POC	30/1768 + 30/1769	DHI
UV transmittance at 254 nm, 1 cm	30/1770	DHI

8.3 Treated discharge water and control discharge water

Table 8.3 Sampling and analysis of treated discharge water and control discharge water

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Microscopy	30/1701	DHI
Organisms <10 µm		
Heterotrophic aerobic bacteria*	30/1706	DHI
Vibrio cholerae	30/1707	DHI
E. coli and enterococci	30/1708	DHI
Physical/chemical properties		
Temperature, pH, O_2, salinity and turbidity	30/1764	DHI
TSS, DOC and POC	30/1768 + 30/1769	DHI
Whole effluent toxicity (WET) (only test cycle B-5)	30/326 (ISO 10253) + 30/305 (ISO/FDIS 16778:2014) + 30/364 (OECD 212)	DHI

* Not sampled in BE test M-1

8.4 Analyses

8.4.1 Physical/chemical analyses

The following physical/chemical analyses were conducted (DHI SOPs 30/1764 and 30/1770):

- pH
- Turbidity
- Salinity
- Temperature
- Dissolved oxygen
- Ballast system pressure
- Ballast and de-ballast operation flow rates
- UV transmittance at 254 nm, 1 cm
- Water volume in retention tanks

8.4.2 Organism size class ≥50 µm

The concentrations of live organisms ≥50 µm in minimum dimension were determined by use of a stereo microscope and a counting chamber (DHI SOP 30/1700). Viable organisms were enumerated by use of standard movement and response stimuli technique. The viable organisms were characterized according to broad taxonomic groups such as crustaceans (e.g. copepods), molluscs, rotifers, nematodes, etc.

For treated discharge samples, the total sample volume of each of the three field replicates (3 × 1 m^3 concentrated samples) was analysed.

8.4.3 Organism size class ≥10 µm and <50 µm

The concentrations of organisms and the presence of taxonomic groups in the inlet water were determined by inverted microscopy (DHI SOP 30/1701).

The numbers of viable organisms ≥10 µm and <50 µm in minimum dimension were determined by microscopic counting after staining with chloromethylfluorescein diacetate (CMFDA) and fluorescein diacetate (FDA) (DHI SOP 30/1701).

8.4.4 Organism size class <10 µm (bacteria)

The concentrations of heterotrophic aerobic bacteria were determined according to ISO 6222 (DHI SOP 30/1706). *E. coli* and enterococci were analysed (DHI SOP 30/1708) using ISO-9308-1 for determination of *E. Coli* and ISO 7899-2 for determination of enterococci. *Vibrio cholerae* was analysed according to ISO 21872 (DHI SOP 30/1707).

9 Results from biological efficacy test cycles

9.1 Inlet and control discharge water

9.1.1 Physical-chemical parameters

For all 17 BE test cycles, the physical-chemical conditions of inlet and control discharge water are summarized in Table 9.1 and Table 9.2. Detailed data on TSS, POC, DOC and UV transmittance are available in Appendix 4. Detailed online measurement data are available in the data logging in Appendix 2.

Table 9.1 Inlet and control discharge water. Average concentrations (three replicates) of total suspended solids (TSS), particulate organic carbon (POC), dissolved organic carbon (DOC), and average measurements of UV transmittance (UV-T).

Test cycle	Sample	TSS (mg/L)	POC (mg/L)	DOC (mg/L)	UV-T (%)
B-1	Inlet	58	6.3	5.2	55
	Control discharge	8.9	0.83	4.6	-
B-2	Inlet	38	9.3	8.3	55
	Control discharge	2.6	1.6	7.4	-
B-3	Inlet	61	6.4	5.4	53
	Control discharge	2.3	0.75	5.9	-
B-4	Inlet	61	8.7	6.5	52
	Control discharge	3.4	0.91	6.2	-
B-5	Inlet	56	7.9	6.8	50
	Control discharge	1.6	0.92	6.1	-
B-6	Inlet	68	7.2	5.5	65
	Control discharge	1.7	0.69	5.8	-
B-7	Inlet	71	9.9	6.4	49
	Control discharge	4.8	1.1	5.7	-
M-1	Inlet	72	7.3	6.0	52
	Control discharge	4.8	1.0	4.9	-
M-2	Inlet	60	10	8.7	60
	Control discharge	3.1	1.4	4.9	-
M-3	Inlet	62	6.4	5.4	52
	Control discharge	1.3	2.2	5.3	-
M-4	Inlet	45	11	6.3	62
	Control discharge	2.5	0.80	5.0	-
M-5	Inlet	55	11	6.1	60
	Control discharge	0.54	0.30	4.2	-
M-6	Inlet	46	6.2	7.1	58
	Control discharge	0.40	1.8	5.4	-
F-1	Inlet	59	6.2	7.2	47
	Control discharge	5.2	0.30	7.3	-
F-2	Inlet	61	7.5	6.4	49
	Control discharge	3.9	0.33	6.5	-
F-3	Inlet	68	6.5	7.5	43
	Control discharge	8.6	0.24	7.0	-
F-4	Inlet	69	7.8	8.5	39
	Control discharge	16	0.31	8.4	-
Require-ments*	Fresh water and brackish water (inlet)	>50	>5	>5	-
	Marine water (inlet)	>1	>1	>1	-

* Minimum water quality characteristics according to the IMO G8 guidelines /2/

Table 9.2 Inlet and control discharge water. Average measurements of dissolved oxygen, pH, salinity, temperature and turbidity.

Test cycle	Sample	Oxygen (%)	pH	Salinity (PSU)	Temp. (°C)	Turbidity (NTU)
B-1	Inlet	102	7.8	19	3.6	32
	Control discharge	89	7.6	19	5.4	10
B-2	Inlet	106	7.7	21	6.0	18
	Control discharge	87	7.5	21	9.2	3.5
B-3	Inlet	100	7.7	19	7.8	31
	Control discharge	76	7.4	19	10	2.9
B-4	Inlet	102	7.8	19	8.7	35
	Control discharge	72	7.5	19	12	1.5
B-5	Inlet	98	8.0	18	21	39
	Control discharge	44	7.5	18	21	1.1
B-6	Inlet	98	7.9	21	6.6	33
	Control discharge*	-	-	-	-	-
B-7	Inlet	93	7.9	21	5.8	36
	Control discharge	66	7.4	21	7.4	3.6
M-1	Inlet	94	7.7	32	3.4	38
	Control discharge	72	7.4	32	1.8	6.5
M-2	Inlet	106	7.7	34	13	25
	Control discharge	75	7.8	35	13	2.7
M-3	Inlet	101	8.0	34	15	33
	Control discharge	41	7.4	34	17	4.6
M-4	Inlet	101	8.0	34	16	24
	Control discharge	59	7.5	34	18	56
M-5	Inlet	97	8.0	34	16	27
	Control discharge	27	7.0	35	18	2.4
M-6	Inlet	99	7.8	37	17	27
	Control discharge	31	7.0	37	17	1.3
F-1	Inlet	103	8.2	0.37	17	41
	Control discharge	81	8.0	0.37	19	5.5
F-2	Inlet	103	8.2	0.39	18	39
	Control discharge	88	7.9	0.38	20	4.1
F-3	Inlet	101	8.3	0.36	16	43
	Control discharge	80	8.0	0.37	18	7.2
F-4	Inlet	97	8.1	0.33	0.66	8.0
	Control discharge	88	8.0	0.34	8.1	14
Require-ments**	Fresh water	-	-	<3	-	-
	Brackish water	-	-	3-32	-	-
	Marine water	-	-	>32	-	-

* Data not logged due to logging error
** Minimum water quality characteristics according to the IMO G8 guidelines /2/
PSU Practical salinity units
NTU Nephelometric turbidity units

The concentrations of total suspended solids (TSS), particulate organic carbon (POC) and dissolved organic carbon (DOC) were in accordance with the minimum water quality characteristics in the IMO G8 guidelines (Table 7.3) in all BE test cycles except for BE

test cycle B-2 where the concentration of TSS was 38 mg/L instead of >50 mg/L. This difference is considered negligible for the BAWAT BWMS and without any influence on the biological performance evaluation. The measured salinities were within the salinity ranges prescribed by the IMO G8 guidelines.

9.1.2 Biological parameters

The densities of viable organisms in the inlet and control discharge water were in accordance with the IMO G8 guidelines (as described in Section 7.3.2) in all test cycles. Detailed data from the biological efficacy analyses are available in Appendix 4.

9.1.2.1 Organism size class ≥50 µm

The average densities of viable organisms ≥50 µm in the inlet water ranged from approx. 370,000 to 1,100,000 organisms/m^3 in the brackish water test cycles and from approx. 200,000 to 320,000 organisms/m^3 in the marine water test cycles and from approx. 190,000 to 620,000 organisms/m^3 in the fresh water test cycles (Table 9.3). In the control discharge water, the average densities of viable organisms ranged from approx. 30,000 to 165,000 organisms/m^3 in the brackish water test cycles and from approx. 12,000 to 66,000 organisms/m^3 in the marine water test cycles and from approx. 59,000 to 160,000 organisms/m^3 in the fresh water test cycles.

In each test cycle, the diversity of organisms ≥50 µm was in accordance with the minimum criteria of five different species divided between three phyla (as described in Section 7.3.2).

A complete taxonomic overview of the phyla and species identified in inlet and control discharge water samples in each of the 17 BE test cycles is available in Appendix 4, Tables A4.7 and A4.8.

Table 9.3 Inlet and control discharge water. Total sample volumes and average concentrations of viable organisms in the size class ≥50 µm. Average of six replicates in inlet water and average of three replicates in control discharge water.

Test cycle	Sample	Total sample volume (m^3)	Organisms/m^3
B-1	Inlet	0.122	716,686
	Control discharge	3	98,517
B-2	Inlet*	0.097	657,420
	Control discharge	3	101,794
B-3	Inlet	0.121	370,864
	Control discharge	3	98,184
B-4	Inlet	0.121	430,106
	Control discharge	3	134,762
B-5	Inlet	0.120	550,594
	Control discharge	3.0	33,104
B-6	Inlet	0.120	543,939
	Control discharge	3.0	110,591
B-7	Inlet	0.120	1,113,383
	Control discharge	3.0	165,258
M-1	Inlet	0.125	220,498
	Control discharge	3	38,554
M-2	Inlet	0.120	201,536
	Control discharge	3	45,199
M-3	Inlet	0.12	272,986
	Control discharge	3	34,912
M-4	Inlet	0.12	213,583
	Control discharge	3.0	66,907
M-5	Inlet	0.110	262,014
	Control discharge	3.0	45,581
M-6	Inlet	0.120	318,125
	Control discharge	3.0	12,073
F-1	Inlet	0.120	232,053
	Control discharge	3.0	59,159
F-2	Inlet	0.120	474,750
	Control discharge	3.0	76,763
F-3	Inlet*	0.098	621,344
	Control discharge	3.0	156,524
F-4	Inlet	0.120	193,458
	Control discharge	3.0	108,794
Require-ments	Inlet**	-	≥100,000
	Control discharge**	≥3	≥100

* In BE test cycles B-2 and F-3 only 5 replicates were sampled at inlet

** Minimum criteria for live organism densities according to the IMO G8 guidelines /2/

9.1.2.2 Organism size class ≥10 and <50 µm

The average densities of viable organisms ≥10 and <50 µm in the inlet water determined by inverted microscopy varied from approx. 1,000 to 3,200 organisms/mL in the brackish water test cycles and from approx. 1,300 to 4,700 organisms/mL in the marine water test cycles and from approx. 3,200 to 8,900 organisms/mL in the fresh water test cycles (Table 9.4). In the control discharge water, the average densities of viable organisms ranged from approx. 140 to 1,300 organisms/mL in the brackish water test cycles and from approx. 400 to 1,500 organisms/mL in the marine water test cycles and from approx. 200 to 1,100 organisms/mL in the fresh water test cycles.

In test cycle B-7, an increase of organisms ≥10 and <50 µm was observed during the storage period in the control tank.

An overview of the algal taxa and species identified in inlet water in the BE test cycles is available in Appendix 4, Tables A4.10 and A4.11.

Table 9.4 Inlet and control discharge water. Average concentrations (three replicates) of viable organisms in the size class ≥10 µm and <50 µm by microscopic counting.

Test cycle	Sample	Microscopy (organisms/mL)
B-1	Inlet	2,100
	Control discharge	367
B-2	Inlet	1,723
	Control discharge	771
B-3	Inlet	2,593
	Control discharge	334
B-4	Inlet	3,164
	Control discharge	145
B-5	Inlet	3,234
	Control discharge	159
B-6	Inlet	1,028
	Control discharge	508
B-7	Inlet	1,219
	Control discharge	1,303
M-1	Inlet	4,693
	Control discharge	431
M-2	Inlet	2,758
	Control discharge	1,492
M-3	Inlet	2,027
	Control discharge	723
M-4	Inlet	1,281
	Control discharge	401
M-5	Inlet	2,821
	Control discharge	494
M-6	Inlet	3,132
	Control discharge	480
F-1	Inlet	3,921
	Control discharge	492
F-2	Inlet	4,075
	Control discharge	217
F-3	Inlet	3,205
	Control discharge	757
F-4	Inlet	8,943
	Control discharge	1,101
Requirements	Inlet*	≥1,000
	Control discharge*	≥100

* Minimum criteria for live organism densities according to the IMO G8 guidelines /2/

9.1.2.3 Organism size class <10 µm (bacteria)

The average densities of viable organisms <10 µm in the inlet and control discharge water are summarized in Table 9.5. In the inlet water, heterotrophic bacteria were present in concentrations from approx. 19,000 to 141,000 CFU/mL in the brackish water test

cycles and from approx. 33,000 to approx. 550,000 CFU/mL in the marine water test cycles and from approx. 24,000 to 248,000 CFU/mL. In the control discharge water, heterotrophic bacteria were present in concentrations from approx. 29,000 to 347,000 CFU/mL in the brackish water test cycles and from approx. >200,000 to approx. 505,000 CFU/mL in the marine water test cycles and from approx. 11,500 to 42,000CFU/mL in the freshwater test cycles.

Table 9.5 Inlet and control discharge water. Average bacterial concentrations (three replicates).

Test cycle	Sample	Heterotrophic bacteria (CFU/mL)	Enterococci (CFU/100 mL)	*E. coli* (CFU/100 mL)	*Vibrio cholerae* (CFU/100 mL)
B-1	Inlet	60,183	41	<1.0	-
	Control discharge	94,250	11	<1.0	Absent
B-2	Inlet	68,417	<1.0	22	-
	Control discharge	47,267	<1.0	1.0	Absent
B-3	Inlet	77,633	1.3	<1.0	-
	Control discharge	81,217	<1.0	<1.0	Absent
B-4	Inlet	53,683	3.3	<1.0	-
	Control discharge	172,000	<1.0	<1.0	Absent
B-5	Inlet	19,717	46	2.7	-
	Control discharge	346,667	1.0	<1.0	Absent
B-6	Inlet	34,500	7.3	<1.0	-
	Control discharge	76,417	<1.0	<1.0	Absent
B-7	Inlet	141,400	<1.0	<1.0	-
	Control discharge	28,800	<1.0	<1.0	Absent
M-1	Inlet	32,900	34	6.7	-
	Control discharge	>200,000	20	<100	Absent
M-2	Inlet	135,000	8.5	<1.0	-
	Control discharge	384,167	<1.0	<1.0	Absent
M-3	Inlet	160,833	31	<1.0	-
	Control discharge	323,333	1.3	<1.0	Absent
M-4	Inlet	102,667	4.7	<1.0	-
	Control discharge	504,167	<1.0	<1.0	Absent
M-5	Inlet	552,500	2.0	<1.0	-
	Control discharge	278,167	<1.0	<1.0	Absent
M-6	Inlet	383,333	4.7	<1.0	-
	Control discharge	505,000	<1.0	<1.0	Absent
F-1	Inlet	248,333	66	<1.0	-
	Control discharge	42,450	2.8	<1.0	Absent
F-2	Inlet	138,500	100	<1.0	-
	Control discharge	40,533	2.5	<1.0	Absent
F-3	Inlet	64,233	77	5.3	-
	Control discharge	39,733	4.0	<1.0	Absent
F-4	Inlet	24,017	37	52	-
	Control discharge	11,517	9.0	4.5	Absent
Require-ments*	Inlet	≥10,000	-	-	-
	Control discharge	-	-	-	-

* Minimum criteria for live organism densities according to the IMO G8 guidelines /2/
CFU Colony-forming units

9.2 Treated water

9.2.1 Physical-chemical parameters

The physical-chemical conditions of the treated water for all 17 BE test cycles are summarized in Table 9.6 and Table 9.7. Detailed data on TSS, POC, DOC and UV-T are available in Appendix 4. Detailed online measurement data are available in the data logging in Appendix 2.

Table 9.6 Treated water. Average concentrations (three replicates) of total suspended solids (TSS), particulate organic carbon (POC) and dissolved organic carbon (DOC).

Test cycle	TSS (mg/L)	POC (mg/L)	DOC (mg/L)
B-1	19	1.3	6.7
B-2	14	0.84	12
B-3	12	1.8	8.6
B-4	18	2.3	9.4
B-5	17	1.1	9.2
B-6	13	1.5	8.6
B-7	14	1.5	9.7
M-1	21	1.1	8.0
M-2	12	2.4	8.0
M-3	13	3.0	6.8
M-4	43	1.4	6.7
M-5	12	0.83	5.8
M-6	18	1.7	7.0
F-1	20	<0.10	9.8
F-2	13	<0.10	9.8
F-3	16	<0.10	9.8
F-4	19	0.18	12

Table 9.7 Treated water. Average measurements of dissolved oxygen, pH, salinity, temperature and turbidity.

Test cycle	Sample	Oxygen (%)	pH	Salinity (PSU)	Temp. (°C)	Turbidity (NTU)
B-1	Treated discharge	5.0	7.1	19	11.0	19
B-2	Treated discharge	5.7	6.8	21	13	11
B-3	Treated discharge	4.0	7.0	19	12	13
B-4	Treated discharge	12	7.2	19	16	25
B-5	Treated discharge	4.4	7.1	18	24	22
B-6*	Treated discharge	-	-	-	-	-
B-7	Treated discharge	5.1	7.1	21	14	11
M-1	Treated discharge	5.6	7.1	32	6.7	21
M-2	Treated discharge	4.3	7.4	35	15	16
M-3	Treated discharge	7.8	7.5	34	21	21
M-4	Treated discharge	10	7.6	34	23	37
M-5	Treated discharge	4.6	7.0	35	22	24
M-6	Treated discharge	4.5	7.1	37	20	26
F-1	Treated discharge	4.1	7.6	0.63	22	19
F-2	Treated discharge	4.7	7.5	0.38	24	11
F-3	Treated discharge	4.5	7.5	0.36	23	13
F-4	Treated discharge	4.5	7.5	0.64	12	13

* Data was not logged in test cycle B-6 due to a logging error
PSU Practical salinity units
NTU Nephelometric turbidity units

9.2.2 Biological parameters

9.2.2.1 Organism size class ≥50 µm

The numbers of viable organisms ≥50 µm at discharge ranged from 0 to 7 organisms/m^3 in the brackish water test cycles, from 0 to 5 organisms/m^3 in the marine water test cycles, and from 0.33 to 142 organisms/m^3 in the freshwater test cycles (Treated discharge samples in Table 9.8).

Table 9.8 Treated water. Total sample volumes and average numbers (three replicates) of viable organisms in the size class ≥50 µm.

Test cycle	Sample*	Total sample volume (m^3)	Organisms/m^3
B-1	Treated discharge	3.0	0
B-2	Treated discharge	3.0	0
B-3	Treated discharge	3.0	3.0
B-4	Treated discharge	3.0	0
B-5	Treated discharge	3.0	0.33
B-6	Treated discharge	3.0	1.0
B-7	Treated discharge	3.0	7.0
M-1	Treated discharge	3.0	0
M-2	Treated discharge	3.0	0
M-3	Treated discharge	3.0	0
M-4	Treated discharge	3.0	4.0
M-5	Treated discharge	3.0	5.0
M-6	Treated discharge	2.9	2.3
F-1	Treated discharge	3.0	0.33
F-2	Treated discharge	3.0	5.3
F-3	Treated discharge	3.0	142
F-4	Treated discharge	3.0	66
Requirements	Treated discharge	-	<10

* Treated discharge samples were collected at discharge. The whole treated discharge sample was counted except in test cycles M-1, M-3, F-3 and F-4 (see Appendix 4).

9.2.2.2 Organism size class ≥10 and <50 µm

Table 9.9 summarizes the concentrations of viable organisms ≥10 and <50 µm in the treated discharge water.

The quantitative evaluation of the performance at discharge was based on microscopic counting after staining with CMFDA and FDA.

The numbers of CMFDA/FDA-stained organisms ≥10 and <50 µm at discharge ranged from 0.67 to 12 organisms/mL in the brackish water test cycles, from 0.92 to 20 organisms/mL in the marine water test cycles, and from 5.8 to 37 organisms/mL in the freshwater test cycles (Treated discharge samples in Table 9.9).

Table 9.9 Treated water. Average numbers (three replicates) of viable organisms in the size class ≥10 µm and <50.

Test cycle	Sample	Microscopy after CMFDA/FDA staining (organisms/mL)
B-1	Treated discharge	11
B-2	Treated discharge	1.8
B-3	Treated discharge	12
B-4	Treated discharge	1.9
B-5	Treated discharge	7.2
B-6	Treated discharge	2.1
B-7	Treated discharge	0.67
M-1	Treated discharge	1.8
M-2	Treated discharge	0.92
M-3	Treated discharge	20
M-4	Treated discharge	2.1
M-5	Treated discharge	3.2
M-6	Treated discharge	4.2
F-1	Treated discharge	5.8
F-2	Treated discharge	6.6
F-3	Treated discharge	37
F-4	Treated discharge	14
Requirements	Treated discharge	<10

9.2.2.3 Organism size class <10 µm (bacteria)

In the treated discharge water the contents of *E. coli* and enterococci were consistently below the ballast water discharge standard of <100 CFU/mL and <250 CFU/mL, respectively. *Vibrio cholerae* was not identified in any of the test cycles (Table 9.10).

Table 9.10 Treated water. Average bacterial concentrations (three replicates).

Test cycle	Sample	Heterotrophic bacteria (CFU/mL)	Enterococci (CFU/100 mL)	*E. coli* (CFU/100 mL)	*Vibrio cholerae* (CFU/100 mL)
B-1	Treated discharge	>2,000,000	1.5	<1.0	Absent
B-2	Treated discharge	>2,000,000	<1.0	<1.0	Absent
B-3	Treated discharge	>2,000,000	1.0	<1.0	Absent
B-4	Treated discharge	>2,000,000	1.0	<1.0	Absent
B-5	Treated discharge	1,601,667	2.3	<1.0	Absent
B-6	Treated discharge	>2,000,000	<1.0	<1.0	Absent
B-7	Treated discharge	>200,000	<1.0	<1.0	Absent
M-1	Treated discharge	-	3.0	<100	Absent
M-2	Treated discharge	>2,000,000	4.0	<1.0	Absent
M-3	Treated discharge	1,630,000	1.3	<1.0	Absent
M-4	Treated discharge	1,140,000	5.5	<1.0	Absent
M-5	Treated discharge	1,261,667	<1.0	<1.0	Absent
M-6*	Treated discharge	1,718,333	<1.0	<1.0	Absent
F-1	Treated discharge	>2,000,000	7.0	<1.0	Absent
F-2	Treated discharge	>2,000,000	1.0	<1.0	Absent
F-3**	Treated discharge	>1,000,000	1.5	19	Absent
F-4	Treated discharge	>2,000,000	1.7	<1.0	Absent
Requirements	Treated discharge	-	<100	<250	<1

CFU Colony-forming units

* Send to SSI for analysis – *Vibrio alginolyticus* detected

** Send to SSI for analysis – *Vibrio cholerae* non-O1 detected

10 Conclusion

Table 10.1 summarizes the numbers of viable organisms in water treated by the BAWAT BWMS at discharge

The performance evaluation leads to the conclusion that the BAWAT BWMS complied with the ballast water discharge standard and fully met all the requirements to the test water in test cycles marked with green in Table 10.1 (failed tests are marked with red). Test cycle B-2 marked with light green complied with the ballast water discharge standard but the concentration of TSS was 38 mg/L instead of >50 mg/L. This difference is considered negligible for the challenge imposed on the treatment by the BAWAT BWMS and without any influence on the biological performance evaluation.

Table 10.1 Average numbers (three replicates) of viable organisms in treated water at discharge.

Test cycle	Organisms ≥50 µm per m³	Organisms ≥10 and <50 µm per mL	Organisms <10 µm Enterococci (CFU/100 mL)	Organisms <10 µm *E. coli* (CFU/100 mL)	Organisms <10 µm *V. cholerae* (CFU/100 mL)
B-1	0	11	1.5	<1.0	Absent
B-2	0	1.8	<1.0	<1.0	Absent
B-3	3.0	12	1.0	<1.0	Absent
B-4	0	1.9	1.0	<1.0	Absent
B-5	0.33	7.2	2.3	<1.0	Absent
B-6	1.0	2.1	<1.0	<1.0	Absent
B-7	7.0	0.67	<1.0	<1.0	Absent
M-1	0	1.8	3.0	<100	Absent
M-2	0	0.92	4.0	<1.0	Absent
M-3	0	20	1.3	<1.0	Absent
M-4	4.0	2.1	5.5	<1.0	Absent
M-5	5.0	3.2	<1.0	<1.0	Absent
M-6	2.3	4.2	<1.0	<1.0	Absent
F-1	0.33	5.8	7.0	<1.0	Absent
F-2	5.3	6.6	1.0	<1.0	Absent
F-3	142	37	1.5	19	Absent
F-4	66	14	1.7	<1.0	Absent
Requirements	<10	<10	<100	<250	<1

Colours:
Green Compliance with the ballast water discharge standard
Light green Compliance with the ballast water discharge standard with deviations in relation to abiotic quality characteristics of the inlet water. The concentration of TSS was 38 mg/L instead of >50 mg/L. This difference is considered negligible for the BAWAT BWMS and without any influence on the biological performance evaluation
Red No compliance with the ballast water standard
CFU Colony-forming unit

11 Quality assurance and quality control

The performance evaluation in land-based test facility of the BAWAT BWMS was conducted in accordance with ISO 9001 by using the DHI Business Management System certified by DNV GL. The DHI Environmental Laboratory is accredited by DANAK, the Danish Accreditation and Metrology Fund, to perform ecotoxicological studies and analyses aiming at the performance evaluation of BWMS in accordance with ISO 17025. The performance evaluation also complied with the conditions included in the QMP, QAPP and SOPs (see Appendix 5). Four amendments describing planned changes to the time schedule for biological efficacy testing given in the QAPP were made during the performance evaluation period (not enclosed). The QMP and QAPP are included in

Appendix 1. On request by DNV GL a total of 3 versions of the QAPP were issued during the land-based testing to reflect changes in the "System Description & Standard Operating Procedures" as provides by BAWAT.

The acting classification society for the land-based performance evaluation of the BAWAT BWMS was DNV GL. DNV GL conducted a review of the QAPP /6/ and /7/ . The overall conclusion in the DNV GL review of the QAPP is cited below:

> *"… all procedures described in the QAPP both on site and in the laboratory was followed. All personnel were well trained and had good knowledge of the methods applied. and I have no further comments to this audit."*

DNV GL staff conducted an onsite inspection during the ballast operation of test cycle M-1 on 20 March 2013. The inspection included the activities at the DHI test facility in Hundested and the analyses performed at the DHI Environmental Laboratory in Hørsholm, Denmark. The treatment process of test cycle M-1 was surveyed by DNV GL, treatment processes of test cycles B-1 – B-7, M-2 – M-6 and F-1 – F-4 were surveyed by DHI.

12 References

/1/ IMO. International Convention for the Control and Management of Ships' Ballast Water and Sediments. London. International Maritime Organization, 2004.

/2/ MEPC. Guidelines for Approval of Ballast Water Management Systems (G8). Resolution MEPC.174(58). Adopted 10 October 2008.

/3/ MEPC. Procedure for Approval of Ballast Water Management Systems that make use of Active Substances (G9). MEPC.169(57). Adopted 4 April 2008.

/4/ Resolution MEPC.173(58). Adopted on 10 October 2008. Guidelines for approval of ballast water sampling (G2).

/5/ BAWAT BWMS - Whole Effluent Toxicity (WET) tests. DHI. July, 2014.

/6/ DNV. Performance evaluation in land-based test facility of BAWAT ballast water management system - Report after survey performed 20.03.13 at DHI`s land based test-facility in Hundested, DK and at the DHI laboratory in Hørsholm, DK, March 2013.

/7/ DNV. Survey Report of the Land-based Tests of BAWAT BWMS, August 2013.

APPENDIX 1

QMP and QAPP

Quality Management Plan

Quality Management Plan

Performance Evaluation of Ballast Water Management Systems

DHI Denmark

Version 3.1

WATER • ENVIRONMENT • HEALTH

June 2012

Quality Management Plan

Performance Evaluation of Ballast Water Management Systems

DHI Denmark
Version 3.1

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Project	Project No.
Quality Management Plan Performance Evaluation of Ballast Water Management Systems DHI Denmark Version 3.1	
Author Gitte I. Petersen	Date 2012.06.20 Approved by Torben Madsen

Revision	Description	By	Checked	Approved	Date
3.1	QMP	G.P	TMA	TMA	20/6-12

Key words	Classification
	☐ Open ☐ Internal ☒ Proprietary

Distribution	No. of copies
Client Classification society DHI: /EAT	

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1 DEFINITIONS

Terms	Definitions
Active substance	Active substance means a chemical or an organism, including a virus or a fungus, that has a general or specific action on or against nonindigenous species
Ballast water management system (BWMS)	A system which processes ballast water to kill, render harmless or remove organisms. The BWMS includes all ballast water treatment equipment and all associated control and monitoring equipment
Classification society	Independent classification society that conducts formal verification of the procedures applied in performance evaluation of BWMS
Client	The manufacturer of a BWMS or related technology, or a party associated with such technologies, requesting a technology performance evaluation (sometimes referred to as vendor)
Guidelines	Guidelines means the IMO Guidelines for Approval of Ballast Water Management Systems (G8) (Reference /2/) and/or Procedure for Approval of Ballast Water Management Systems that Make Use of Active Substances (G9) (Reference /3/); in addition, performance evaluation of BWMS may also seek to verify compliance with the U.S. Coast Guard final rule (Reference /4/) and the ETV protocol (Reference /5/)
IMO convention	The International Convention for the Control and Management of Ship's Ballast Water and Sediments adopted by the International Maritime Organization (IMO) (Reference /1/)
International Maritime Organization (IMO)	United Nations specialized agency with responsibility for the safety and security of shipping and the prevention of marine pollution by ships
Land-based test	Land-based test means the performance evaluation of the BWMS conducted by use of the test facility and including operation of the BWMS in accordance with the guidelines
Pilot test	Pilot test means any experiment, including laboratory studies, used to test the BWMS with the purpose to identify and eliminate problems prior to initiation of formal performance evaluation meeting the guidelines
Quality assurance project plan (QAPP)	Project-specific technical document reflecting the implementation of quality assurance and quality control activities, including specifics of the BWMS to be tested, the testing organisation, and other conditions affecting the actual design and implementation of the required tests and evaluations Note: The DHI Business Management System applies quality assurance plan as the equivalent term for the QAPP
Quality management plan (QMP)	Generic standard operating procedure within the DHI Business Management System describing the project management and quality control management structure
Services	When used in this QMP the term 'services' has the meaning described in section 3
Shipboard test	Shipboard test means the performance evaluation of the BWMS installed on-board a vessel conducted in accordance with the guidelines
Standard operating procedure (SOP)	Document describing the procedures or characteristics for analyses, operations or tests Note: In-house methods may be used in the absence of a recognized standard, if they are commonly accepted for testing of BWMS or scientifically documented

U.S. Coast Guard	The U.S. Coast Guard is an organisation with the United States Department of Homeland Security. The Coast Guard is amending its regulations on ballast water management and engineering equipment by establishing a standard for the allowable concentration of living organisms in ships' ballast water discharged in waters of the United States and by establishing an approval process for BWMS

2 INTRODUCTION

The International Maritime Organization (IMO) has adopted the International Convention for the Control and Management of Ships' Ballast Water and Sediments /1/ to reduce the risk of spreading of harmful aquatic organisms and pathogens released with ballast water.

The IMO convention requires that all ships comply with specified water quality requirements (D2) before ballast water is released into the environment.

The performance evaluation of ballast water management systems (BWMS) aims at documenting compliance with the requirements stated in international guidelines, e.g.:

- Guidelines for Approval of Ballast Water Management Systems (G8) /2/
- Procedure for Approval of Ballast Water Management Systems that Make Use of Active Substances (G9) /3/.

DHI provides services in relation to performance evaluation of maritime technologies and particularly BWMS within the DHI Ballast Water Centre which includes land-based test facilities and laboratories in Denmark and Singapore. The land-based test facility in Denmark (Hundested) is known as the DHI Maritime Technology Evaluation Facility (hereafter referred to as the "test facility").

The DHI Ballast Water Centre is organized with a Ballast Water Facility Board including two members from the management in DHI Denmark and two members from the management in DHI Singapore. The object of the Board is to coordinate the development and marketing of services related to the performance evaluation of BWMS within the DHI Group.

The quality management plan (QMP) is a generic standard operating procedure within the DHI Business Management System.

3 SERVICES

The QMP covers the services provided by DHI Ballast Water Centre at the facilities below:

DHI
Agern Allé 5
DK-2970 Hørsholm
Denmark

and

DHI Maritime Technology Evaluation Facility
Færgevejen 18
DK-3390 Hundested
Denmark

The services include:

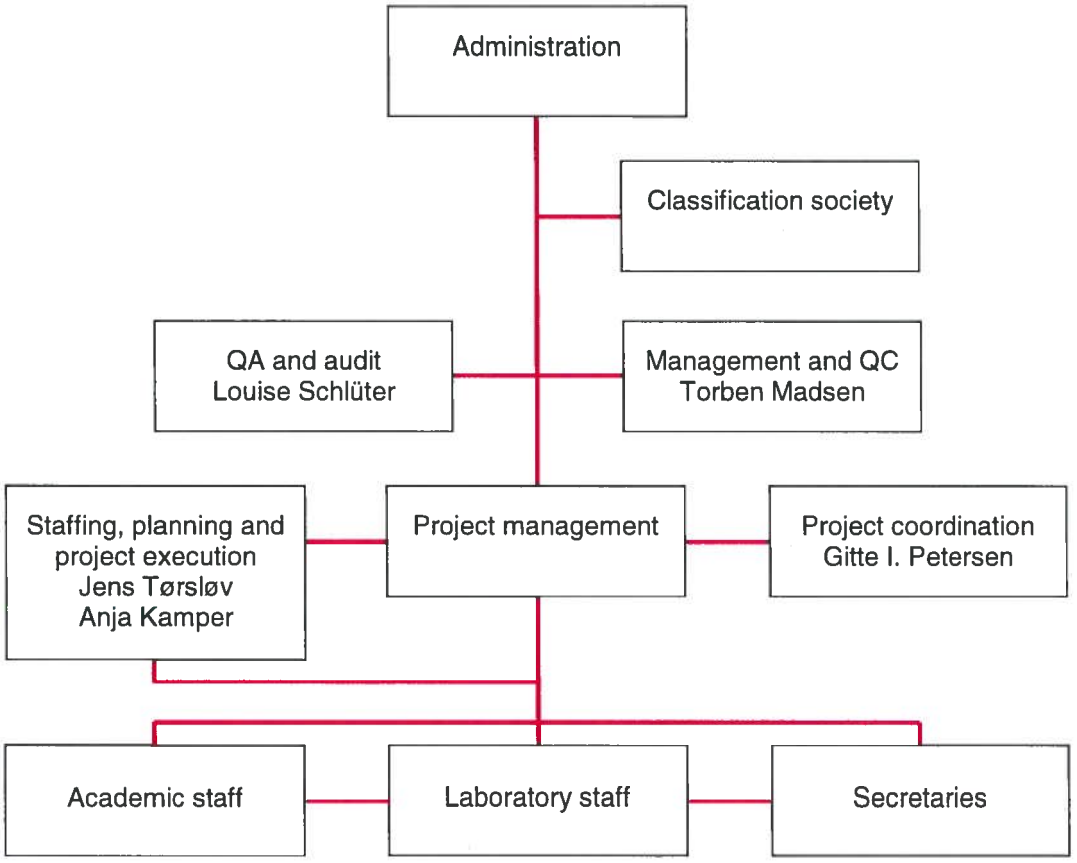
- Pilot-tests of BWMS, or ballast water treatment equipment, including laboratory studies, to identify and eliminate problems prior to initiation of formal performance evaluation meeting the guidelines
- Land-based tests of BWMS, or ballast water treatment equipment, conducted at the test facility and aiming at formal performance evaluation meeting the guidelines (e.g. type approval)
- Shipboard tests of BWMS, or ballast water treatment equipment, conducted on board vessels on which the technology is installed and aiming at formal performance evaluation meeting the guidelines (e.g. type approval).

The above activities are collectively referred to as the "services" whereas individual activities are referred to as "projects".

The aim of the services is to provide independent, third party documentation for the performance of maritime technologies. High quality of the services is ensured through extensive quality management and use of skilled staff.

4 ORGANISATION

The project organisation is illustrated below.



4.1 Quality assurance

Senior biologist Louise Schlüter (Ph.D.) is assigned by DHI's Quality Assurance (QA) Unit as internal auditor.

4.2 Management and quality control

Head of department Torben Madsen (Ph.D.) is quality supervisor for all projects (described in the section on Services) and has the overall responsibility for the services under DHI Ballast Water Centre, Denmark. This includes the following tasks:

- Member of the Ballast Water Test Facility Board for DHI Ballast Water Centre
- Overall responsibility for the test facility and the environmental laboratory including safe conditions of work and decisions on investments and maintenance expenses
- Negotiation of contracts with clients
- Appointment of project managers and staff responsible for quality control (QC) of individual data (data-level QC) and maintenance of staff experience records (allocation of projects managers for specific projects is the responsibility of the head of projects)
- Maintenance of the QMP with updated versions as appropriate
- Maintenance of generic standards that can serve as formats for drafting the quality assurance project plan (QAPP) and approval of the methods applied in land-based and shipboard tests
- Quality control of the QAPP, standard operating procedures (SOPs) and all project proposals, deliverables and reports

- Documentation in relation to
  - Staff training and experience
  - Facilities and their maintenance
  - Records of complaints

4.3 Project coordination

Business area manager Gitte I. Petersen (Ph.D.) is responsible for the coordination, timely execution and the overall scientific quality of the services. This includes the following tasks:

- Business development and marketing
- Co-ordination of the services to ensure optimal logistics at the test facility, including decisions related to the practical installation of clients and their technology and timing of tests
- Maintenance of the test facility including routine technical maintenance and dialogue with the head of department in relation to investments and maintenance expenses
- Instruction of staff with responsibility for specific tasks such as, e.g., test facility technical operations and production of test water
- Principal scientific expert with responsibility for the overall scientific quality of the services including compliance with official guidelines and protocols and requirements from classification societies; this implies input to the QAPP, revisions and implementation of SOPs, and contributions to data interpretation and reporting in collaboration with the project manager
- Participation in discussions with the classification society on important matters, particularly draft and final reports, together with the project manager

4.4 Staffing, planning and project execution

Head of projects Jens Tørsløv (Ph.D.) has the overall responsibility for allocation of staff, planning and project execution in coordination with the business area manager or the project manager as appropriate.

Laboratory manager Anja Kamper (M.Sc.) allocates laboratory technicians for a specific project as part of the laboratory capacity planning by allocation of responsibility from the head of projects. Furthermore, the laboratory manager appoints one or more test co-ordinators among the laboratory technicians or the academic staff for on-site coordination of land-based test cycles.

4.5 Project management

The **project manager** is responsible for the management and efficient performance of the project in accordance with the contract between the client and DHI, the QMP and the QAPP.

The project manager's tasks include:

- Organisation and management of the project

- Meetings and other communication with the client to ensure that all necessary information is available in due time
- Preparation of the draft and final QAPP with detailed description of the project, including time schedule of activities and deliverables; the QAPP shall be made available to all staff participating in the project
- Facilitation of the process for comments and responses to the draft QAPP in dialogue with the client and the classification society
- Preparation of amendments and deviations to the QAPP
- Communication of the project time schedule to the classification society to enable external audit
- Participation in discussions with the classification society on important matters, particularly draft and final reports, together with the business area manager
- Co-ordination and dialogue with the laboratory manager in relation to the practical organisation of work involving laboratory technicians; the project manager shall in due time inform the laboratory manager on the types of tests and the required capacity to enable laboratory capacity planning
- Contracts with subcontractors as appropriate for meeting the project deliverables (e.g. chemical analytical laboratory)
- Approval of initiation of the test cycles and interruption of test cycles, e.g. in case of irregularity
- Preparation of reports

4.6 Academic staff, laboratory staff and secretaries

The tasks of the academic staff, the laboratory staff and the secretaries include:

- Maintenance of materials and equipment
- Test facility technical operations
- Test co-ordinator function, i.e. co-ordination and keeping timely records of the activities at the test facility during land-based tests
- Production of test water and monitoring of test water quality
- Sampling at the test facility
- Analysis and data processing, including data-level QC
- Contributions to test reports
- Archiving of documents and raw data
- Contributions to QAPPs and SOPs

5 PERFORMANCE OF PROJECT

5.1 Contract

A contract between the client and DHI is negotiated and signed according to the DHI manual for project management.

5.2 Quality Assurance Project Plan

The QAPP corresponds to the quality assurance plan in the DHI Business Management System and is a project specific document describing the technology to be tested, the test facility, and other conditions affecting the actual design and implementation of the study. The QAPP is required for performance evaluation of BWMS in land-based or shipboard tests conducted according to international guidelines, but a QAPP may be established for any study where a formal study protocol is needed.

The QAPP is

- Prepared by the project manager
- Signed by the project manager and the quality supervisor (head of department)
- Forwarded to the classification society for review and comments
- Forwarded to the client for review, acceptance and signature.

The QAPP typically includes the following titles:

1. Project description and treatment performance objectives
2. Project organisation and personnel responsibilities
3. Description of the testing laboratory
4. Description of ballast water management system
5. Experimental design
6. Challenge conditions
7. Sampling and analysis plan
8. Data management, analyses and reporting
9. Validity criteria
10. Pass criteria
11. Quality assurance and control
12. Time schedule
13. References

Amendments and deviations to the QAPP are approved and signed by the project manager. Amendments describe planned changes whereas deviations describe unplanned changes to the QAPP.

The QAPP is subject to internal audit in accordance with the procedures for internal audit of the DHI Quality Management System.

5.3 Services

The project will be conducted as described in the QAPP and subsequent amendments and deviations or, alternatively, as described in the contract between the client and DHI for projects for which no QAPP is prepared.

5.3.1 Pilot tests

Pilot tests can be initiated when the technology (or BWMS) is ready for testing and DHI's deliverables are defined. With the purpose to identify problems and appropriate

adjustments of the technology, pilot tests may e.g. be conducted in the laboratory or at the test facility. Initiation of testing is decided by the project manager in agreement with the client.

5.3.2 Land-based tests

Land-based tests can be initiated when the technology, typically a fully integrated BWMS, is installed and ready for operation. Initiation of testing is decided by the project manager in agreement with the client.

The project manager decides when a test cycle in the land-based test is completed and valid, when appropriate by reference to the IMO G8 or G9 guidelines /2; 3/, US standards /4; 5/ or other standards. If required, the project manager can decide to interrupt a test cycle due to technical malfunctioning of the test facility or the technology, insufficient state of biological or physical parameters or for other reasons related to the quality of the test water.

5.3.3 Shipboard tests

Shipboard testing can be initiated when the technology, typically a fully integrated BWMS, is installed on the vessel and ready for operation. Initiation of testing is decided by the project manager in agreement with the client.

The project manager decides when a test cycle in the shipboard test is completed and valid by reference to the IMO G8 guidelines /2/ or, if appropriate, to US standards /4; 5/. If required, the project manager can decide to interrupt a test cycle due to technical malfunctioning of the technology, insufficient state of biological or physical parameters or for other reasons related to the water quality.

5.4 Reports

Reports are prepared with the details, format and language described in the contract between the client and DHI.

5.4.1 Performance evaluation of BWMS aiming at type approval

For land-based or shipboard tests of BWMS conducted as part of the type approval process (e.g. under the IMO convention or U.S. Coast Guard final rule), the report is typically structured by use of the appropriate headings in the QAPP.

The report shall include all relevant technical and analytical data and will typically contain the following items:

- Name of the client
- Executive summary
- Introduction (including a description of the test facility)
- Experimental design (including the dates for initiation and completion of tests or test cycles and procedures stated in the approved QAPP)
- Results (presented in summarizing tables and as raw data)
- Description of the BWMS (provided by the client)
- The signed QMP and QAPP with all amendments and deviations

The report shall be signed by the project manager and the head of projects.

The final report will be prepared in English and forwarded to the client.

6 QUALITY MANAGEMENT PROCESSES

6.1 Quality assurance

The services are conducted in accordance with the principles of ISO 9001 by using the DHI Business Management System and the procedures in the QMP. The DHI Business Management System is found compliant with ISO 9001 as part of the ISO 17025 accreditation of the DHI environmental laboratory.

The DHI quality manager is responsible for assigning a trained internal auditor from DHI's Quality Assurance Unit to each project in accordance with the procedures for internal audit in the DHI Business Management System (section on Quality). The internal auditor shall not be involved in solving the specific project or in any project deliverables.

The DHI Business Management System (section on Quality; Internal Audit) describes procedures for audit and evaluation and the process of periodic internal auditing of projects and activities including audit responsibilities and planning, auditor training and competences and audit reporting.

The DHI Business Management System (section on Quality; Correction and Prevention) describes procedures for corrective actions, i.e. how deviations identified during operation and auditing are corrected and how future occurrence of the same deviations is prevented (preventive actions).

6.2 Document and record control

The DHI Business Management System (section on Quality; Documents and Records) includes a procedure describing the process of drafting, revising and approving documentation.

The DHI Business Management System (section on Quality/ Laboratory Analysis/ Testing and Products with reference to SOPs 30/921 and 30/937) describes how records of the test are stored, transferred, maintained and controlled in order to ensure data integrity for a period defined in the QAPP, but not shorter than five (5) years after issue of the final report.

6.3 Subcontractor management

The DHI Business Management System (Section on Consulting / Administration / Contracting) describes how it is ensured that subcontractors follow quality requirements.

In addition, analytical laboratories providing analyses of any kind should:

- Maintain an ISO 17025 accreditation with the quality management system required herein.

- Apply accredited analytical methods when available.
- Apply other methods according to either international standard methods or in-house methods that are in all cases validated as required for accredited methods.

SOP 30/700 furthermore describes how it is ensured that purchased items such as chemicals and glassware are controlled, accepted and calibrated.

6.4 Staff competence management

The DHI Business Management System (section on Human Resources; Development) describes how it is ensured that the projects are conducted by staff with adequate competences and knowledge. This is done by maintaining a list of functions in the test process with competence requirements and responsibilities. The list is supported by reference to staff files in the DHI CV database.

6.5 Facility management

The DHI Business Management System (Laboratory Analysis and Testing with reference to SOP 30/945) describes how it is ensured that facilities and equipment are available and fit for the purposes.

6.6 Management review

The DHI Business Management System (section on Quality; Management Review) describes how the DHI management is ensuring that DHI Ballast Water Centre (Denmark) is working according to this quality manual through mechanisms such as e.g. an annual management review process.

The quality manager is responsible for maintenance and development of the quality system and for the internal auditing of all aspects of the system – with daily reference to the Director, Group R&D and Quality Management. The DHI Business Management System contains rules for reviews of the quality system.

6.7 Complaint management

The DHI Business Management System (section on Customer Satisfaction) describes how complaints are recorded, resolved and reported. If not resolved, complaints are handled according to the contract between the client and DHI.

7 REFERENCES

/1/ IMO. International Convention for the Control and Management of Ships' Ballast Water and Sediments. London. International Maritime Organization, 2004.

/2/ MEPC. Guidelines for Approval of Ballast Water Management Systems (G8). Resolution MEPC.174(58). Adopted 10th October 2008.

/3/ MEPC. Procedure for Approval of Ballast Water Management Systems that Make Use of Active Substances (G9). Resolution MEPC.126(53) Adopted 22nd July 2005.

/4/ U.S. Coast Guard. Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters. Federal Register, Vol. 77, No. 57, March 23, 2012.

/5/ U.S. Environmental Protection Agency, Environmental Technology Verification Program. Generic Protocol for the Verification of Ballast Water Treatment Technology. EPA/600/R-10/146, September 2010.

APPENDIX A

BMWS testing-specific Standard Operating Procedures (SOPs)

SUBJECT/SUBSUBJECT	SOP NO.
ANALYTICAL METHOD ZOOPLANKTON ANALYSIS (≥50 µm)	30/1700:05
ANALYTICAL METHOD MICROSCOPIC ENUMERATION AND IDENTIFICATION OF MICROORGANISMS (LUGOL AND CMFDA/FDA)	30/1701:03
ANALYTICAL METHOD DETERMINING PRIMARY PRODUCTION OF MICROALGAE	30/1702:04
ANALYTICAL METHOD DETERMINING DIVERSITY OF MICROALGAE COMMUNITIES BY HPLC ANALYSIS OF PIGMENTS	30/1703:03
ANALYTICAL METHOD DETERMINATION OF VIABLE ALGAE BY MPN	30/1704:03
MICROBIOLOGICAL TESTS DETERMINATION OF TOTAL NUMBER OF BACTERIA BY EPIFLUORESCENCE MICROSCOPY	30/1705:03
MICROBIOLOGICAL TESTS DETERMINATION OF HETEROTROPHIC PLATE COUNT	30/1706:03
MICROBIOLOGICAL TESTS DETERMINATION OF *VIBRIO CHOLERAE* IN WATER	30/1707:03
MICROBIOLOGICAL TESTS DETERMINATION OF TOTAL COLIFORM, *E.COLI* AND ENTEROCOCCI Colilert*-18 AND Enterolert-E	30/1708:03
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MEASUREMENT METHOD DETERMINATION OF DOC AND POC	30/1769:03

APPENDIX B

Overview of lists

Overview of lists

The lists mentioned below are kept together with the rest of quality documentation.

Classification society

DHI holds a statement describing the Classification society that has certified the DHI Maritime Technology Evaluation Facility.

List of sub-contractors

DHI keeps a list of sub-contractors used during the test. The list contains information on name of company, address, contact person, e-mail, telephone number and deliveries.

List of project managers

DHI keeps a list of appointed project managers and their experience records. The project manager's competence is documented in an available CV.

List of staff approved for functions at the test facility

DHI keeps a list of persons working at the test facility. The list contains information on the person's activities, responsibility and documentation for training. The person's competence is documented in an available CV.

List of Standard Operating Procedures

DHI keeps a list of SOPs, including those used in relation to projects conducted at the test facility.

A P P E N D I X C

Template for amendments to QAPP

AMENDMENT

AMENDMENT NUMBER

QAPP DOCUMENT TITLE AND MONTH OF ISSUE

DATE OF AMENDMENT

DESSCRIPTION OF AMENDMENT

REASON FOR AMENDMENT

IMPACT OF AMMENDMENT

PREVENTATIVE ACTION

If relevant, action to prevent that the same cause of amendment will occur in the future.

SIGNED BY

_____

Project manager

Copy to be sent to the client, the classification society and the DHI Quality Assurance Unit.

A P P E N D I X D

Template for deviations to QAPP

DEVIATION

DEVIATION NUMBER

QAPP DOCUMENT TITLE AND MONTH OF ISSUE

DATE OF DEVIATION

DESCRIPTION OF DEVIATION

REASON FOR DEVIATION

IMPACT OF DEVIATION

PREVENTIVE ACTION

If required, actions to be taken to prevent consequences of deviation

SIGNED BY

_____

Project manager

Copy to be sent to the client, the classification society and the DHI Quality Assurance Unit.

Quality assurance project plan Version 1

Performance evaluation in land-based test facility of BAWAT ballast water management system

BAWAT

Quality assurance project plan

March 2013

Performance evaluation in land-based test facility of BAWAT ballast water management system

Prepared for	**BAWAT**
Represented by	**Mr Kim Diederichsen**

DHI land-based test facility in Hundested

This report has been prepared under the DHI Business Management System certified by DNV and specifically for ballast water management system testing certified by Lloyd's Register	
Quality Management	BWMS Testing
ISO 9001	IMO Resolution MEPC.174(58) Annex part 2
Quality Management System certified according to DS/EN ISO 9001 by Det Norske Veritas, Business Assurance, Danmark A/S	Lloyd's Register

Project No	11812682
Classification	Confidential

Author	Morten Bjergstrøm	

QC	Torben Madsen	

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B Description of the ballast water management system as provided by the client
C Overview of DHI SOPs

Abbreviations

Abbreviation	Description
BE	Biological efficacy
BWMS	Ballast water management system
CFU	Colony forming units
CMFDA	Chloromethylfluorescein diacetate
DNV	Det Norske Veritas
DO	Dissolved oxygen
DOC	Dissolved organic carbon
DQI	Data quality indicator
FDA	Fluorescein diacetate
IMO	International Maritime Organization
kVA	Kilovolt-ampere
MEPC	Marine Environment Protection Committee
POC	Particulate organic carbon
PSU	Practical salinity units
QA	Quality assurance
QAPP	Quality assurance project plan
QC	Quality control
QMP	Quality management plan
SOP	Standard operating procedure
TRO	Total residual oxidants
TSS	Total suspended solids
UV-T	UV transmittance
WET	Whole effluent toxicity

1 Project description and treatment performance objectives

1.1 Background and objectives

For an application for final approval, the IMO International Convention for the Control and Management of Ships' Ballast Water and Sediments /1/ requires a performance evaluation of ballast water management systems (BWMS) according to the principles laid down in Resolution MEPC.174(58) /2/, generally referred to as IMO G8 guidelines, and, for systems that make use of active substances, also Resolution MEPC.169(57) /3/, generally referred to as IMO G9 guidelines. The purpose of the performance evaluation is to assure that BWMS approved by administrations are capable of meeting the ballast water performance standard in Regulation D-2 /1/, also known as the IMO D-2 standard, in land-based and shipboard evaluations and do not cause unacceptable harm to the vessel, crew, environment or public health.

The objective of the project is to conduct a performance evaluation of the BWMS in a land-based test facility with the aim to meet the testing requirements in Resolution MEPC.174(58) /2/.

1.2 Client and ballast water management system

The client requesting the performance evaluation is:

BAWAT A/S
Diplomvej 381
DK-2800 Kongens Lyngby

The client is the manufacturer of the BAWAT BWMS.

1.3 Classification society

The classification society appointed by the client for inspection and certification of the project is:

Det Norske Veritas A/S (DNV)
Mariesvej 30
NO-1363 Høvik
Norway

1.4 Testing laboratory

The project is conducted by DHI Denmark (www.dhigroup.com) with the following facilities:

Mailing address:

DHI
Agern Allé 5
DK-2970 Hørsholm
Denmark
Att. Torben Madsen

DHI Maritime Technology Evaluation Facility
Færgevejen
DK-3390 Hundested
Denmark

DHI Denmark and its facilities are described in detail in Chapter 3.

The project manager for this project is Morten Bjergstrøm, M.Sc.

2 Project organisation and personnel responsibilities

The project organisation is illustrated in Figure 2.1.

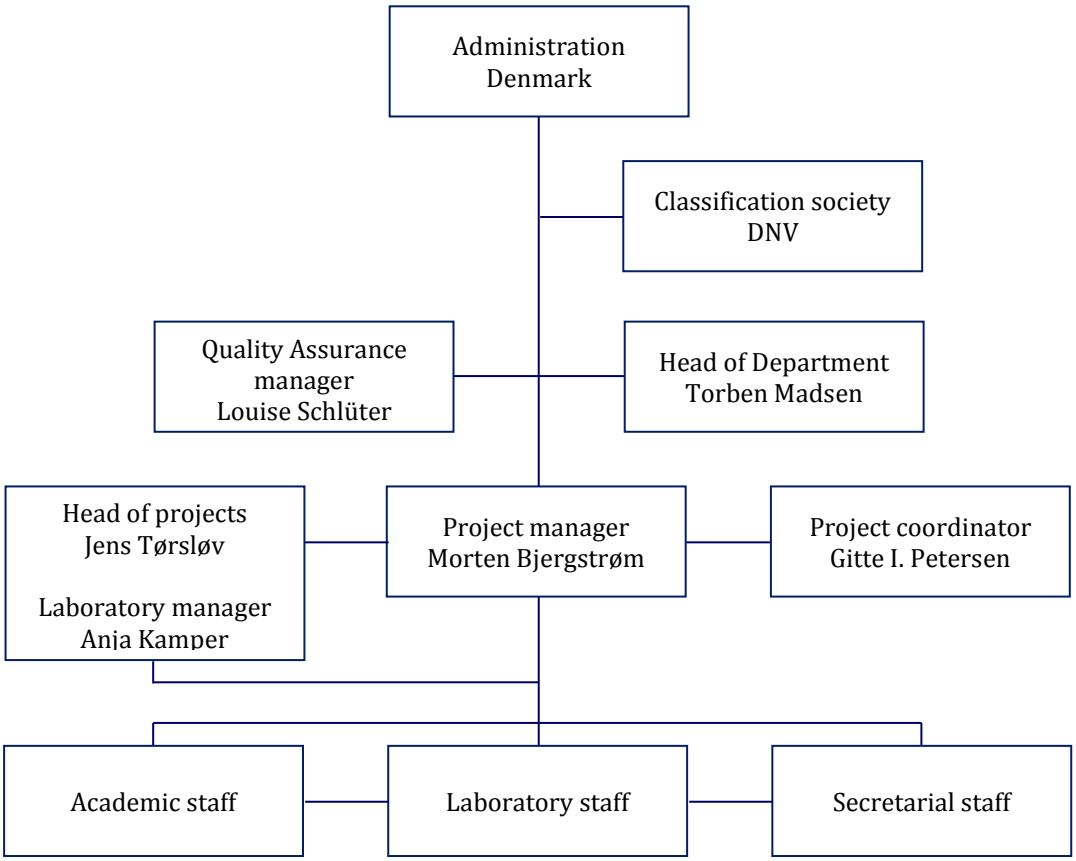

Figure 2.1 The DHI project organisation

2.1 Quality assurance

Senior biologist Louise Schlüter (Ph.D.) is assigned by DHI's Quality Assurance (QA) Unit as internal auditor (see Chapter 11). This includes the following tasks:

- Drafting of a plan for quality assurance
- Monitoring of compliance with the quality management plan (QMP), the quality assurance project plan (QAPP) and the standard operating procedures (SOPs) by audit including the project manager and the laboratory staff
- Monitoring compliance with the appropriate guidelines by audit including the project manager
- Verification of the presence of applicable staff training records
- Drafting of audit reports and verification that audit responses are appropriate and that corrective action has been implemented effectively
- Verification that the final product complies with DHIs standards for QA (Chapter 11) and, particularly, the QMP, the QAPP and the guidelines and standards.

2.2 Management and quality control

Head of department Torben Madsen (Ph.D.) is quality supervisor for all projects and has the overall responsibility for the services related to performance evaluation of BWMS provided by DHI Denmark. This includes the following tasks:

- Member of the Ballast Water Test Facility Board for DHI Ballast Water Centre, a coordinating structure between DHI Denmark and DHI Singapore
- Overall responsibility for the liaison and contractual relations between DHI and Lloyds Register EMEA (certification of test facility), between DHI and the Danish Accreditation and Metrology Fund, DANAK (accreditation of analyses), and between DHI and the Independent Laboratory (subcontractor agreement)
- Negotiation of contracts with clients
- Appointment of project managers and staff responsible for quality control (QC) of individual data (data-level QC) and maintenance of staff experience records (allocation of project managers for specific projects is the responsibility of the head of projects)
- Maintenance of the QMP /4/ with updated versions as appropriate
- Quality control of the QAPP, SOPs and all project proposals, deliverables and reports
- Documentation in relation to
    - Staff training and experience
    - Facilities and their maintenance
    - Records of complaints

2.3 Project coordinator

Business area manager Gitte I. Petersen (Ph.D.) is responsible for the coordination, timely execution and the overall scientific quality of the services. This includes the following tasks:

- Business development and marketing
- Contact and dialogue with Lloyds Register EMEA prior to inspections and for management of the actions and documentation, in collaboration with the laboratory manager, as required to comply with the Certificate of Compliance issued by Lloyds Register EMEA
- Contact and dialogue with the Independent Laboratory prior to inspections and for management of the actions and documentation, in collaboration with the laboratory manager, as required to comply with the agreement between DHI and the Independent Laboratory
- Coordination of the services to ensure optimal logistics at the test facility, including decisions related to the practical installation of clients and their technology and timing of tests
- Maintenance of the test facility including routine technical maintenance and dialogue with the head of department in relation to investments and maintenance expenses
- Instruction of staff with responsibility for specific tasks such as test facility technical operations and production of test water
- Principal scientific expert with responsibility for the overall scientific quality of the services, including compliance with official guidelines, standards, protocols and requirements from classification societies and Independent Laboratories; this implies input to the QAPP and the Test Plan, revisions and implementation of SOPs, and contributions to data interpretation and reporting in collaboration with the project manager
- Participation in discussions with the classification society or the Independent Laboratory on important matters, particularly draft and final reports, together with the project manager

2.4 Staffing, planning and project execution

Head of projects Jens Tørsløv (Ph.D.) has the overall responsibility for allocation of staff, planning and project execution in coordination with the business area manager or the project manager as appropriate.

Laboratory manager Anja Kamper (M.Sc.) allocates laboratory technicians for a specific project as part of the laboratory capacity planning by allocation of responsibility from the head of projects. Furthermore, the laboratory manager appoints one or more test co-ordinators among the laboratory technicians or the academic staff for on-site co-ordination of land-based test cycles.

The laboratory manager is responsible for the contact and dialogue with DANAK prior to inspections and for management of the actions and documentation as required in order to comply with the ISO 17025 accreditation /5/.

2.5 Project management

The project manager is responsible for the management and efficient performance of the project in accordance with the contract between the client and DHI, with the QMP and with the QAPP.

The project manager's tasks include:

- Organisation and management of the project
- Meetings and other communication with the client to ensure that all necessary information is available in due time
- Preparation of the draft and final QAPP with detailed description of the project, including time schedule of activities and deliverables; the QAPP shall be made available to all staff participating in the project
- Facilitation of the process for comments and responses to the draft QAPP in dialogue with the client and the classification society
- Preparation of potential amendments and deviations to the QAPP
- Communication of the project time schedule to the classification society to enable external audit
- Participation in discussions with the classification society on important matters, particularly draft and final reports, together with the project coordinator
- Co-ordination and dialogue with the laboratory manager in relation to the practical organisation of work involving laboratory technicians; the project manager shall in due time inform the laboratory manager on the types of tests and the required capacity to enable laboratory capacity planning
- Contracts with subcontractors as appropriate for meeting the project deliverables (e.g. chemical analytical laboratory)
- Approval of initiation of the test cycles and interruption of test cycles, e.g. in case of irregularity
- Preparation of reports

2.6 Academic, laboratory and secretarial staff

The tasks of the academic, the laboratory and the secretarial staff include:

- Maintenance of materials and equipment
- Test facility technical operations
- Test co-ordinator function, i.e. co-ordination and keeping of timely records of the activities at the test facility during land-based tests
- Production of test water and monitoring of test water quality
- Sampling at the test facility
- Analysis and data processing, including data-level QC
- Contributions to test reports
- Archiving of documents and raw data
- Contributions to QAPPs and SOPs

2.7 Client

The tasks of the representative of the client include:

- Signing a Contract with DHI for the BWMS performance evaluation project
- Project management of the client's activities in the project, including the liaison with DHI and decisions in relation to the testing
- Review and comments to the draft QAPP and approval of the final QAPP
- Collaboration with DHI to establish all necessary arrangements prior to initiation of the test
- Review and comments to draft test reports
- Dismantling and removal of the BWMS from the test facility after ended testing

3 Description of testing laboratory

3.1 DHI Denmark

DHI is an independent, international consulting and research organisation established in Denmark and today represented in all regions of the world with a total of more than 1,000 employees. Our objectives are to advance technological development, governance and competence in the fields of water, environment and health. DHI works with governmental agencies and authorities, contractors, consultants and numerous industries.

DHI has no involvement, intellectual or financial, in the mechanics, design or marketing of the products and technologies that are being evaluated. To ensure that DHI's tests are uncompromised by any real or perceived individual or team bias relative to test outcomes, DHI's test activities are subject to rigorous quality assurance (QA), quality control (QC) and documentation.

DHI's quality management system is certified according to ISO 9001 by DNV (Det Norske Veritas). The certification is facilitated by the implementation of the DHI Business Management System (see Chapter 11).

3.2 DHI Environmental Laboratory

DHI's Environmental Laboratory has an accreditation according to ISO 17025 /5/, including ecotoxicological studies and analyses related to the performance evaluation of BWMS. Furthermore, the laboratory is authorized to carry out ecotoxicological studies in compliance with the OECD Principles of Good Laboratory Practice (GLP) /6/.

DHI's Environmental Laboratory and staff normally analyse all samples collected during the performance evaluation of BWMS. If required, specialized chemical analyses of, e.g., active substances or disinfection by-products, are conducted by a subcontractor identified in the section on Subcontractors.

3.3 DHI Maritime Technology Evaluation Facility

DHI holds a Certificate of Compliance issued by Lloyd's Register EMEA for the performance of land-based and shipboard testing of BWMS (Appendix A).

The travel time from the DHI Maritime Technology Evaluation Facility (hereafter the 'test facility') to the DHI Environmental Laboratory is approx. 50 min, which enables analysis or treatment of the samples within 6 hours.

The test facility is used to conduct biological evaluations of maritime technologies. The test facility is covered by the International Safety Port System (ISPS). Hundested Harbour is registered at IMO's website (Port facilities) under Port ID No. 266076DKHUN, Port facility 1651.

The test facility includes seven cylindrical tanks constructed in galvanized steel and coated with a non-toxic top coating:

- One open 750-m^3 source tank, Tank D in Figure 3.1. The source tank is equipped with a propeller, which creates a slow circulation in order to maintain the homogeneity of the test water. A bridge across the top of the source tank is established for monitoring the homogeneity.
- Six closed 250-m^3 retention tanks, Tanks A1, B1, C1, A2, B2 and C2 in Figure 3.1. Tanks A1 and A2 are also described as 'control tanks' and are used for untreated test water. Tanks B1, C1, B2 and C2 are retention tanks for treated test water. Each of the six retention tanks is equipped with a submersible agitator (with three-blade propeller), to create a slow circulation in order to maintain homogeneity of the test water.

The piping connecting source tank, control tanks, retention tanks, pump and BWMS is made of polyethylene. The diameters are 315 mm and 350 mm for the piping connecting the A1, B1 and C1 tanks and 400 mm and 500 mm for the piping connecting the A2, B2 and C2 tanks.

The piping system connecting the source tank and the retention tanks is equipped with sampling ports. The sampling ports are equipped with the following sample outlets:

1. Sample outlet for ≥1-m^3 samples (to be used for analysis of organisms ≥50 µm)
2. Sample outlet for ≥10-L samples (to be used for analysis of organisms ≥50 µm and organisms ≥10 to <50 µm)
3. Sample outlet for microbiology samples
4. Sample outlet for samples for analysis of dissolved organic carbon (DOC), particulate organic carbon (POC), total suspended solids (TSS) and transmittance

The test facility is equipped with sensors for automatic logging of flow, pressure, water levels, temperature, dissolved oxygen, pH, salinity and turbidity.

The test facility includes a main pump with a flow performance of 250-500 m^3/hour. By use of a harbour piping, this pump can be used to provide a continuous flow of brackish water directly from the harbour to the BWMS with a capacity of up to approx. 300 m^3/hour. Furthermore, the test facility includes electrical generator power supply up to 150 kVA.

If needed to fulfil the test water quality requirements, appropriate volumes of cultivated organisms can be added to the source tank by an auxiliary pump.

The exact configuration of the test facility piping and equipment may be subject to minor changes.

The procedures, guidelines or characteristics for analyses, operations or tests performed in the DHI Environmental Laboratory, at the test facility or on board a vessel are described in SOPs.

For this specific test, the retention tank C2 was modified with a central tower and tarpaulins to create appropriate barriers. The tarpaulins are fixed to the central tower and the wall of the retentions tank by use of wires.

The detailed modifications are illustrated in Figures 3.2-3.4.

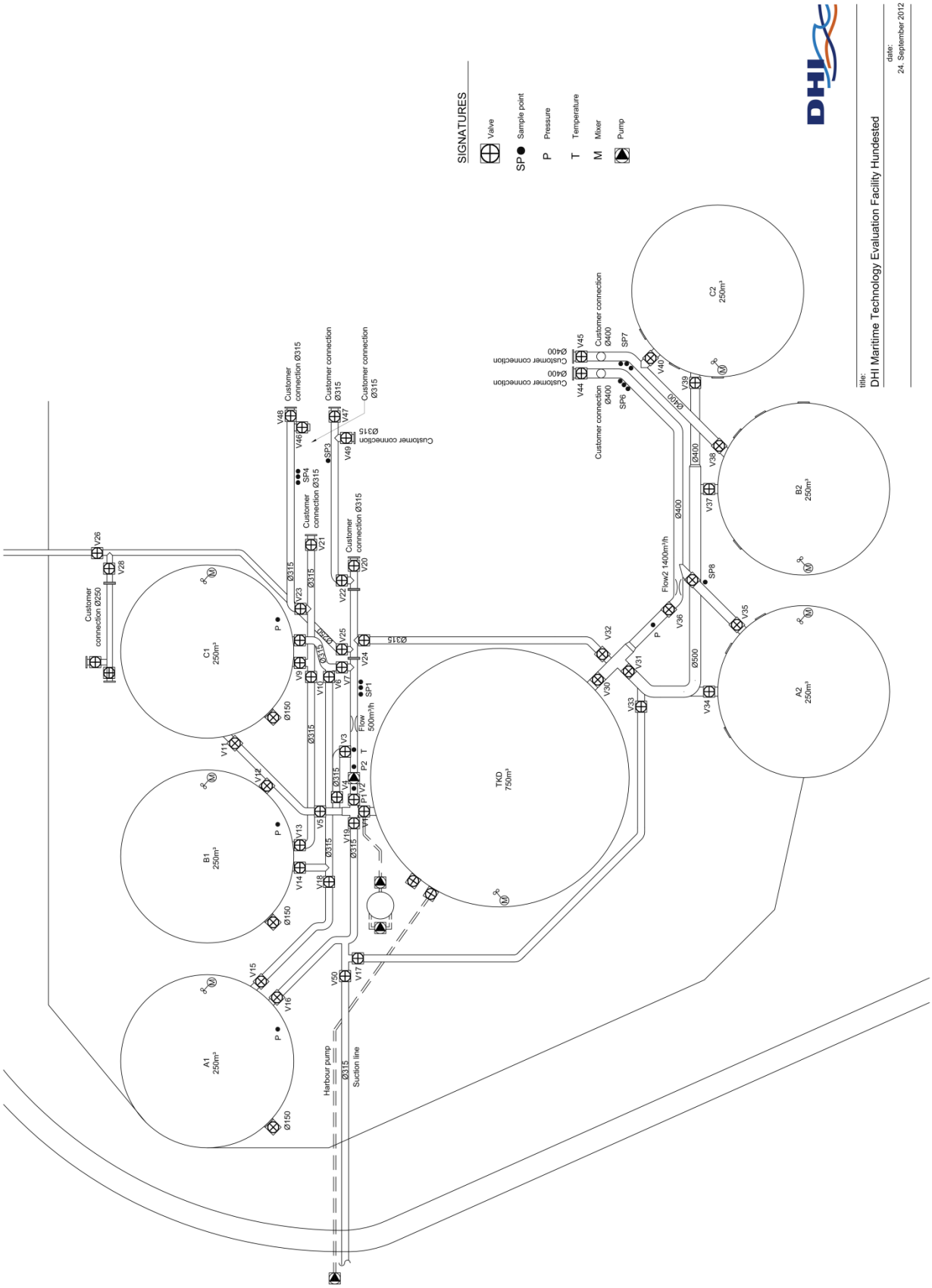

Figure 3.1 DHI Maritime Technology Evaluation Facility, Hundested, Denmark

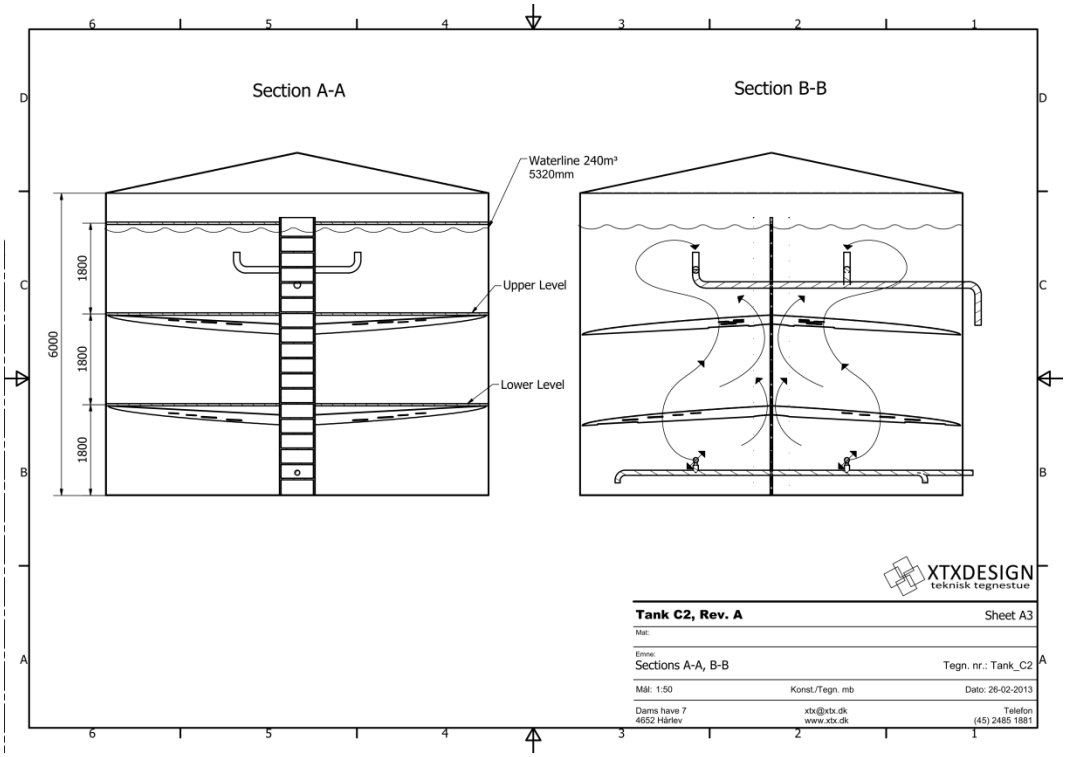

Figure 3.2 Cross sections of retention tank modifications

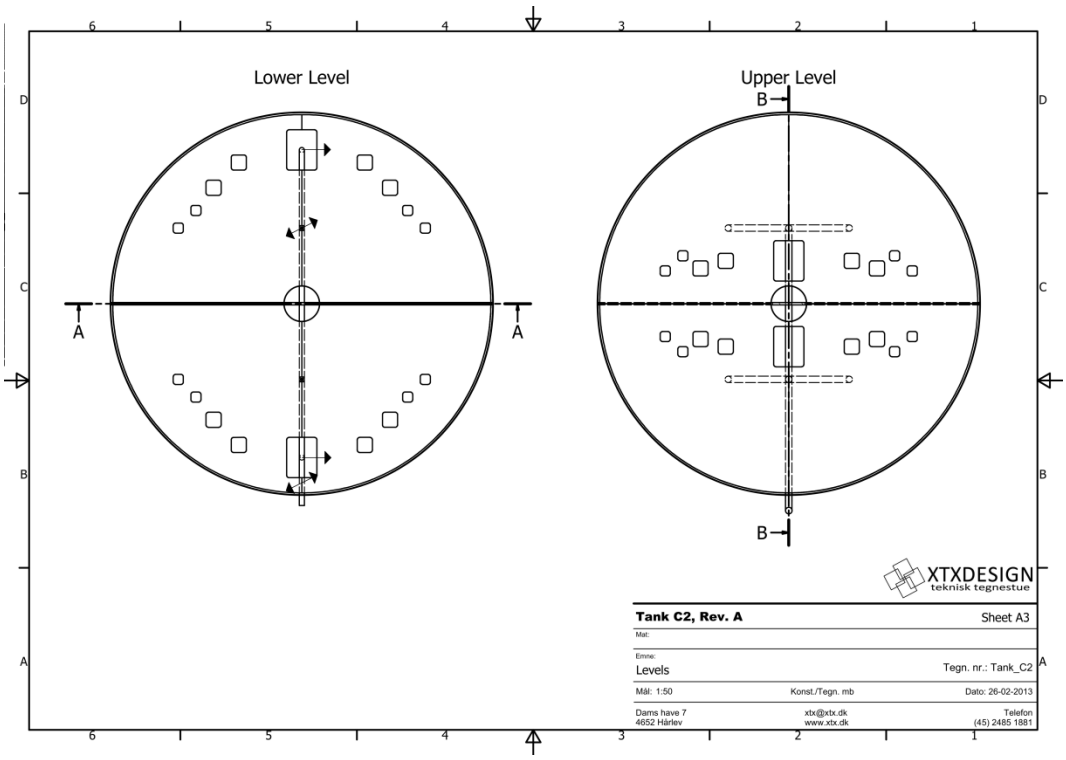

Figure 3.3 Tarpaulin design

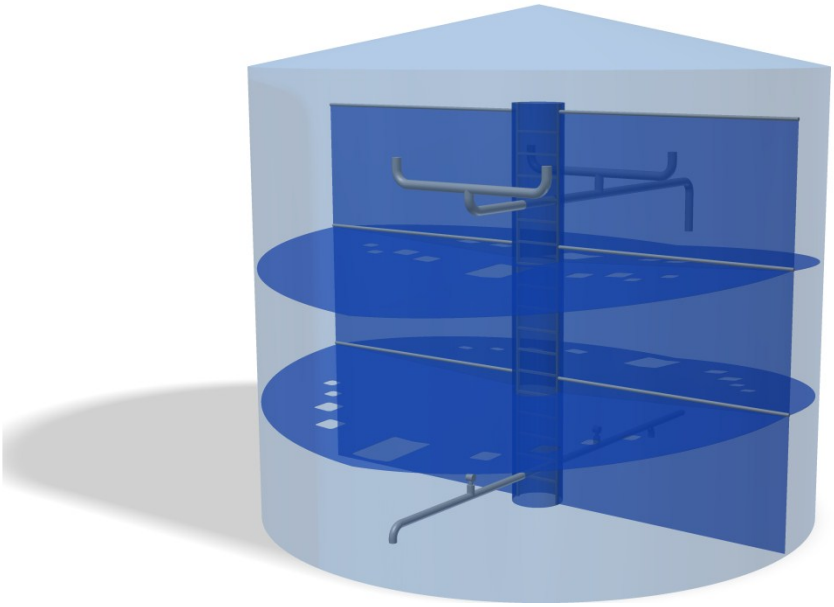

Figure 3.4 3D-view of retention tank modifications

3.4 Subcontractors

Statens Serum Institut
Artillerivej 5
DK-2300 København S

For verification of *Vibrio cholerae* according to DHI SOP 30/1707.

4 Description of ballast water management system

The description of the BWMS as provided by the client is enclosed in Appendix B.

5 Experimental design

5.1 Installation and operation of the BWMS

The BWMS shall be ready to enter the performance evaluation. Prior to the start of the performance evaluation of the BWMS, it is the client's responsibility to have met all requirements for initiation of testing set forth by the classification society appointed by the client.

The client is expected to deliver the BWMS to the test facility in due time before the initiation of the performance evaluation (see chapter on Time schedule). The BWMS shall be delivered in a container, which can protect the equipment, and installed in accordance with the directions of DHI.

The BWMS will be operated by the client during all test cycles.

5.2 Water types applied in the land-based test

The present land-based test with the BAWAT BWMS will be conducted with the following water types:

- Fresh water (salinity <3 PSU)
- Brackish water (salinity 3-32 PSU)
- Marine water (salinity > 32 PSU)

The land-based test will include three (3) sets of biological efficacy (BE) test cycles, each consisting of five (5) replicate BE test cycles with duration of at least five (5) days. Each set of BE test cycles will be conducted with test water representing one salinity range.

5.3 Biological efficacy verification testing

5.3.1 BWMS treatment process

The BE test cycles will be conducted by use of the source tank (Tank D), control tank (Tank A2) and one retention tank per test cycle (Tank C2) (Figure 3.1).

In the BWMS, the treatment of the test water will include the following steps (for definition and characterisation of test water, see Section 6.1):

1. A fraction of the test water (200-250 m^3) contained in the source tank will be transferred to the retention tank by pumping and treated by the BWMS in-tank*
2. Another fraction of the same test water (200-250 m^3) will be pumped directly into the control tank without passing the BWMS (control water). The control water serves as a control of BWMS performance*
3. Piping system and sample ports will be cleaned (DHI SOP 30/1763)

* The control and retention tanks may be filled simultaneously.

During ballasting, the flow, pressure, temperature, dissolved oxygen, pH, salinity, turbidity and water levels in the tanks will be recorded automatically (DHI SOP 30/1764).

Samples will be collected before treatment by use of relevant inlet sample ports. Sampling will be initiated when the flow rate has reached steady-state conditions, i.e. up to 5 minutes from start of operation (DHI SOPs 30/1738 and 30/1762). Samples will be labelled according to procedures described in DHI SOP 30/1750.

5.3.2 Storage of treated and untreated test water

Following the treatment of the test water with the BWMS, the treated water will be stored in the retention tank for at least five days ± 4 hours. The same storage time will be applied for the control water.

5.3.3 Discharge of test water

1. Treated water contained in the retention tank will be discharged into the harbour (treated discharge water)
2. Control water contained in the control tank will be discharged into the harbour (control discharge water)
3. The retention tanks, piping system and sample ports will be cleaned (DHI SOP 30/1763)

During de-ballasting, the flow, pressure, water temperature, dissolved oxygen, pH, salinity, turbidity and water levels in the tanks will be recorded automatically (DHI SOP 30/1764).

Samples of the treated discharge water will be collected by use of the sampling port on the BWMS discharge line whereas samples of the control discharge water will be collected on the MTEF discharge line. The samples will be collected by use of approximated isokinetic sampling methodology with fixed sample volumes according to principles described in MEPC.173(58) (G2) /7/.

6 Challenge conditions

6.1 Test water

6.1.1 Source water applied in the land-based test

Source water means the body of water from which water is drawn for the land-based test. The IMO G8 guidelines /2/ describes three distinct water types that may be applied in the land-based test:

Fresh water (salinity < 3 PSU)

Brackish water (salinity 3 - 32 PSU)

Marine water (salinity >32 PSU)

When fresh water is used, the source water will be collected from e.g. the Arresø Canal according to DHI SOP 30/1736 on collection of fresh water. Organism densities in the collected fresh water often exceed the minimum criteria for live organisms in test water with an order of magnitude allowing for dilution of the natural fresh water with potable water.

When brackish water is used, the source water will be collected immediately south of the pier adjacent to the test facility according to DHI SOP 30/1735; under normal conditions, the natural salinity of the source water will be 15-20 PSU.

When marine water is used, the source water will be collected immediately south of the pier adjacent to the test facility according to DHI SOP 30/1735, and brine will be added to achieve the required salinity.

6.1.2 Test water – water quality characteristics

Test water means the inlet water as contained in the source tank just prior to treatment. In land-based tests, source water may be adjusted to achieve the required challenge conditions.

In the source water, the natural concentrations of dissolved organic carbon (DOC), particulate organic carbon (POC) and total suspended solids (TSS) are analysed, after which the test water will be prepared to meet the water quality parameters in Table 6.1.

Table 6.1 Minimum water quality characteristics in compliance with the IMO G8 guidelines /2/.

Parameter	Test water		
	Fresh (<3 PSU)	Brackish (3-32 PSU)	Marine (>32 PSU)
Dissolved organic carbon (DOC)	>5 mg/L	>5 mg/L	>1 mg/L
Particulate organic carbon (POC)	>5 mg/L	>5 mg/L	>1 mg/L
Total suspended solid (TSS)	>50 mg/L	>50 mg/L	>1 mg/L

If necessary in order to obtain the stated water quality parameters, the concentrations of DOC, POC and mineral materials (MM) will be increased by additions of lignin sulphonate (DOC), starch (POC) and kaolin clay (MM) as described in DHI SOP 30/1737.

6.1.3 Test water – biological organism conditions

The natural densities of live organisms in the test water are analysed with reference to size classes, after which the test water will be prepared to meet the biological parameters in Table 6.2.

Table 6.2 Minimum criteria for densities of live organisms in the test water according to the IMO G8 guidelines /2/

Organism size class	Total concentration	Diversity
≥50 µm	100,000 organisms/m^3	5 species across 3 phyla
≥10 µm and <50 µm	1,000 organisms/mL	5 species across 3 phyla
<10 µm	10,000/mL as culturable aerobic heterotrophic bacteria	Not applicable

If necessary to obtain the stated minimum criteria, the densities of live organisms will be increased by addition of harvested indigenous organisms and/or cultured species as described in DHI SOP 30/1734. Addition of harvested and/or cultured species is recorded in the data logging.

Heterotrophic bacteria are typically present in the test water in densities exceeding the minimum criteria described in Table 6.2.

7 Sampling and analysis plan

7.1 Sample overview in BE verification testing

Table 7.1 Overview of sampling and purpose of samples

Parameter	Inlet water to BWMS and control tank	Treated discharge water	Control discharge water	Sample collection
Ballasting operations				
Volume	×	×	×	Continuous
Pressure	×	×	×	Continuous
Flow	×	×	×	Continuous
Other parameters*	×	×	×	Continuous
Water quality conditions				
Temperature, salinity, turbidity, pH, DO**	×	×	×	Continuous
TSS, DOC***, POC*** and UV-T****	×	×	×	Discrete grab (3 replicates; start, middle, end)
Concentrations of live organisms				
Viable organisms ≥50 µm	×******	×	×	Discrete (3 replicates; time integrated)
Viable organisms ≥10 and <50 µm	×	×	×	Discrete (3 replicates; each representing approx. a third of the operation period)
Viable organisms <10 µm (heterotrophic aerobic bacteria, *E. coli*, enterococci and *Vibrio cholerae*)	×	×	×	Discrete grab (3 replicates; start, middle, end)
Whole Effluent Toxicity (WET)*****	-	×	×	Discrete (time integrated)

* Operational parameters to ensure that the systems have been operated correctly and in accordance with the Operation and Maintenance manual
** Dissolved oxygen
*** Measured in inlet and discharge samples
**** UV-transmittance at 254 nm, 1 cm, measured in inlet samples
***** Only in BE test cycles to be decided later
****** Collected as discrete grab samples (3 replicates; start, middle, end)

Triplicate flow-integrated samples will be collected. The samples will be stored in thermo boxes with cooler bricks in the dark from the time of collection until handling of the samples in the DHI Environmental Laboratory.

7.2 Inlet water

Table 7.2 Sampling and analysis of inlet water to BWMS and control tank

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Microscopy	30/1701	DHI
Organisms <10 µm		
Heterotrophic aerobic bacteria	30/1705	DHI
E. coli and enterococci	30/1708	DHI
Physical/chemical		
Temperature, pH, O_2, salinity and turbidity	30/1764	DHI
TSS, DOC and POC	30/1768 and 30/1769	DHI
UV-transmittance at 254 nm, 1 cm	30/1770	DHI

7.3 Treated discharge water and control discharge water

Table 7.3 Sampling and analysis of treated discharge water

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Microscopy	30/1701	DHI
Organisms <10 µm		
E. coli and enterococci	30/1708	DHI
Vibrio cholerae	30/1707	DHI
Physical/chemical		
Temperature, pH, O_2, salinity and turbidity	30/1764	DHI
TSS, DOC and POC	30/1768 and 30/1769	DHI

Table 7.4 Sampling and analysis of control discharge water

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Microscopy	30/1701	DHI
Organisms <10 µm		
E. coli and enterococci	30/1708	DHI
Vibrio cholerae	30/1707	DHI
Physical/chemical		
Temperature, pH, O_2, salinity and turbidity	30/1764	DHI
TSS, DOC and POC	30/1768 and 30/1769	DHI

8 Data management, analyses and reporting

8.1 Data management

During the land-based test, logging of data related to

- Personnel participating in cleaning and maintenance at the test facility and collection of samples
- Operational procedures and monitoring
- Sampling and analysis

is performed in accordance with the data logging procedures described in the respective DHI SOPs. A complete overview of the DHI SOPs used for BWMS performance evaluation is presented in Appendix C.

An Access-based database and the procedures described in DHI SOP 30/1750 are used for storage of data generated from the BE test cycles and for marking completed QC of individual data. This data-level QC is made with reference to data quality indicators described in the DHI SOPs.

All generated data and all other records and information relevant to the quality and integrity of the performance evaluation, including a copy of the database file(s) and original raw data, will be retained in the archives of DHI for a period of five years after issue of the final report.

8.2 Analyses

8.2.1 Organism size class ≥50 µm

Compliance with the pass criterion in Chapter 10 will be verified by use of the direct count of organisms ≥50 µm in minimum dimension.

The concentrations of live organisms ≥50 µm in minimum dimension are determined by use of a stereo microscope and a counting chamber according to DHI SOP 30/1700. Viable organisms are enumerated by use of standard movement and response stimuli technique. The viable organisms are characterized according to broad taxonomic groups such as crustaceans (e.g. copepods), molluscs, rotifers, worms, etc.

8.2.2 Organism size class ≥10 µm and <50 µm

Compliance with the pass criterion in Chapter 10 will be verified by use of the total of viable organisms determined by the vital staining methodology.

To support the determination of concentrations of organisms in the ≥10 µm and <50 µm size class, a combination of the following analytical methods will be applied.

Inverted microscopy (DHI SOP 30/1701). The concentrations of organisms and the presence of taxonomic groups in the inlet water are determined by inverted microscopy.

Vital staining with fluorescein diacetate (FDA) and chloromethylfluorescein diacetate (CMFDA) (DHI SOP 30/1701). FDA and CMFDA are added to a subsample and, after incubation, the subsample is examined by use of a microscope under epifluorescence. Organisms labelled by either FDA or CMFDA are considered viable as described in DHI SOP 30/1701.

8.2.3 Organism size class <10 µm

The concentrations of heterotrophic aerobic bacteria will be determined according to DHI SOP 30/1706 (ISO 6222). *E. coli* and enterococci will be analysed according to DHI SOP 30/1708 using ISO-9308-1 for determination of *E. Coli* and ISO 7899-2 for determination of enterococci. *Vibrio cholerae* will be analysed according to the method described in DHI SOP 30/1707.

8.2.4 Physical/chemical analyses

The measurements conducted at the test facility according to DHI SOPs 30/1764 and 30/1766 will include:

- pH
- Temperature
- Salinity
- Turbidity
- Dissolved oxygen
- Ballast system pressure
- Ballast system flow rates
- Water volume in retention tanks

The analyses conducted at the DHI Environmental Laboratory will include the following measurements:

- TSS
- POC
- DOC
- UV-transmittance at 254 nm, 1 cm

8.3 Amendments, deviations and reports

Amendments are planned changes to the QAPP. Deviations are unplanned changes. Amendments and deviations will be signed by the project manager and documented in the file and the final report.

The following reports will be prepared:

- Draft final report compiling all relevant data from the test cycles, data interpretation and conclusion
- Final report

9 Validity criteria

A valid BE test cycle includes:

Concentrations of live organisms in control discharge water being (a) ≥100 organisms/m^3 for the organism size class ≥50 µm and (b) ≥100 organisms/mL for the organism size class ≥10 µm to <50 µm (IMO G8 guidelines, Annex, Part 2, Section 2.3.36 /2/)

10 Pass criteria

A valid BE test cycle is regarded as successful if it meets the performance standard for treated ballast water at discharge (IMO Regulation D-2 /1/):

1. The average density of organisms larger than or equal to 50 µm in minimum diameter in the replicate samples shall be less than 10 viable organisms per m^3 at discharge
2. The average density of organisms smaller than 50 µm and larger than or equal to 10 µm in minimum diameter in the replicate samples shall be less than 10 viable organisms per mL at discharge as determined by vital staining

3. The average density of *Vibrio cholerae* (serotypes O1 and O139) shall be less than 1 colony forming unit (CFU) per 100 mL at discharge
4. The average density of *E. coli* in the replicate samples shall be less than 250 CFU per 100 mL at discharge
5. The average density of intestinal enterococci in the replicate samples shall be less than 100 CFU per 100 mL at discharge

11 Quality assurance and control

11.1 Quality assurance

The project is conducted in accordance with the principles of ISO 9001 by using the DHI Business Management System and the procedures in the QMP /4/.

The DHI quality manager is responsible for assigning a trained internal auditor from DHI's Quality Assurance Unit to each project in accordance with the procedures for internal audit in the DHI Business Management System (Section on Quality). The internal auditor shall not be involved in solving the specific project or in any project deliverables.

The DHI Business Management System (Section on Quality; Internal Audit) describes procedures for audit and evaluation and the process of periodic internal auditing of projects and activities including audit responsibilities and planning, auditor training and competences and audit reporting.

The DHI Business Management System (Section on Quality; Correction and Prevention) describes procedures for corrective actions, i.e. how deviations identified during operation and auditing are corrected and how future occurrence of the same deviations is prevented (preventive actions).

11.2 Quality control

Quality control of individual data, or data-level QC, of BWMS operational conditions, sampling and analyses is conducted with reference to data quality indicators (DQI) in the DHI SOPs by staff appointed for this task (see Section 2.2). The data quality indicators include accuracy, precision, bias, representativeness, completeness, comparability, and sensitivity. The DQI and how they are monitored and evaluated are described in the relevant DHI SOPs.

Records of completed data-level QC are stored in an Access-based database (DHI SOP 30/1750), and a copy of the relevant database file(s) will be retained in the DHI archives for a period of five years after issue of the final report.

Quality control of the QAPP, DHI SOPs and all project proposals, deliverables and reports is conducted by management (see Section 2.2).

12 Time schedule

The testing is expected to be initiated March 2013. The biological efficacy testing will be performed with one test every week or two tests every second week throughout the spring 2013 (to the extent possible).

Table 12.1 Time schedule for the biological efficacy testing

Test cycle	Intake	Discharge
1	13 March	18 March
2	27 March	2 April
3	9 April	15 April
4	16 April	22 April
5	23 April	29 April
6-10	23 April to 21 May	-
11-15	21 May to 20 June	-

The classification society will be regularly updated by BAWAT A/S as the testing progresses.

DHI decides the applied test water salinities and the timing of the test cycles within the access period.

Dependent on weather conditions and the possibilities of preparing the right test water quality, the land-based test cycles will be conducted as outlined above. Ballasting is performed on a weekday in the morning and the de-ballasting is performed after at least 5 days from approx. 08:00 am, if at all practicable.

A draft final report will be prepared within ten (10) weeks after the successful completion of the planned test cycles.

A final report will be issued three weeks after the client's approval of the draft final report.

13 References

[1] IMO. International Convention for the Control and Management of Ships' Ballast Water and Sediments (IMO Regulation D-2). London. International Maritime Organization, 2004.

[2] MEPC. Guidelines for Approval of Ballast Water Management Systems (G8). Resolution MEPC.174(58). Adopted 10th October 2008.

[3] MEPC. Procedure for Approval of Ballast Water Management Systems that Make Use of Active Substances (G9). Resolution MEPC.169 (57). Adopted 4th April 2008.

[4] Quality management plan. Performance Evaluation of Ballast Water Management Systems. DHI Denmark. Version 3.1. June 2012.

[5] EN ISO/IEC 17025. General requirements for the competence of testing and calibration laboratories /ISO/IEC 17025, 2005.

[6] OECD Principles of Good Laboratory Practice (as revised in 1997). Organisation for Economic Co-operation and Development (OECD), Paris. ENV/MC/CHEM (98)17.

[7] Resolution MEPC.173(58). Adopted on 10 October 2008. Guidelines for approval of ballast water sampling (G2).

14 Approval of quality assurance project plan

DHI Ballast Water Centre

Project management Date: 2013.03.07

Morten Bjergstrøm

Quality control Date: 2013.03.07

Torben Madsen

This QAPP is accepted and my signature authorizes the study to proceed as described in this document.

Client Date:

Kim Diederichsen
BAWAT A/S

APPENDIX A

Certificate of compliance, ISO 9001 certificate, accreditation and GLP authorisation

COPY

Certificate no: **DS/I093222-A**
Page 1 of 1

Lloyd's Register Certificate of Compliance

Office: **Lloyd's Register EMEA**
Copenhagen Design Support Centre, Statutory Section
Strandvejen 104A, 2nd floor
DK-2900 Hellerup
Denmark

Date: **09 May 2012**

This certificate is issued to **DHI Ballast Water Centre, Denmark**

DHI Ballast Water Centre, Denmark

The Document(s) listed in paragraph 1 of the appendix have been examined for compliance with:

- Resolution MEPC.174(58), Annex part 2

and are found to comply from quality assurance and quality control aspects subject to the following:

1.1. It is required to maintain full and accurate log files in order to demonstrate correct quality measures

1.2. The Quality Assurance Project Plan is a project specific document and should as such be subject to review and commenting prior to each project start-up.

1.3. This design appraisal document is to be kept together with quality management plan.

1.4. Subject certificate is valid until 15 June 2015.

1. The documents listed below have been examined

Drawing No.	Rev.	Title	Status	Date
Date: 07 Sep 2011	**2.3**	**Quality Management Plan**	**B**	**09 May 2012**

2. The documents listed below have been considered together with the submitted documents in the appraisal

Drawing No.	Rev.	Title
11810704	**02**	**Quality Assurance Project Plan**

Appraisal Status Key

B Examined and found to comply with §2.2, Part 2 of the annex of IMO Resolution MEPC 174 (58)

Martin Schabert
Statutory Department
Copenhagen Design Support Centre
Surveyor to Lloyd's Register EMEA

LLOYD'S REGISTER EMEA
Lloyd's Register
M. Schabert
COPENHAGEN DESIGN SUPPORT CENTRE

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DNV BUSINESS ASSURANCE

MANAGEMENT SYSTEM CERTIFICATE

Certificate No. 109333-2012-AQ-DEN-DANAK

This is to certify that

DHI Group

has been found to conform to the management system standard:

DS/EN ISO 9001:2008

This certificate is valid for the following product or service ranges:

Consulting, software, research & development and laboratory testing, analysis & products within the area of water, environment & health

Locations included in the certification will appear in the appendix.

Place and date:

Hellerup, 2012-03-23

DET NORSKE VERITAS,
BUSINESS ASSURANCE, DANMARK A/S

This certificate is valid until:

2015-01-10

The audit has been performed under the supervision of:

Jan Carsten Schmidt
Lead Auditor

DANAK
SYSTEM Reg.nr. 5001

Jens Peter Høiseth
Managing Director

Lack of fulfilment of conditions as set out in the Certification Agreement may render this certificate invalid.

ACCREDITED UNIT: DET NORSKE VERITAS, BUSINESS ASSURANCE, DANMARK A/S, TUBORG PARKVEJ 8, 2., DK-2900, HELLERUP, DANMARK, TEL:+45 39 45 48 00, WWW.DNVBA.COM

DNV BUSINESS ASSURANCE

APPENDIX TO CERTIFICATE

This appendix refers to certificate no. 109333-2012-AQ-DEN-DANAK

DHI Group

Locations included in the certification are as follows:

Site Address	Scope:
Agern Allé 5 2970 Hørsholm, Denmark	Consulting, MIKE© by DHI Software Development, Sales & Support, Solutions Software Development, Research, Development & Innovation and Laboratory Analysis, Testing & Products
INCUBA Science Park, Gustav Wieds Vej 10 8000 Århus, Denmark	Consulting, Solutions Software Development and Research, Development & Innovation
Drakegatan 6, 412 50 Göteborg, Sweden	Consulting, MIKE© by DHI Software Sales & Support
Kyrkogatan 3, 222 22 Lund, Sweden	Consulting, MIKE© by DHI Software Sales & Support
Svartmangatan 18, 111 29 Stockholm, Sweden	Consulting, MIKE© by DHI Software Sales & Support
Honnörsgatan 16, Box 3287, 350 53 Växjö, Sweden	Consulting, MIKE© by DHI Software Sales & Support

This certificate is valid until:

2015-01-10

The audit has been performed under the supervision of:

Jan Carsten Schmidt
Lead Auditor

DANAK
SYSTEM Reg.nr. 5001

Place and date:

Hellerup, 2012-03-23

DET NORSKE VERITAS,
BUSINESS ASSURANCE, DANMARK A/S

Jens Peter Høiseth
Managing Director

Lack of fulfilment of conditions as set out in the Certification Agreement may render this certificate invalid.

ACCREDITED UNIT: DET NORSKE VERITAS, BUSINESS ASSURANCE, DANMARK A/S, TUBORG PARKVEJ 8, 2., DK-2900, HELLERUP, DANMARK, TEL:+45 39 45 48 00, WWW.DNVBA.COM

Accreditation to testing

COPY DANAK

Company:	**DHI**
	Agern Allé 5 **DK-2970 Hørsholm**
Registration number:	**26**
Valid:	**24-10-2012 to 31-07-2015**

Scope:

Testing

Product

- **Biological items**
- **Chemicals and chemical products**
- **Construction products**
- **Environmental samples**

Test Type

- **Biological and biochemical testing**
- **Chemical testing**
- **Microbiological testing**
- **Ionising radiation and radiochemistry**
- **Sampling**

Testing is performed according to the current list of test methods approved by DANAK.

The company complies with the criteria in EN ISO/IEC 17025:2005 – General requirements for the competence of testing and calibration laboratories and demonstrates technical competence for the defined scope and the operation of a quality management system (refer joint ISO-ILAC-IAF Communiqué dated January 2009, www.danak.dk).

Issued the 24 October 2012

Jesper Høy / **Kirsten Jebjerg Andersen**

In case of any disputes, the Document in Danish language shall have priority.

Den Danske Akkrediterings- og Metrologifond

COPY DANAK

GOOD LABORATORY PRACTICE

STATEMENT OF COMPLIANCE

Laboratory inspection and study audits for compliance with the OECD Principles for Good Laboratory Practice were carried out at

Laboratory: DHI

on

Dates: 21st and 22nd October 2011

The laboratory inspection and study audits have been carried out in accordance with the regulation settled in Order No. 906 of 14th September 2009 from the Danish Ministry of Environment. The laboratory has been monitored for GLP Compliance within the following scope:

Type of products:

- *Industrial chemicals*
- *Pesticides*
- *Biocides*

Type of tests:

- *Environmental toxicity studies on aquatic and terrestrial organisms.*
- *Studies of behaviour in water, soil and air, bioaccumulation*

The laboratory was found to be operating in compliance with the OECD Principles of Good Laboratory Practice.

Date: 08 August 2012

Jesper Høy
Managing director, DANAK

Kirsten Jebjerg Andersen
GLP inspector, DANAK

Den Danske Akkrediterings- og Metrologifond

APPENDIX B

Description of the ballast water management system as provided by the client

Bawat A/S

BAWAT Document 2012.009 / 2013-03-05

Land-based Test
System Description
& Standard Operating Procedures

Changes from BD 2012.009 dated 2012 09 27:

1. In section 1.1 changes have been made to the description of the BAWAT process steps:
    a. A few editorial changes
    b. In step 2 oxygen content target has been changed to 2.0 mg/L or less.
    c. In step 3 the sentence "Shortly …… minutes" has been deleted.
2. Section 2.1:
    a. Component 2.8 added.
    b. Figure 2.1/1 updated
    c. Rationale of and description of the cooling circuit added .incl. new figure 2.1/3.
3. Fact box has been added in section 2.2.
4. In section 2.5.1 text has been updated and extended re. number of recirculations.
5. In section 2.5.2 text has been updated re. pump rate, etc.
6. In section 2.7.1 text has been updated and extended.
7. In section 2.8.2 text re. addition of oxygen to the nitrogen flow has been added.
8. Oxygen sensor added in section 2.10.2
9. In section 2.11:
    a. A fact box regarding Henry's Law has been inserted.
    b. Information re. oxygen content in nitrogen gas has been added.
    c. Target DO level has been changed to 2.0 mg/L or less.
    d. Pasteurization temperature in land-based test have changed to 72 °C.
    e. The text re. the recirculation factor has been updated and extended.
    f. A new section re. temperature in treatment tank has been added.
10. In section 3.2 instructions re. valve positions have been added.
11. New section 3.4 describing procedures re. cooling of treated water has been added. Consequently following sections have been renumbered.
12. Oxygen sensor added in section 3.5.5

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1. INTRODUCTION

The present **BAWAT Document #2012.009** describes the BAWAT Land-based Test set-up at DHI's test facilities in Hundested, Denmark, its main components and the main standard operating procedures.

1.1. BACKGROUND

The BAWAT Ballast Water Treatment System is an **In-Tank** system treating the ballast water (BW) in the ballast water tanks. Most other process systems for the same purpose are **In-Line** systems treating the water after the ballast water pumps before it enters the tanks.

Basically the BAWAT system is a recirculation system, where the BW after it has been pumped into the BW tank, is recirculated in a loop from the top of the BW tank, and re-introduced into the tank through a combination of Rotary Jet Heads (RJH) and fixed nozzles appropriately installed in the bottom section of the tank. (Please see figure 1.1/1 below.)

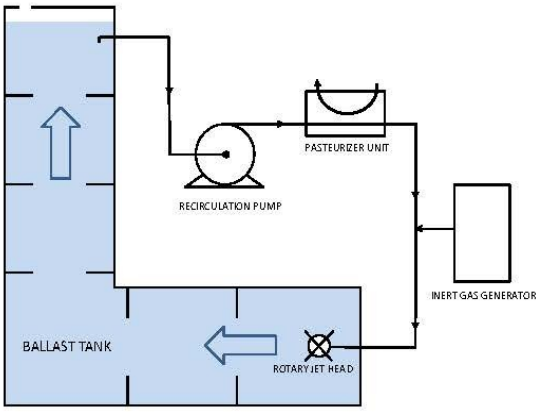


Figure 1.1/1:
Basic schematics of the BAWAT System

In the recirculation loop injection of gas such as nitrogen (N_2) or atmospheric air or a mixture of these take place on the pressure side of the pump. Further, a heat treatment system is built into the recirculation loop making it possible to apply a two-step treatment process, namely a deoxygenation of the ballast water in the tank combined with a heat treatment of the water in a pasteurizing unit.

The BAWAT System is particularly characterized by:

- The existing ballast system is operated without alterations/modifications.
- Simplicity and with a very small footprint, thereby facilitating retrofits.
- All process components have long term positive marine track records.
- No upgrade of BW pumps and associated piping and power generators are required.

It has been established, that to meet the criteria stipulated in Regulation D-2 of the 2004 Ballast Water Convention re. the content of microorganisms in the ballast water at discharge, it is necessary to apply

at least two different treatment principles. Most In-Line systems apply filtration of the incoming ballast water through 30 -50 µm filters as a first step, whereafter the filtered ballast water is exposed to either UV radiation, ultrasonic, ozone or other biocides.

Also the BAWAT System applies two distinct process principles, namely deoxygenation and pasteurization. The de-ox process effectively eradicate the zooplankton while at the same time nearly eliminate corrosion in the ballast tanks. The pasteurization process will eliminate both the phytoplankton and the bacteria to levels below the IMO requirements.

The BAWAT System normally will treat one tank at a time. Typically the system is installed allowing a port and a starboard tank to be treated simultaneously. Therefore, the system could be installed with one larger pump unit and one larger pasteurizing unit, or as a double system unit with two identical units, each having 50% capacity compared to one large system. One such system installed to handle the port side tanks, and one to handle the starboard side tanks. The treatment of the fore – and aft peak tanks, can be handled by either of these two systems.

In more details the BAWAT System will be operated as follows:

1. After the ballast water has been pumped into the ship's BW tanks and the ship has left harbor, the ship is in a situation where it has both surplus energy and waste heat available. The BAWAT System's recirculation pump(s) are started, and the recirculation of the ballast water is initiated, sucking from the top of the BW tank and reinjecting the water through Rotary Jet Heads and fixed nozzles properly installed in the lower part of the BW tanks. When recirculation has been established, heat in form of steam or hot condensate is supplied to the pasteurizer, and inert gas from the inert gas generator is injected into the recirculation line at a pressure a little higher than the pump pressure being around 2.5 – 5 bar. The inert gas injected after the pasteurizer will dissolve in the ballast water en route to the nozzles inside the BW tank. The nozzles will generate a very effective in-mixing of micro bubbles of inert gas into the ballast water by establishing a Non Stationary Flow Pattern at the entrance of the tank which effectively will be "pushing out" the oxygen from the BW.

2. The recirculation is maintained until the oxygen content in the water is below 2.0 mg/L and the total tank volume has passed at least once through the pasteurizer.
   The water is now treated to specification, and the pump is switched to start sucking from the next tank to be treated, after the valves to the just treated tank have been closed.

3. The treated water now rests in the tank until it has to be pumped overboard.

Besides effectively fulfilling the established biological treatment criteria for a BWT system, the BAWAT System further offers two important side benefits to the ship owner.

Firstly, by applying a de-ox process; the corrosion processes in the BW tanks will nearly be eliminated. Secondly, the installed Rotary Jet Heads will act as very efficient tank cleaners, which will be able to flush and clean the inlet part of the BW tanks effectively, thereby being able to exert a satisfactory sludge control of the BW tank system.

2. DESCRIPTION OF THE LAND-BASED TEST SET-UP

Contrary to other Ballast Water Treatment Systems – whether already type approved or in the type approval process – the BAWAT System utilizes various pieces of equipment already installed on the ship combined with proprietary components supplied by BAWAT.

Therefore, the BAWAT System installation will vary physically from ship to ship, however, will operate under the same principles and guidelines and controlled under identical process parameters.

In the sections below the land-based test set-up is described with reference to shipboard BAWAT System installations.

2.1. OVERVIEW

Figure 2.1/1 shows the test set-up at the DHI facilities in Hundested, the main components and measuring and sampling points in schematic form.

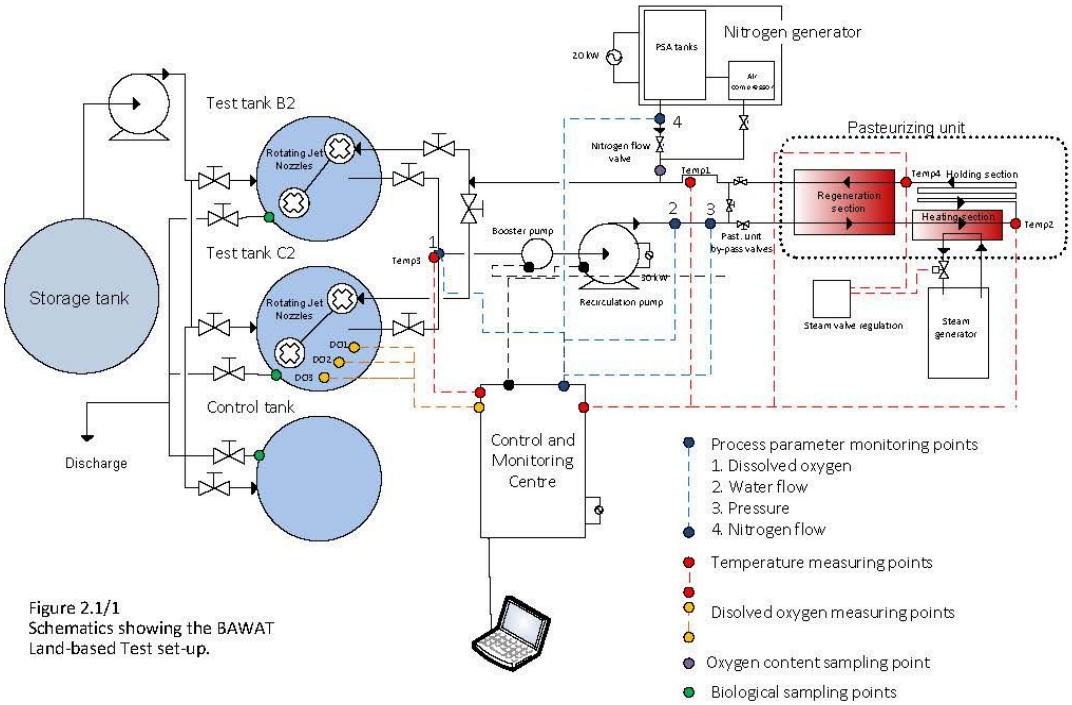


Figure 2.1/1
Schematics showing the BAWAT Land-based Test set-up.

The BAWAT System equipment has been built into three ISO containers – Figure 2.1/2:

1. A 10' container with
   - 1.1. Main pump for recirculation (Booster pump is placed outside container)
   - 1.2. Main system valve
   - 1.3. Control and Monitoring Centre

1.4. Sensors for water flow, pressure and dissolved oxygen content in the water

1.5. Connection to PC for monitoring and data logging

2. A 20' container with

2.1. Pasteurizing unit

2.2. Pasteurizing temperature regulation

2.3. Pasteurizing unit by-pass valve

2.4. Temperature sensors

2.5. Nitrogen generator

2.6. Gas flow regulation and – meter

2.7. Gas flow injection

2.8. Oxygen meter in nitrogen flow

3. A 10' foot container with the steam generator (Fuel tank and water softener are placed outside container)

The pre-insulated pipes constituting the holding section of the pasteurizing unit are placed on top of and across the two first mentioned containers.

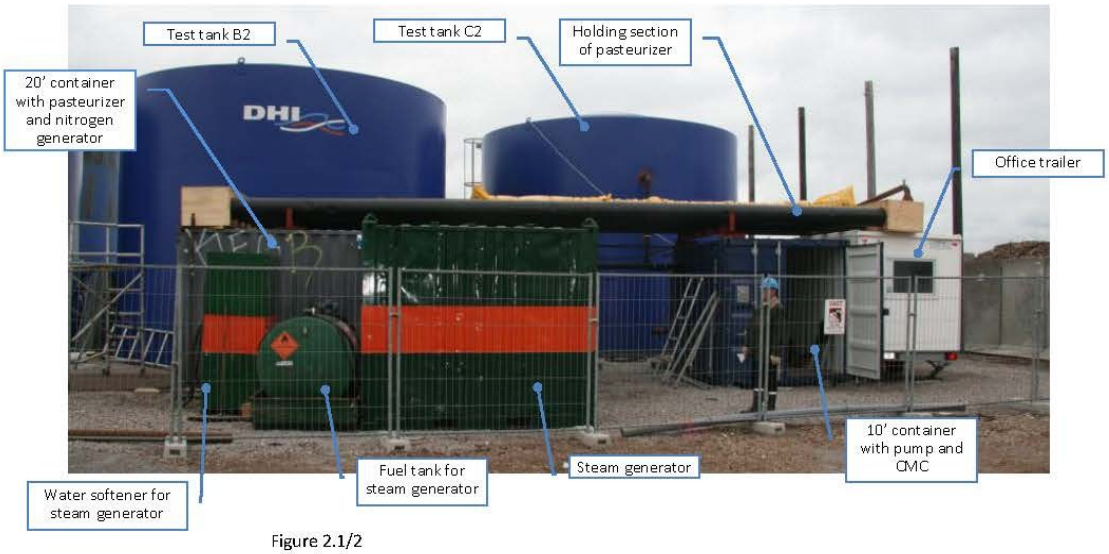


Figure 2.1/2
Test site.

The BAWAT system treatment process involves a recirculation of the water in the treatment tank through a pasteurizing unit. The ΔT (temperature increase) over the pasteurizing unit is 4 – 5 °C. This will increase the temperature in the treated tank by approximately the ΔT times the number of water recirculations during the treatment. The actual temperature increase will depend on the cooling conditions (temperature, wind, etc.) at the time of treatment. However, the temperature in the control tank will only change very slightly again depending on the actual temperature and wind condition at the time of the treatment.

The differences in after-treatment water temperatures between the treatment tank and the control tank can be considered an experimental artifact, as the temperature increase in a ship's BWT after

treatment are expected to very slight due to the efficient heat exchange through the ship's sides.

In order to mitigate the consequences of this artifact a cooling circuit has been establish in the land based test set-up in accordance with Figure 2.1/3. The plate heat exchanger utilized as the regeneration section of the pasteurizer unit is after treatment connected as a cooling heat exchanger using harbor pool water to cool the treatment tank water in accordance with section 3.4 below.

COOLING CIRCUIT INSTALLATION

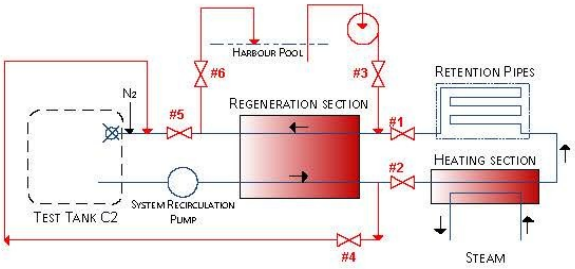


Figure 2.1/3
Cooling circuit installation.

2.2. TANKS

The BAWAT land-based tests takes place at DHI's test facilities in Hundested (Figure 2.2/1) utilizing three tanks of 250 m^3 each. Two tanks will be internally modified as described in principle below and in details in the DHI QAPP and the third tank be will used as a 'controltank' i.e. no treatment will take place in this tank.

Please observe: At present only one tank (C2) has been modified and connected to the BAWAT System equipment.

The test water is pumped into the tanks from the 750 m^3 reservoir tank, in which the test water is synthesized.

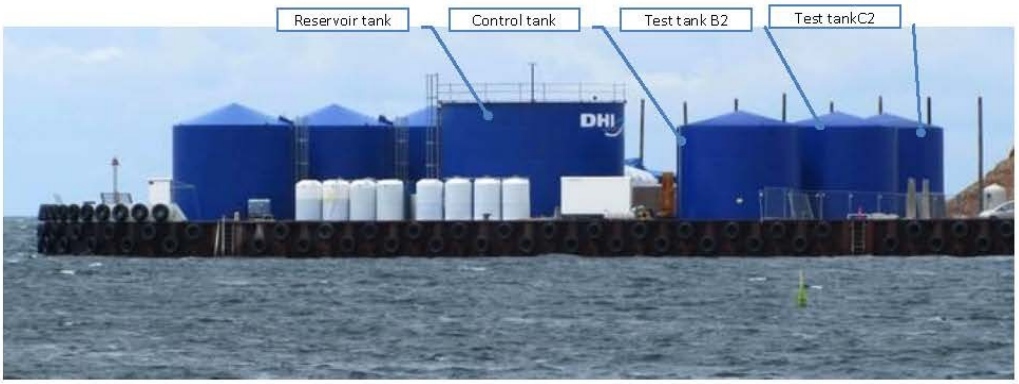


Figure 2.2/1: The DHI test installation from the sea.

The test tanks at the DHI facilities in Hundested are designed purely for the purpose of testing In–Line BWT systems, only serving as retention tanks for the treated water arriving from the BWTS. The tanks, however, in which the BAWAT System shall be tested, play an integral part of the system. The test tanks in Hundested therefore had to be modified so as to resemble normal ballast tanks as closely as possible.

In general, the recirculation system in a BAWAT System always will suck the water from right below the water surface in top of the ballast water tank, and will re-inject the water at the bottom of the ballast water tank trough the jet nozzles.

The nitrogen gas used a.o. for de-oxygenation is injected into the recirculation loop well before the tank, and will always consist of smaller and larger bubbles. The smaller bubbles primarily will facilitate the de-oxygenation of the water and will rise relatively slowly in the water, whereas the larger nitrogen bubbles will serve to agitate and mix the water in the individual compartments of the ballast water tanks. Compared to the flow of the main body of the water caused by the pumps, these larger nitrogen bubbles are travelling 4-500 times faster through the tank than the water.

Due to the basic construction of the ship and the ballast water tanks the nitrogen bubbles will always tend to move along the inner side of the ballast water tank tending to generate an upward movement of the water along the inner side of the tank.

To establish the same general movement pattern – flow regime - in the cylindrical tanks in Hundested, it was first of all necessary to establish an "inner side" in the tanks, and then ensure that the majority of the larger nitrogen bubbles ascended following this "inner side".

The "inner side" was established by hanging a vertical tarpaulin diametrically in the tank, thus separating the tank into two equal parts.

To establish tree compartments in each half of the tank equivalent to the longitudinally decks inside a ship's ballast water tanks, two 'half-moon' shaped pieces of tarpaulin were expanded from the inside cylindrical surface of the tank towards the diameter. The first half-moon positioned approx. 1/3 of the height of the tank up from the bottom and the second half moon 2/3 up from the bottom. They were positioned with a slight slope of 5 degrees towards the diameter

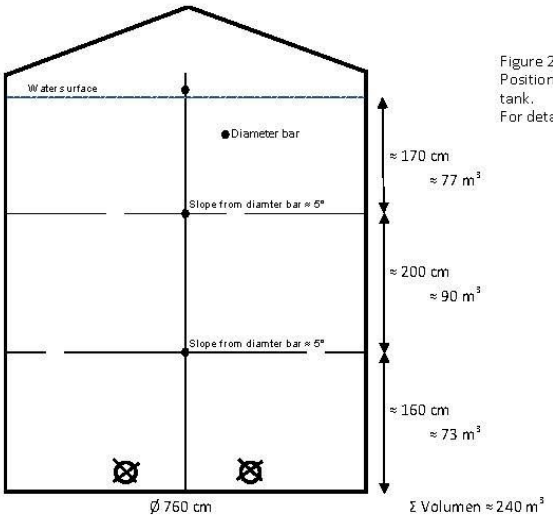


Figure 2.2/2
Positions of vertical and horizontal tarpaulins in tank.
For details please refer to the DHI description.

The intention of the tank modifications were to establish a flow pattern in the tank very similarly to what has been observed both in the 1:10 test tank at DTU, and also in the ballast water tanks of the 7.500 DWT tanker , Bro Gothenburg.

Visual inspection from the observation hatch in the top of the tank confirm that a flow pattern as intended with the main bubble flow ascending at the diameter bar seems to have been established.

Further, deoxygenation tests in the D2 test tank confirm that the deoxygenation courses observed here is qualitatively similar to analogue observations in 1:10 tank at DTU and on Bro Gothenburg.

The configuration will be optimized during pre-test runs before the land-based trials are initiated.

Please observe that the photograhs in this section show the original tarpaulin setup. Hole-configuration has been modified in the present set-up.
For details please refer to the relevant QAPP section prepared by DHI.

Figure 2.2/3-4
Tarpaulin construction inside tank B2.

2.3. ROTATING JET NOZZLES

2.3.1. SHIPBOARD INSTALLATION

The BAWAT System utilizes a combination of rotating jet nozzles and fixed nozzles to introduce N_2 filled bubbles into the ballast water at the bottom of the ballast water tanks.

In a given ship's ballast tank one rotating jet nozzle will be placed in the tank segment where the ballast water is pumped into and out of the tank, and in the L-shaped tanks a series of fixed nozzles will be placed longitudinally one in each structural segment of the ballast water tank. In other tank constructions the fixed nozzles will be placed in positions creating a flow regime in the tank that agitates the ballast water in all compartments of the tank.

The water jets from the rotating jet nozzle will in addition to the introduction of nitrogen bubbles into the water remove sludge from the vicinity of the bell mouth through which the ballast water is pumped in and out of the ballast water tank and thus prevent the sludge from being washed out during the de-ballasting operation.

The relevant size of the rotating jet nozzle as well as the fixed jet nozzles will depend on required process time of the actual ballast water tank depending again on the actual tank size and the available pump capacity.

2.3.2. LAND-BASED TEST INSTALLATION

In the land based test set-up two rotating jet nozzles of the type **'IsoMix IM 25 Rotary Jet Mixer'** and two fixed Ø21 mm nozzles are installed in the tank – please see Figures 2.3.2/1 to 3.

Please see **Appendix 5.1** for specifications of the IsoMix IM 25 Rotary Jet Mixer.

Figure 2.3.2/1
Iso-Mix IM 25

Figure 2.3.2/2
Rotating Jet Nozzle and fixed jet nozzle in test tank.

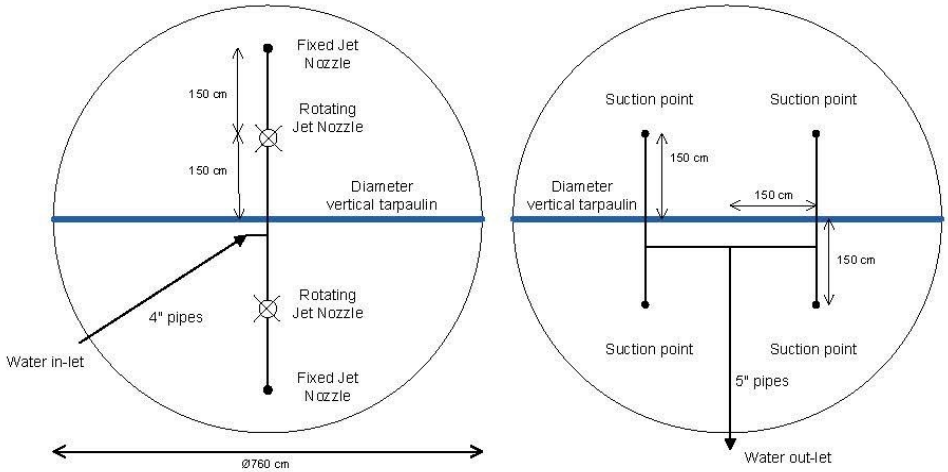


Figure 2.3.2/3
Positions of RJNs and FJNs at buttom of tank and suction points at tank top.

2.4. SUCTION POINTS

2.4.1. SHIPBOARD INSTALLATION

The BAWAT System circulates the ballast water from just below the water surface in the ballast water tanks through the treatment system to be reinjected through the nozzles at the bottom of the tanks as described above.

In the L-shaped ballast water tanks parallel suction points will be distributed longitudinally. The number of suction points, their precise placement and dimensions of the pipes will depend on the actual tank volume, the pump capacity and required process time. In other tank constructions the suction points will be placed and dimensioned to allow an unhindered water flow in the recirculation loop.

If the ballast water tanks are not filled to their maximum volume it is necessary to lower the suction point to below the actual water surface. This will be done by installing in a vertical pipe a series of floater operated valves that will open sequentially when the water level drops.

2.4.2. LAND-BASED TEST INSTALLATION

In the land-based test set-up four suction points are placed 0.5 m below the water surface as shown in figure 1.3.3/1. The pipe openings are facing upwards to avoid a direct flow of air bubbles into the pipes. Figure 1.3.3/2 shows the placement of the horizontal plane.

Please see Figure 2.3.2/3 for positioning of suction points.

Figure 2.4.2/1
Suction point in top of tank.

2.5. RECIRCULATION PUMP

2.5.1. SHIPBOARD INSTALLATION

In a ship board BAWAT System installation the existing ballast water pumps will be used as recirculation pumps and the ballast water piping will – after installation of remotely operated valves and low pressure suction piping from the top of the ballast water tanks to be attached the ballast pipes at the bottom of the tanks – be used as the low pressure suction piping in the recirculation loop.

The ballast water volume in a given ballast water tank will typically have to be recirculated between 2.5 and 4.0 times to ensure that 99.9% of the ballast water in the tank passes through the pasteurizing unit. The exact number of recirculations will primarily depend on the actual construction of the tank specifically on the number of compartments in which the tank can be considerate to be divided into.

The optimal treatment time will depend on the ship's schedule, speed, available energy for pasteurization, pump operation and nitrogen production, etc.

It is, however, expected - as a rule of thumb - that tanks in smaller ships shall be treated in 3 - 8 hours and larger ships in 16 – 24 hours. As an example: In a 30,000 DWT tanker the average ballast water tank is approximately 1,000 m^3. Running the ballast water pump as the recirculation pump in the BAWAT System at 500 m^3/h will give a process time in the tank of max. 8 hours.

2.5.2. LAND-BASED TEST INSTALLATION

In the land-based test set-up the tank size is 240 m^3. The recirculation pump system (see below) gives a pump rate of maximum 130 m^3/h allowing the BAWAT process to be carried out in less than 7 hours.

The main recirculation pump is an Iron Pumps' electrical centrifugal pump type CNLe 100/200 in series with a smaller electrical centrifugal pump (Desmi Pump PVLN, 4") serving as a 'booster' pump increasing system pressure and pump above the main pump's specification.

For specifications see **Appendix 5.4**

The pump and below described flow meter, dissolved oxygen sensor and the Control & Monitoring Centre are installed in a 10' container.

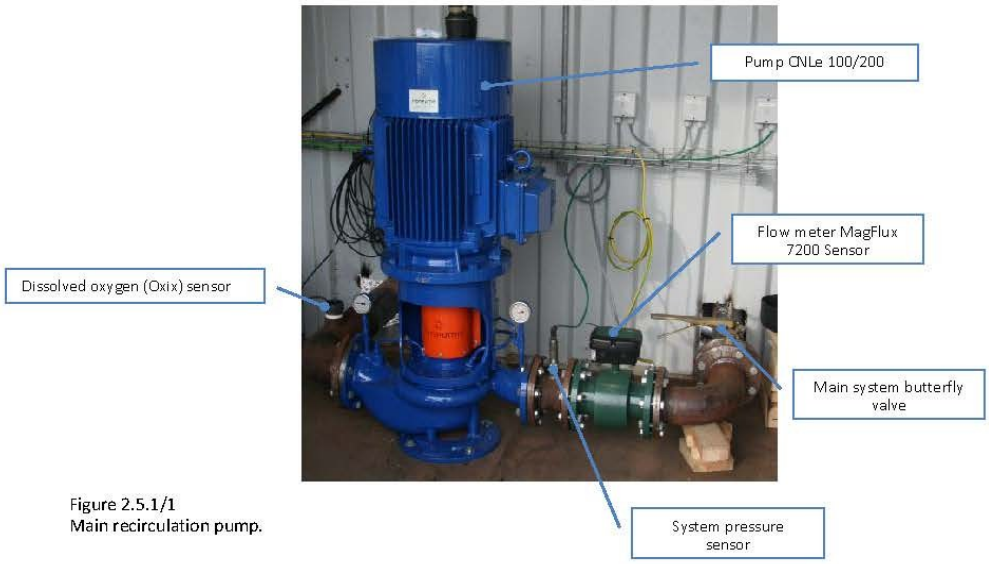


Figure 2.5.1/1
Main recirculation pump.

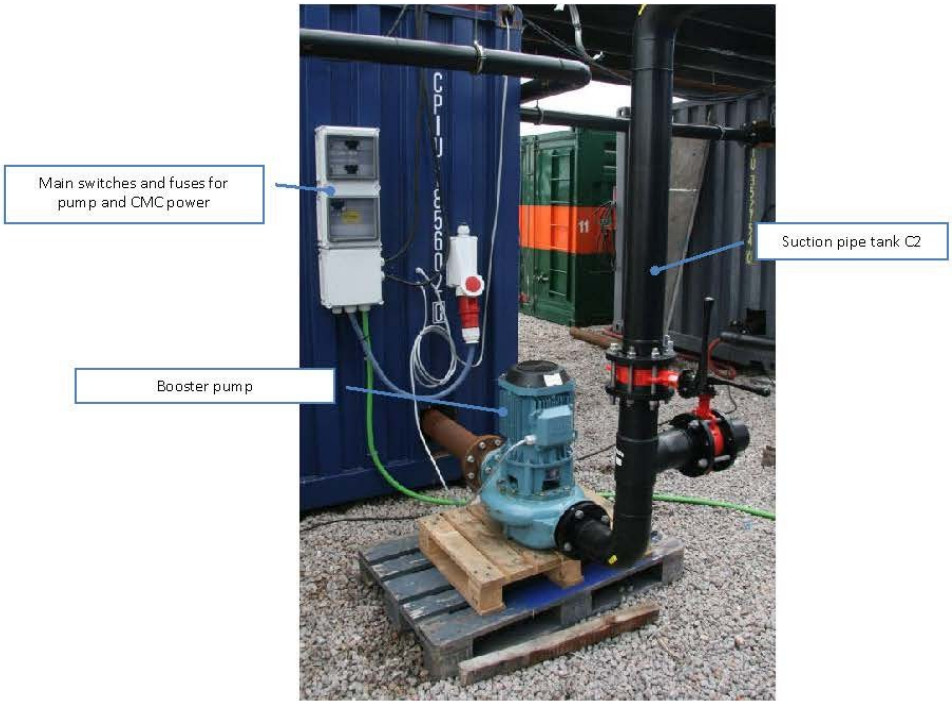


Figure 2.5.1/2
Booster pump.

2.6. PASTEURIZING UNIT

2.6.1. SHIPBOARD INSTALLATION

The BAWAT System implements a two-step process combining de-oxygenation and pasteurization. The shipboard mounted pasteurization unit consists of three parts – please see Figure 2-6-1/1:

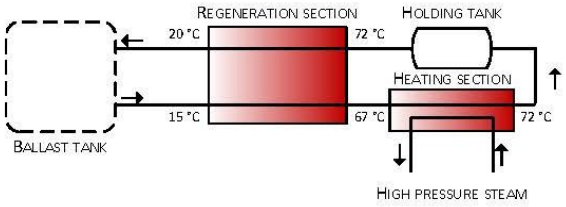


Figure 2.6.1/1
Pasteurizing unit principle

1. A Regeneration Section – a plate heat exchanger - in which in-coming water from the ballast water tank is heated by the out-going water from the holding tank.
2. A Heating Section – another plate heat exchanger – in which the water from the first heat exchanger is heated by low pressure steam supplied by the ship's existing installations, e.g. a dedicated steam generator or waste heat economizer.

3. A Holding Tank the purpose of which is to maintain the pasteurizing temperature achieved in the heating unit for a given time.

The temperatures indicated in the figure above are examples only. The temperature difference between the water flowing out of the ballast water tank and the water flowing back into the tank (ΔT) is in this example 5 °C.

The ΔT value as such has no effect on the BAWAT System efficacy and can be adjusted according to the requirements of the actual ship owner's priorities regarding capacity costs (CAPEX) and operational costs (OPEX) again depending on various issues as the actual costs of steam on a given ship.

2.6.2. LAND-BASED TEST INSTALLATION

In the land-based test set-up the pasteurizing unit comprises of

1. A Regeneration Section being a Sondex S86/200 plate heat exchanger with a ΔT of 5 °C at 150 m^3/h. (See **Appendix 5.3** for detailed specifications.)
2. A Heating Section being a Sondex S22/80 plate heat exchanger. (See **Appendix 5.3** for detailed specifications.)
3. A Holding Unit consisting of 60 m of Ø210 mm pre-insulated pipes with total water volume of 2.3 m^3. The unit gives a holding time of 1 min and has a temperature difference measured between inlet and outlet of less than 1 °C at a flow rate of 140 m^3/h.

Figure 2-6-1/2-3
Pasteurizing unit sections

2.7. STEAM GENERATOR

2.7.1. SHIPBOARD INSTALLATION

In a shipboard mounted BAWAT installation the heating medium in the above described pasteurizing unit could be low pressure steam supplied by the ship's existing or updated installations, e.g. a dedicated steam generator, waste heat economizer or jacket cooling water heat exchange.

The heat requirement of the BAWAT System depends on the specifications of the installed pasteurization unit, but will typically be equivalent to approximately 0.02 ton of steam per 1 m^3 of ballast water treated.

As an example: A 30.000 DWT tanker holds typically 12,000 m^3 of ballast water. A full BAWAT System treatment of this volume of ballast water will require approximately 240 tons of steam over a 48 h period of time equal to 5 tons/h.

2.7.2. LAND-BASED TEST INSTALLATION

In the land-based test set-up the steam is supplied by an oil burner driven Clayton Steamgenerator Type E-150 with a capacity of 2.3 – 2.4 tons/h at 3 bar installed in a 10' container. (Specifications see **Appendix 5.2**)

The steam pressure and consequently the temperature on the hot side of the heat exchanger in the heating section of the pasteurization unit is regulated by an automatic, motorized valve operated via an electronic circuit with temperature sensors in the water flow at the inlet and outlet of the holding section of the pasteurizing unit. The water temperature can be held within ±1 °C of the set temperature.

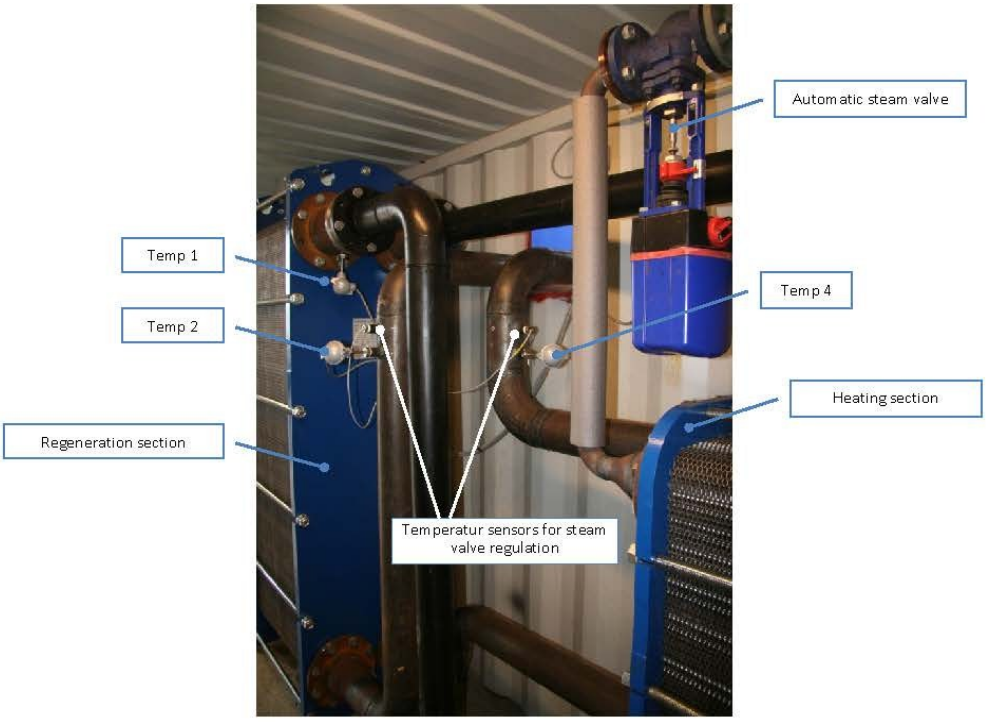


Figure 2.7.2/1: Temperature sensors in pasteurizer unit

Figure 2.7.2/2: Control panel for setting and control of Pasteurizing temperature located in 20' container.

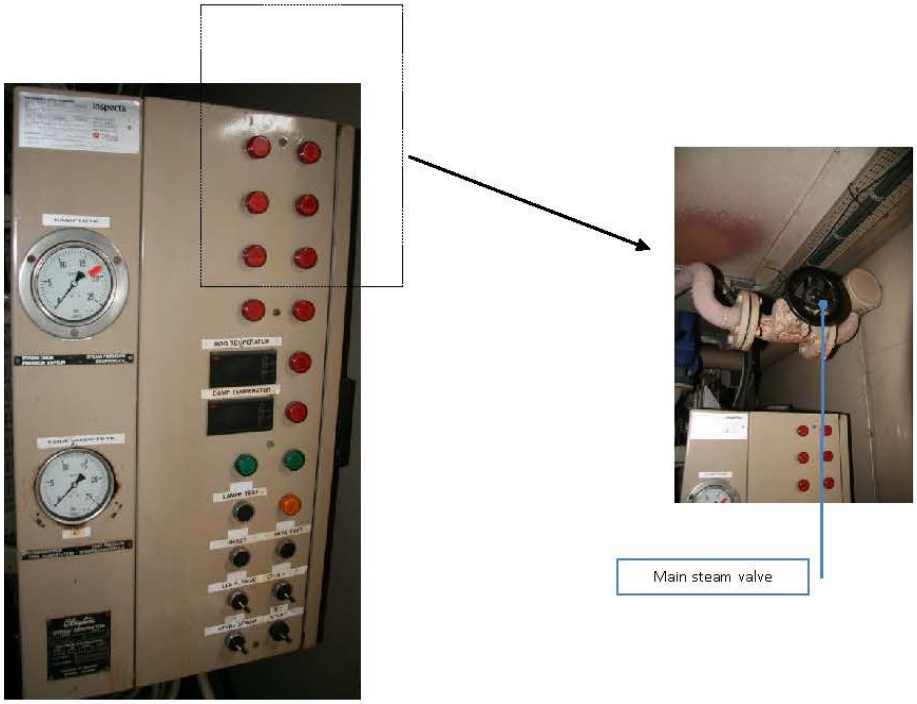


Figure 2.7.2/3-4: Location of main steam valve in steam container.

2.8. NITROGEN GENERATOR

2.8.1. SHIPBOARD INSTALLATION

In a ship board mounted BAWAT installation the required nitrogen flow will either be supplied from an already installed nitrogen generator system used for tank blanketing or from a dedicated BAWAT System installation.

Nitrogen for marine applications is for the main part produced either by the Membrane Technology or by the Pressure Swing Adsorption (PSA) Technology.

2.8.2. LAND-BASED TEST INSTALLATION

In the land-based test set-up a PSA generator from Gazcon with a capacity of 21 Nm^3/h is installed. The nitrogen flow rate necessary for the upcoming tests will be approx. 12 m^3/h. (See **Appendix 5.5** for specifications.)

The purity of the nitrogen is dependent on the flow rate and at 18 m^3/h the purity will - according to the manufacturer's specifications - be 99.7% N_2, the balance being argon and O_2. The oxygen concentration in the nitrogen determines the minimum obtainable dissolved oxygen level in the treated water. In shipboard installations the oxygen content can vary from 0.01 % to 2.00 % oxygen depending on the actual nitrogen flow.

In order to run the tests under the most challenging conditions oxygen in the form of compressed atmospheric air will be added to the nitrogen stream. The actual oxygen content of max- 2 % will measured shortly before injection into the water piping.

Figure 2.8.2/1-3
Nitrogen generator

Figure 2.8.3/4
Nitrogen injection

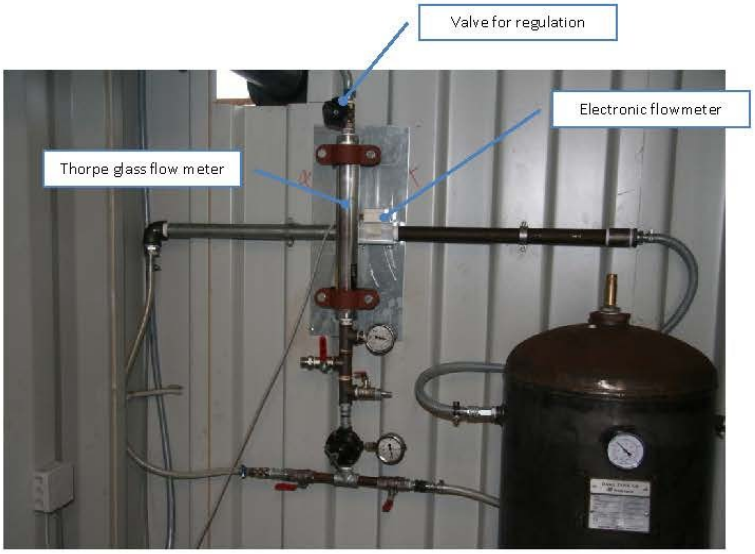


Figure 2.8.3/5
Nitrogen flow regulation

2.9. PIPING AND VALVES

2.9.1. SHIPBOARD INSTALLATION

In a ship board BAWAT installation the ballast water pipes will be used on the suction side of the recirculation pump

2.9.2. LAND-BASED TEST INSTALLATION

In the land-based test set-up suction side pipes are 5" PE pipes and pressure side pipes are 4" PE pipes apart from high temperature pipes between the regeneration and the heating sections of the pasteurizing unit, where the pipes are made of steel.

All valves are manually operated butterfly-valves.

A coarse strainer (1 mm openings) is placed on the pressure side of the pump to withhold welding debris, etc. originating from the assembly of the piping. The sieve is removed again before operation of the system.

2.10. CONTROL AND MONITORING CENTRE AND SENSOR PLACEMENTS

2.10.1. SHIPBOARD INSTALLATION

In a ship board BAWAT installation all control, monitoring and data logging functions in the BAWAT System will handled by a Control and Monitoring Centre (CMC) most likely placed with the ship's ballasting system controls and most likely interfaced with this system. Apart from the basic functionality of controlling the BAWAT process in one ballast water tank the shipboard CMC will among other routines have preprogrammed routines for running the entire treatment process in all tanks automatically switching from one tank to the next when treatment in the first tank has been completed.

2.10.2. LAND-BASED TEST INSTALLATION

In the land-based test set-up a prototype of the coming CMC is applied, however, only containing features relevant to the land-based test set-up. The CMC is basically identical to the CMC used in the 1:10 tank tests (See **Appendix 5.12**: BAWAT Document 2012.007 entitled "1:10 Test Tank Description & Standard Operating Procedures") modified to control the equipment applied in general and to log temperature data, also.

The CMC is built around SCADA (**S**upervisory **C**ontrol **A**nd **D**ata **A**cquisition) equipment and software supplied by MJK Automation A/S.

The CMC consists of

- Datalogger and software: (Specifications in **Appendix 5.9**)
  - Connect base (MJK)
  - MJK Monitors
  - IGSS (Interactive Graphic SCADA System) software (7-Technologies)
- Switches, automatic fuses, relays, etc.
- The main pump is running at max speed, but the speed of the booster pump can be regulated by a frequency converter,

and receives data from the following sensors:

- Dissolved oxygen: (Specifications in **Appendix 5.6**)
  - SuSix/Oxix converter (MJK)
  - Oxix sensors
    - Three sensors are placed in tank C2 one in each vertical segment (See figure 3.1.9/1) of the tank (DO 1, DO 2 and DO 3)
    - A fourth sensor (DO 0) is placed in the water flow just before the main recirculation pump thus in effect measuring the dissolved oxygen content at the suction points at the top of the tank.
- Oxygen sensor : (Specifications in **Appendix5.14**)
- Pressure: (Specifications in **Appendix 5.7**)
  - Pressure transmitter (0-6 bar) (MJK)
    - The pressure sensor is placed after the main pump.
- Water flow: (Specifications in **Appendix 5.8**)
  - MagFlux 7200 Sensor DN32EN/PN40 (MJK)
  - MagFlux converter (MJK)
    - The water flow is measured just after the main recirculation pump.
- Temperature sensors
  - The temperature is measured
    - in all dissolved oxygen sensors (Only temperature in the DO 0 sensor is logged (Temp 3)),
    - at the outlet from the pasteurizing unit (Temp 1) and at the inlet and outlet of the holding section of the pasteurizing unit (Temp 2 and Temp 4, respectively.
    - The pasteurizing temperature, T_{Past}, is defined as (Temp 2+ Temp 4)/2.

- Nitrogen flow:
  - Two types of flow sensors are applied
    - A Thorpe type glass flow meter
    - An electronic flow meter the output of which is logged in the Connect Base (**Appendix 5.10**)

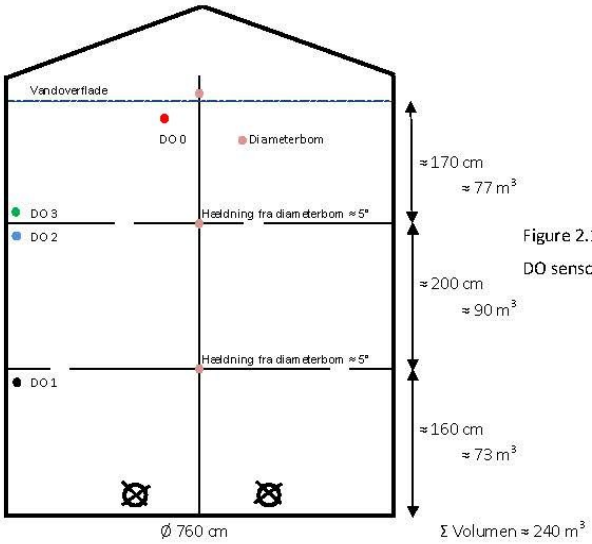


Figure 2.10.2/1
DO sensors in tank C2

2.10.3. Control and monitoring centre (CMC)

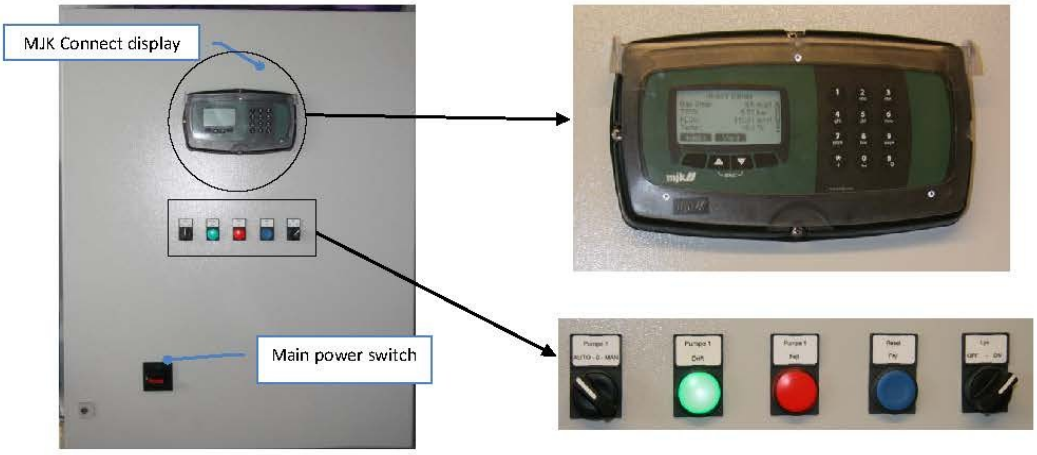


Figure 2.10.3/1-3 CMC Main panel

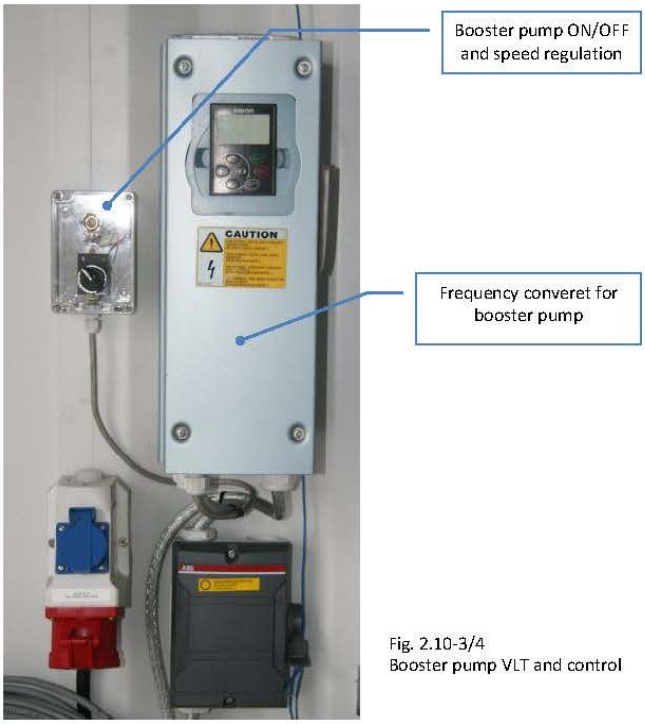


Fig. 2.10-3/4
Booster pump VLT and control

2.10.4. IGSS SCREEN

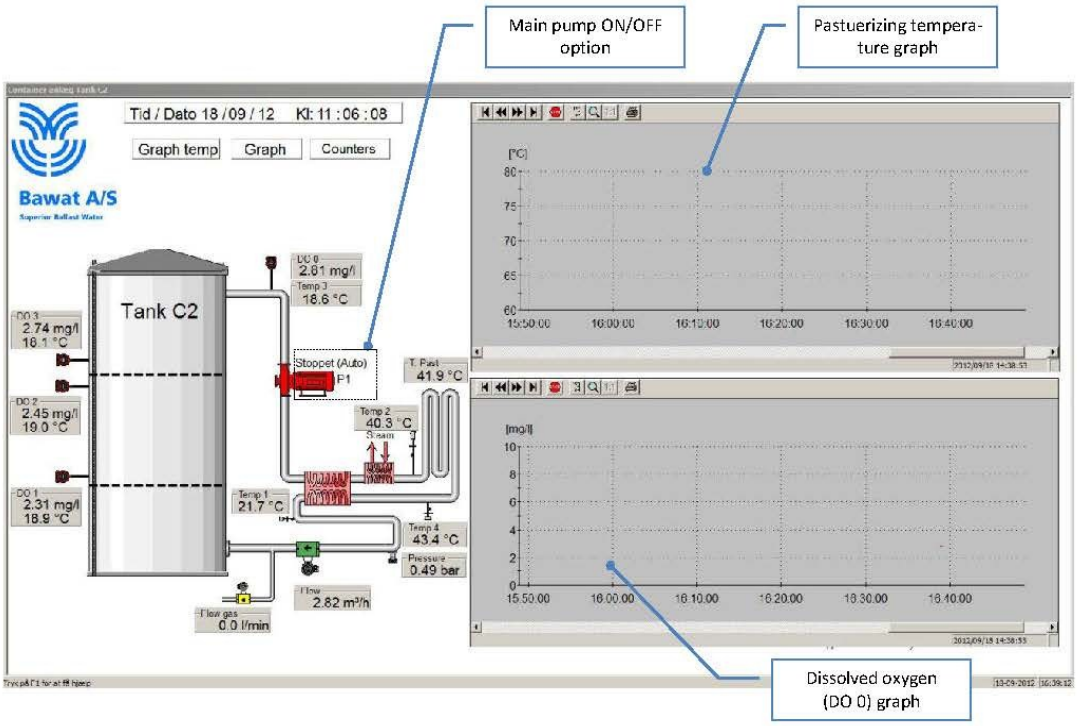


Figure 2.10.4/1: IGSS screen picture. Graphs not shown as system not in operation

2.11. PROCESS PARAMETERS

2.11.1. Main process parameters

The three main process parameters in the BAWAT System are:

1) The content of dissolved oxygen in the treated water = $\mathbf{DO_{treated}}$.

> The dexoygenation follows Henry's Law: "At a constant temperature, the amount of a given gas that dissolves in a given type and volume of liquid is directly proportional to the partial pressure of that gas in equilibrium with that liquid."
> Through the surface of the micro bubbles created by the injection of nitrogen under pressure into the water the nitrogen in the bubbles is exchanged with the oxygen dissolved in the water and thus reducing the dissolved oxygen content of the water. The level to which the dissolved oxygen can be dissolved is dependent on the oxygen content of the nitrogen gas injected.

2) The level of Pasteurization Units (PU) applied in the pasteurization process = $\mathbf{PU_{applied}}$.

> The destructive effect on micro-organisms of pasteurization is determined by the retention time and the temperature applied. It is calculated in terms of pasteurization units (PU) and is a measure for the microbiological effect of the heat treatment.
> It is calculated as follows:
> **PU = 'Retention time at temperature' * $1.393^{(Temperature - 60\,°C)}$**

3) The **ρ_{min}-factor.**

> For a given pump rate the ρ-factor tells how many times a water volume equal to the water volume in the ballast water tank has passed through the pump.
> ρ_{min} is defined as the minimum number of times the ballast tank volume must pumped through the pump to ensure that a minimum of 99.9% of the water elements has passed the pump and consequently also the pasteurizing unit.

Re 1. Deoxygenation level

In the land-based test the dissolved oxygen content in the test water will be reduced to 2.0 mg/L or less.

Further, in the land-based tests the oxygen level in the nitrogen flow will be kept at 2 %.

Re.2. Pasteurization

In the land-based test a pasteurization temperature of 72 °C and a retention time of not less than 1 min will be applied.

Re 3. The Recirculation Factor.

Since an important part of the annihilation process in the BAWAT System takes place outside the ballast tank during the treatment process, namely the pasteurization, it is important to ensure that essentially all part of the ballast water (99.9%) passes through the pasteurization unit.

If a "plug flow" could be established in the recirculation loop, the ballast water volume would need to be pumped through the pasteurizer one time only. However, due to the internal mixing of the water in the ballast water tank taking place during the process, more than one recirculation is required to ensure that all water volume elements are passing through the pasteurizer at least one time.

In general, a ballast tank is constructed as a number of parallel sections each consisting of a number compartments in series which in most tanks form an L-shaped volume stretching longitudinally. The ballast water during the BAWAT treatment, will be recirculated from the top of the tank and reintroduced at the bottom of the tank mixed with the nitrogen. The water then moves slowly up through the tank towards the top.

A mathematical model describing the water flow in typical ballast water tanks have been developed at Denmark's Technical University[1].The models show that the de-oxygenation of the water takes place very quickly in the lower compartment at the introduction of the nitrogen micro bubbles through the nozzles.

The de-oxygenated water then moves slowly from compartment to compartment and is agitated by the larger bubbles of nitrogen. These bubbles are rising through the tank primarily along the inside of the tank structure, generating a mixing of the water in each compartment facilitating that all water elements are moved around and mixed into the main flow passing upwards towards the top. The speed of the rising bubbles relative to the slow moving water is in the order of 4-500 times faster.

The mathematical models indicate that in a typical L-shaped ballast water tank a recirculation factor (ρ_{min}) of between 2.0 and 5.5 should ensure that at least 99.99% of the water has passes through the pasteurizer.

A series of pasteurizing tests with biological sampling in the 1:10 tank at DTU, BAWAT A/S have shown that a ρ_{min} factor of between 2.0 and 2.5 results in satisfactory reduction of zooplancton, phytoplancton and bacteria meeting the D2 criteria. (Please see **Appendix 5.10**)

In several tests it has further been shown, that a deoxygenation to below 2.0 mg/L will reduce the zooplankton content to well below the D2 criteria and there are strong indications that deoxygenation to this level results in a substantial reduction of the phytoplankton concentration as well. The remaining phytoplankton and the bacteria are killed by pasteurization.

Before deciding finally on which ρ_{min} factor will be used in the land-based tests in Hundested, a number of tests will be performed in the 250 m^3 tanks, partly with de-oxygenation only, and partly in a pilot test also involving analysis of the full spectre of zooplankton phytoplankton and bacteria.

Based on the mathematical model and the deoxygenation experiments mentioned, it has been decided to recirculate the water 4 times in the land-based tests in Hundested.

2.11.2. Water temperature in treated tank

As mentioned above the BAWAT system treatment process involves a recirculation of the water in the treatment tank through a pasteurizing unit. The ΔT (temperature increase) over the pasteurizing unit is 4 – 5 °C. This will increase the temperature in the treated tank by approximately the ΔT times the number of water recirculations during the treatment. The actual temperature increase will depend on the cooling conditions (temperature, wind, etc.) at the time of treatment. However, the temperature in the control tank will only change very slightly again depending on the actual temperature and wind condition at the time of the treatment.

[1] Jakob K. Huusom and John Villadsen, Department of Chemical and Biochemical Engineering, DTU: Treatment of Ballast Tank Water in different scales – modelling of the ballast tank, and experimental validation of the model. (Included as **Appendix 5.13**)

The differences in after-treatment water temperatures between the treatment tank and the control tank can be considered an experimental artifact, as the temperature increase in a ship's BWT after treatment are expected to be very slight due to the efficient heat exchange through the ship's sides.

In order to mitigate the consequences of this test artifact a cooling circuit has been establish in the land based test set-up in accordance with Figure 2.1/3. The plate heat exchanger utilized as the regeneration section of the pasteurizer unit is after treatment connected as a cooling heat exchanger using harbor pool water to cool the treatment tank water in accordance with section 3.4.

The treated tank will be cooled to approximately 3 – 4 °C above the water temperature in the control tank. However, cooling will only take place if the water temperature in the treated tank is above 15 °C as below this temperature biological activity in both tanks will be low and more or less identical.

3. STANDARD OPERATING PROCEDURES

The Standard Operating Procedures implemented in the Land-based Test Series follow the principles of the SOPs implemented in the 1:10 tank test outlined in BAWAT Document 2012.007 entitled "1:10 Test Tank Description & Standard Operating Procedures" (**Appendix 5.12**), however, duly modified to reflect the installed equipment and interfaces to the DHI installations and the DHI sampling procedures to be followed.

For convenience the main routines are included below.

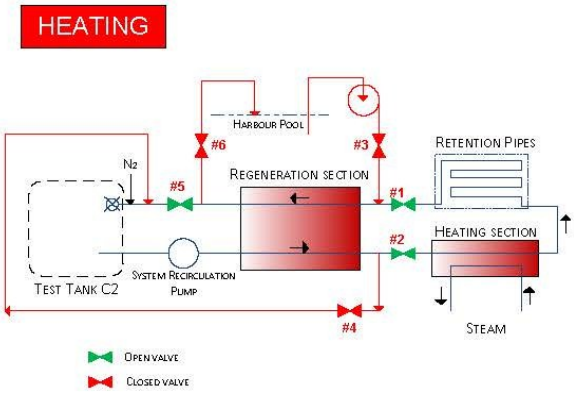
3.1. FILLING AND EMPYING OF TANKS

The tanks are filled and emptied according to the SOPs implemented by DHI and by DHI personnel.

3.2. SYSTEM START-UP

To start-up the system the following steps are required:

1) Valvepositions in the cooling circuit must be as follows:



2) The on-site diesel driven electric generator is turned on according to the SOPs implemented by DHI and by DHI personnel.
3) Main power and system on-off switches are turned to ON. **Figure 2.10.3/1**.
4) The laptop is connected to the CMC and the IGSS (Interactive Graphical SCADA System) program is opened on laptop. Figure 2.4.10/1 shows the screen picture.
5) The steam generator is turned on and adjusted to deliver the necessary steam volume in accordance with the Operational Manual supplied by Clayton, Inc. See **Appendix 5.2**.
6) The requested pasteurization temperature is entered into the keypad on the steam pressure regulation unit in accordance with the Operational Manual supplied by the manufacturer. See **Appendix5.2** and **Figure 2.7.2/2**.

7) When the required steam pressure is established the main steam valve is opened. The valve is located above the control panel in the steam generator container. **Figure 2.7.2/3-4**.

8) Pumps are switched on and regulated to the required flow on the CMC control box and the booster pump VLT. See **Figure 2.10.3/1-4.** Main pump can also be switched on via IGSS program – **figure 2.10.4/1.**

9) The main water flow valve is opened. See **figure 2.5.1/1**.

10) The nitrogen generator is turned on in accordance with the Operational Manual supplied by Gazcon A/S. See **Figures 2.8.2/1-3**.

11) The nitrogen injection valve is opened and nitrogen flow established by manual adjustment of the gas valve. See **Figure 2.8.3/5**.

3.3. SYSTEM SHUT-DOWN

To shut-down the system the following steps are required:

1) The steam generator is switched off in accordance with the Operational Manual supplied by Clayton, Inc. See **Appendix 5.2**

2) Main water flow valve is closed and the pumps are switched off. See **figures 2.5.1/1; 2.10.3/1-4; 2.10.4/1.**

3) Nitrogen injection valve is closed and nitrogen generator is switched off in accordance with the Operational Manual supplied by Clayton, Inc. See **Figures 2.8.3/5;2.8.2/1-3.**

4) Main power and system on-off switches are turned to OFF. **Figure 2.10.3/1.**

5) IGSS program is closed.

6) Data log file is copied to hard drive and USB stick.

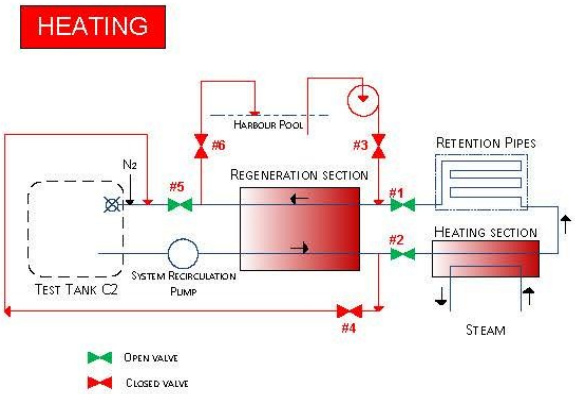
7) Laptop is disconnected.

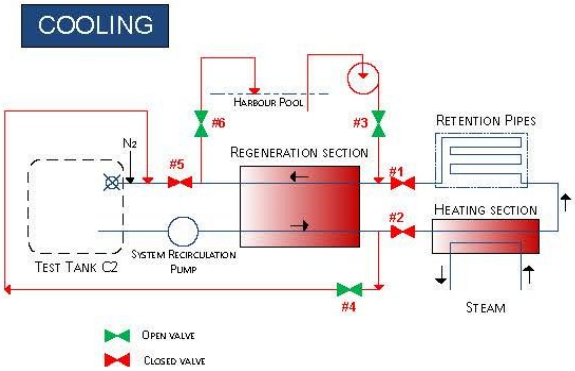
3.4. COOLING OF TREATED WATER

Steps described in section 3.3, 1) through 3) are carried out and the following procedure is followed:

1) Pump is lowered into harbor pool and connected to powersupply.

2) Valveposition are changed according to the following:





3) Harbour pump is switched on.
4) Temperatures in testtank are monitored on CMC and when the target temperature has been reached the harbor pump is switched off and valves #3 and #6 are closed.

3.5. MEASUREMENTS

3.5.1. WATER FLOW

Water flow data are recorded in the data logging system and can continuously be read on the IGSS co sole and on the MJK Connect display (Fig. 1.3.7/3).

3.5.2. PRESSURE

System water data are recorded in the data logging system and can continuously be read on the IGSS console and on the MJK Connect display (Fig. 1.3.7/3).

3.5.3. TEMPERATURES

Temperatures are recorded in the data logging system and can continuously be read on the IGSS console and on the MJK Connect display (Fig. 1.3.7/3).

3.5.4. DISSOLVED OXYGEN

Dissolved oxygen content in the water are recorded in the data logging system and can continuously be read on the IGSS console and on the MJK Connect display (Fig. 1.3.7/3).

3.5.5. GAS FLOW

The N_2 flow is are recorded in the data logging system and can continuously be read on the IGSS console and on the MJK Connect display (Fig. 1.3.7/3).

3.5.6. BIOLOGICAL SAMPLING AND MEASUREMENTS

Biological samples are collected according to relevant DHI SOPs.

3.6. DATA RECORDING AND PROCESSING

All process data are automatically recorded in the MJK Datalogging system:

1) Data points

   {Absolute time; Dissolved Oxygen at DO 0 [mg/L]; Dissolved Oxygen at DO 1 [mg/L]; Dissolved Oxygen at DO 2 [mg/L]; Dissolved Oxygen at DO 3 [mg/L]; Water Flow [m^3/h]; Pressure [bar]; Gas Flow [NL/min]; Temperature #1 [°C]; Temperature #2 [°C]; Temperature #3 [°C]; Temperature #4 [°C]}

   are collected every 30 seconds.

2) Selected, recorded data is continuously presented on screen by the IGSS software package.
3) The data are transferred into a Microsoft Excel spreadsheet for data processing.
4) The 'Raw data' and the subsequent Excel data processing files are stored (i) on the attached laptop, (ii) on a USB data storage stick, (iii) on a separate laptop and (iv) on a Drop-Box data storage facility.

Data are processed in Microsoft Excel and presented in graphical form. Figure 2.5 shows an example from the preliminary tests in the D2 test tank.

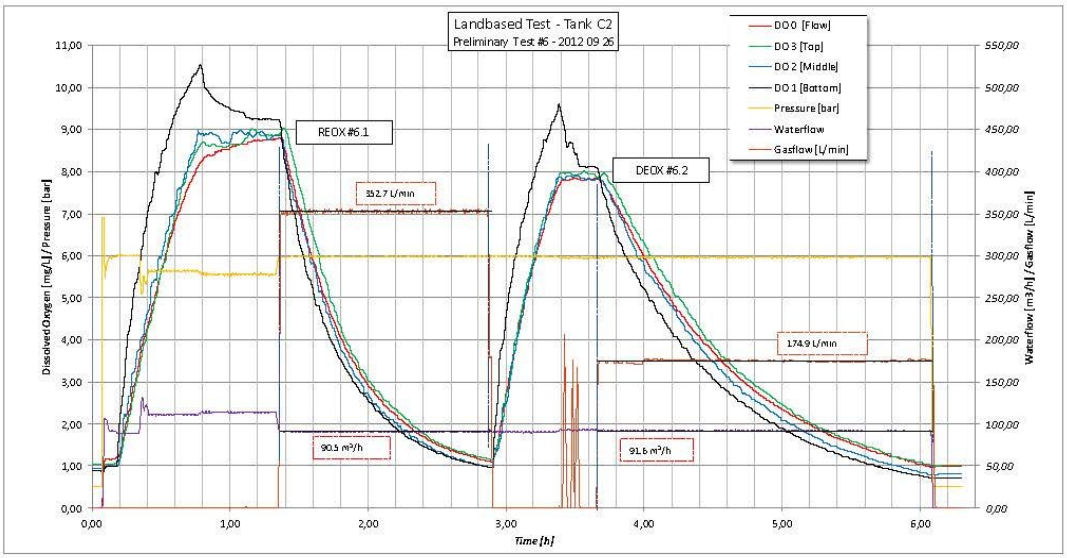


Figure 3.5: Example of graphic data presentation

4. EMERGENCY PROCEDURES

4.1. SHIPBOARD INSTALLATION

In shipboard BAWAT System installations existing equipment will part of the installations, e.g. the ballast pump and the nitrogen generator. For these the ship's emergency procedures will apply.

The proprietary BAWAT components to be installed will be equipped with emergency stops where appropriate and emergency procedures will be established.

It should be observed that ballast water tanks after treatment with the BAWAT System and after de-ballasting might contain a higher level of nitrogen than the content in 'normal' atmospheric air. Therefore in the procedures for entering a ballast water tank, special attention should be paid to ensure that after the normal and customary aeration procedure, the oxygen content is acceptable for entering.

As a side remark it should be kept in mind, that nitrogen in itself is slightly lighter than air. Therefore it will not pose the same problem as CO_2 , which might accumulate in the bottom of the tank, because its specific gravity is 50% higher than it is for air.

4.2. LAND-BASED TEST INSTALLATION

In the land-based test installation the following emergency procedures will apply:

4.2.1. STEAM GENERATOR

The steam generator is equipped with an emergency stop switch located as shown in figure 4.2.1/1.

In case of any malfunction of the steam generator, rupture of a steam pipe or connection in the steam generator container, in the 20' container with the pasteurizer or outside any of the containers the emergency switch must be activated and personnel evacuated from the vicinity of the system until the steam pressure has subsided.

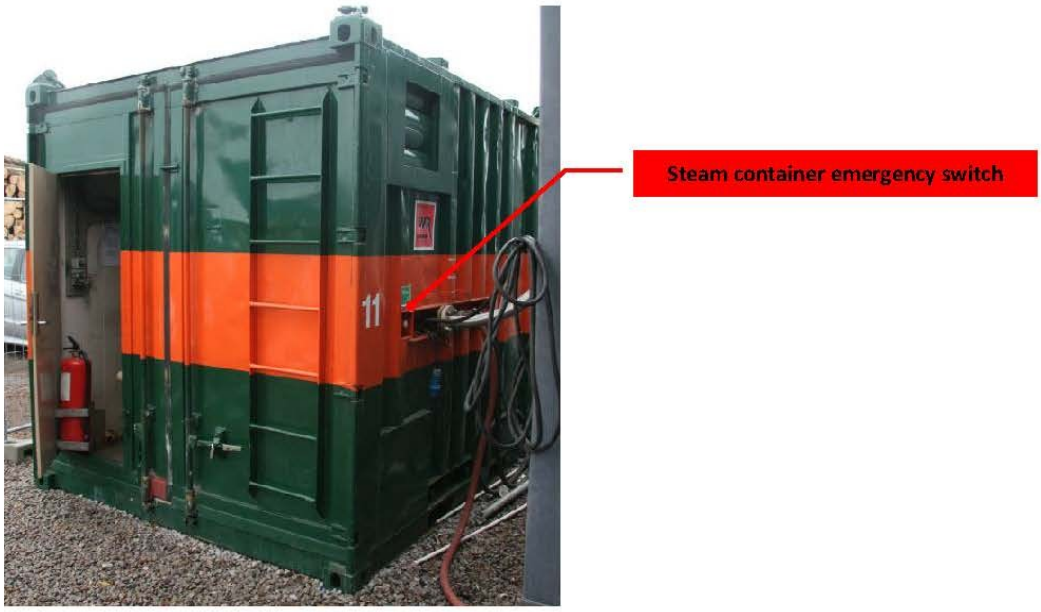


Figure 4.2.1/1: Location of steam generator emergency switch.

4.2.2. 20' CONTAINER

In case of escape of high pressure steam caused by a steam pipe rupture please refer to section 4.2.1 above.

The 20' container houses the nitrogen generator. In case of a generator malfunction there is a risk of increased nitrogen content in the air inside the container. Therefore, during operation of the generator at least one of the container doors must be fully open. Further, the feed-through openings of the various pipes through the container walls are constantly kept open to allow ventilation.

The compressor is equipped with an emergency switch located as shown in figure 4.2.2/1.

In case of malfunction of the nitrogen generator the emergency switch must be activated.

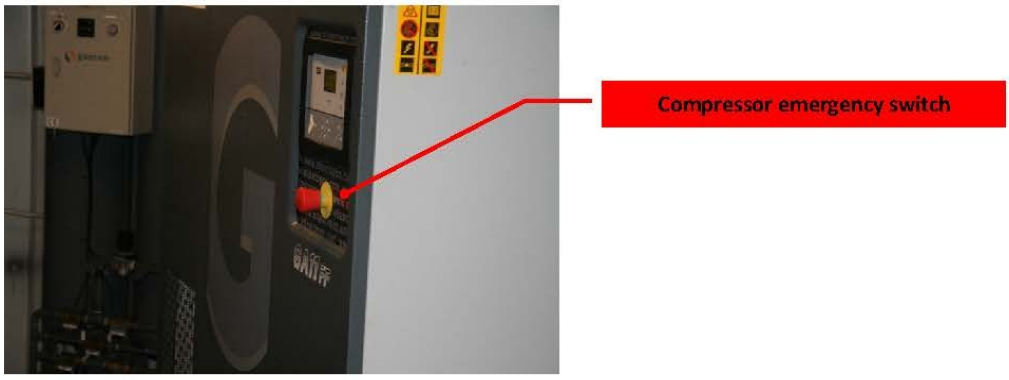


Figure 4.2.2/1: Location of compressor emergency switch.

4.2.3. 10' CONTAINER

The 10' container houses the BAWAT Control and Monitoring Centre (CMC) and the main recirculation pump.

The main fuse box with Residual Current Circuit Breakers is located outside on the back wall of the container – figure 4.2.3/1. In case of a malfunction in the pumps or the CMC that requires immediate power-down the power can be cut in the shown fuse box or on by turning the power switch to OFF on the front of the CMC unit inside the container - figure 4.2.3/2.

Figure 4.2.3/1: Main fuse box with Residual Current Circuit Breakers is located outside on the back wall of the 10' container.

5. APPENDICES

Appendices are available in digital form on a DVD or for download.

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5.2. STEAM GENERATOR SYSTEM
5.3. PASTEURIZER UNIT
5.4. IRON PUMPS CENTRIFUGAL PUMP
5.5. NITROGEN GENERATOR
5.6. DISSOLVED OXYGEN MEASUREMENT
5.7. PRESSURE MEASUREMENT
5.8. WATER FLOW MEASUREMENT
5.9. DATALOGGER AND SOFTWARE
5.10. NITROGEN FLOW INSTRUMENTATI
5.11. BIOLOGICAL TESTS (DHI)
5.12. BAWAT DOCUMENT 2012.007 ENTITLED "1:10 TEST TANK DESCRIPTION & STANDARD OPERATING PROCEDURES"
5.13. JAKOB K. HUUSOM AND JOHN VILLADSEN, DEPARTMENT OF CHEMICAL AND BIO-CHEMICAL ENGINEERING, DTU: TREATMENT OF BALLAST TANK WATER IN DIFFERENT SCALES – MODELLING OF THE BALLAST TANK, AND EXPERIMENTAL VALIDATION OF THE MODEL.
5.14. OXYGEN SENSOR

APPENDIX C

Overview of DHI SOPs

SUBJECT/SUBSUBJECT	DHI SOP NO.
ANALYTICAL METHOD DETERMINATION OF VIABLE ORGANISMS ≥50 µm	30/1700
ANALYTICAL METHOD DETERMINATION OF VIABLE ORGANISMS ≥10 µm AND < 50 µm	30/1701
ANALYTICAL METHOD DETERMINATION OF PRIMARY PRODUCTION OF MICROALGAE	30/1702
ANALYTICAL METHOD DETERMINATION OF VIABLE ALGAE BY RE-GROWTH ASSAY	30/1704
MICROBIOLOGICAL TESTS DETERMINATION OF TOTAL NUMBER OF BACTERIA BY EPIFLUORESCENCE MICROSCOPY	30/1705
MICROBIOLOGICAL TESTS DETERMINATION OF HETEROTROPHIC PLATE COUNT	30/1706
MICROBIOLOGICAL TESTS DETERMINATION OF *VIBRIO CHOLERAE* IN WATER	30/1707
MICROBIOLOGICAL TESTS DETERMINATION OF TOTAL COLIFORM, E.COLI AND ENTEROCOCCI BY Colilert*-18, Enterolert-E or Bio-Rad MUG/MUD kit	30/1708
MEASUREMENT METHOD TRO MEASUREMENT IN WATER	30/1732
HARVESTING, CULTURING AND ADDITION OF ORGANISMS	30/1734
COLLECTION OF SEAWATER	30/1735
COLLECTION OF FRESH WATER	30/1736
CRITERIA FOR TEST WATER ADDITION OF DOC, POC, MM AND BRINE	30/1737
SAMPLING PREPARATION, SUBSAMPLING AND TRANSPORTATION OF SAMPLES	30/1738
DATABASE SAMPLES, LABELS AND DATA SHEETS	30/1750
OPERATION OF THE DHI MTEF	30/1762
CLEANING RETENTION TANKS; PIPINGS AND OTHER EQUIPMENT AT TEST SITE	30/1763
MEASUREMENT METHOD ON-LINE MONITORING OF PRESSURE, TEMPERATURE, FLOW RATES AND QUALITY PARAMETERS AT TEST SITE	30/1764
MEASUREMENT METHOD FLUORESCENCE	30/1765
MEASUREMENT METHOD TURBIDITY	30/1766
DHI MTEF HEALTH AND SAFETY	30/1767
MEASUREMENT METHOD DETERMINATION OF TSS	30/1768
MEASUREMENT METHOD DETERMINATION OF DOC AND POC	30/1769
MEASUREMENT METHOD DETERMINATION OF TRANSMITTANCE	30/1770

Quality assurance project plan Version 2

Performance evaluation in land-based test facility of BAWAT ballast water management system

BAWAT

Quality assurance project plan

March 2013

Performance evaluation in land-based test facility of BAWAT ballast water management system

Prepared for	**BAWAT**
Represented by	**Mr Kim Diederichsen**

DHI land-based test facility in Hundested

This report has been prepared under the DHI Business Management System certified by DNV and specifically for ballast water management system testing certified by Lloyd's Register	
Quality Management	BWMS Testing
ISO 9001	IMO Resolution MEPC.174(58) Annex part 2
Quality Management System certified according to DS/EN ISO 9001 by Det Norske Veritas, Business Assurance, Danmark A/S	Lloyd's Register

Project No	11812682
Classification	Confidential

Author	Morten Bjergstrøm	

QC	Torben Madsen	

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B Description of the ballast water management system as provided by the client
C Overview of DHI SOPs

Abbreviations

Abbreviation	Description
BE	Biological efficacy
BWMS	Ballast water management system
CFU	Colony forming units
CMFDA	Chloromethylfluorescein diacetate
DNV	Det Norske Veritas
DO	Dissolved oxygen
DOC	Dissolved organic carbon
DQI	Data quality indicator
FDA	Fluorescein diacetate
IMO	International Maritime Organization
kVA	Kilovolt-ampere
MEPC	Marine Environment Protection Committee
POC	Particulate organic carbon
PSU	Practical salinity units
QA	Quality assurance
QAPP	Quality assurance project plan
QC	Quality control
QMP	Quality management plan
SOP	Standard operating procedure
TRO	Total residual oxidants
TSS	Total suspended solids
UV-T	UV transmittance
WET	Whole effluent toxicity

1 Project description and treatment performance objectives

1.1 Background and objectives

For an application for final approval, the IMO International Convention for the Control and Management of Ships' Ballast Water and Sediments /1/ requires a performance evaluation of ballast water management systems (BWMS) according to the principles laid down in Resolution MEPC.174(58) /2/, generally referred to as IMO G8 guidelines, and, for systems that make use of active substances, also Resolution MEPC.169(57) /3/, generally referred to as IMO G9 guidelines. The purpose of the performance evaluation is to assure that BWMS approved by administrations are capable of meeting the ballast water performance standard in Regulation D-2 /1/, also known as the IMO D-2 standard, in land-based and shipboard evaluations and do not cause unacceptable harm to the vessel, crew, environment or public health.

The objective of the project is to conduct a performance evaluation of the BWMS in a land-based test facility with the aim to meet the testing requirements in Resolution MEPC.174(58) /2/.

1.2 Client and ballast water management system

The client requesting the performance evaluation is:

BAWAT A/S
Diplomvej 381
DK-2800 Kongens Lyngby

The client is the manufacturer of the BAWAT BWMS.

1.3 Classification society

The classification society appointed by the client for inspection and certification of the project is:

Det Norske Veritas A/S (DNV)
Mariesvej 30
NO-1363 Høvik
Norway

1.4 Testing laboratory

The project is conducted by DHI Denmark (www.dhigroup.com) with the following facilities:

Mailing address:

DHI
Agern Allé 5
DK-2970 Hørsholm
Denmark
Att. Torben Madsen

DHI Maritime Technology Evaluation Facility
Færgevejen
DK-3390 Hundested
Denmark

DHI Denmark and its facilities are described in detail in Chapter 3.

The project manager for this project is Morten Bjergstrøm, M.Sc.

2 Project organisation and personnel responsibilities

The project organisation is illustrated in Figure 2.1.

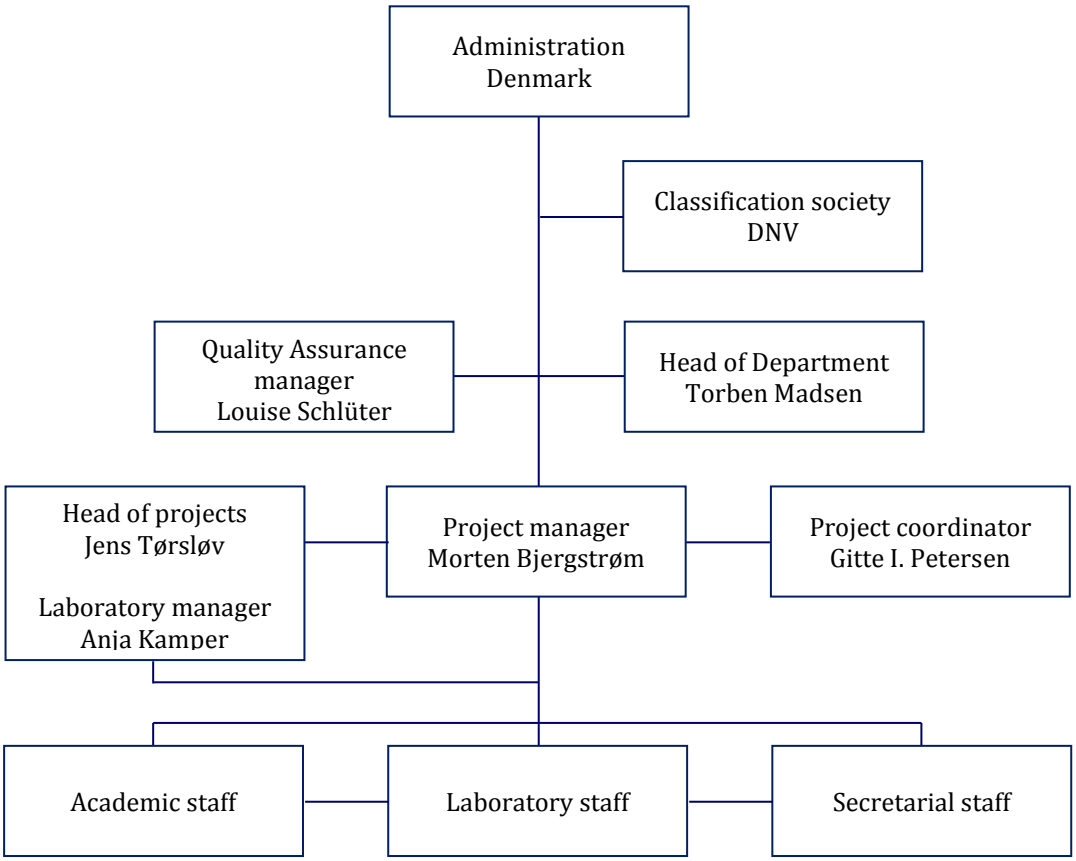

Figure 2.1 The DHI project organisation

2.1 Quality assurance

Senior biologist Louise Schlüter (Ph.D.) is assigned by DHI's Quality Assurance (QA) Unit as internal auditor (see Chapter 11). This includes the following tasks:

- Drafting of a plan for quality assurance
- Monitoring of compliance with the quality management plan (QMP), the quality assurance project plan (QAPP) and the standard operating procedures (SOPs) by audit including the project manager and the laboratory staff
- Monitoring compliance with the appropriate guidelines by audit including the project manager
- Verification of the presence of applicable staff training records
- Drafting of audit reports and verification that audit responses are appropriate and that corrective action has been implemented effectively
- Verification that the final product complies with DHIs standards for QA (Chapter 11) and, particularly, the QMP, the QAPP and the guidelines and standards.

2.2 Management and quality control

Head of department Torben Madsen (Ph.D.) is quality supervisor for all projects and has the overall responsibility for the services related to performance evaluation of BWMS provided by DHI Denmark. This includes the following tasks:

- Member of the Ballast Water Test Facility Board for DHI Ballast Water Centre, a coordinating structure between DHI Denmark and DHI Singapore
- Overall responsibility for the liaison and contractual relations between DHI and Lloyds Register EMEA (certification of test facility), between DHI and the Danish Accreditation and Metrology Fund, DANAK (accreditation of analyses), and between DHI and the Independent Laboratory (subcontractor agreement)
- Negotiation of contracts with clients
- Appointment of project managers and staff responsible for quality control (QC) of individual data (data-level QC) and maintenance of staff experience records (allocation of project managers for specific projects is the responsibility of the head of projects)
- Maintenance of the QMP /4/ with updated versions as appropriate
- Quality control of the QAPP, SOPs and all project proposals, deliverables and reports
- Documentation in relation to
    - Staff training and experience
    - Facilities and their maintenance
    - Records of complaints

2.3 Project coordinator

Business area manager Gitte I. Petersen (Ph.D.) is responsible for the coordination, timely execution and the overall scientific quality of the services. This includes the following tasks:

- Business development and marketing
- Contact and dialogue with Lloyds Register EMEA prior to inspections and for management of the actions and documentation, in collaboration with the laboratory manager, as required to comply with the Certificate of Compliance issued by Lloyds Register EMEA
- Contact and dialogue with the Independent Laboratory prior to inspections and for management of the actions and documentation, in collaboration with the laboratory manager, as required to comply with the agreement between DHI and the Independent Laboratory
- Coordination of the services to ensure optimal logistics at the test facility, including decisions related to the practical installation of clients and their technology and timing of tests
- Maintenance of the test facility including routine technical maintenance and dialogue with the head of department in relation to investments and maintenance expenses
- Instruction of staff with responsibility for specific tasks such as test facility technical operations and production of test water
- Principal scientific expert with responsibility for the overall scientific quality of the services, including compliance with official guidelines, standards, protocols and requirements from classification societies and Independent Laboratories; this implies input to the QAPP and the Test Plan, revisions and implementation of SOPs, and contributions to data interpretation and reporting in collaboration with the project manager
- Participation in discussions with the classification society or the Independent Laboratory on important matters, particularly draft and final reports, together with the project manager

2.4 Staffing, planning and project execution

Head of projects Jens Tørsløv (Ph.D.) has the overall responsibility for allocation of staff, planning and project execution in coordination with the business area manager or the project manager as appropriate.

Laboratory manager Anja Kamper (M.Sc.) allocates laboratory technicians for a specific project as part of the laboratory capacity planning by allocation of responsibility from the head of projects. Furthermore, the laboratory manager appoints one or more test co-ordinators among the laboratory technicians or the academic staff for on-site co-ordination of land-based test cycles.

The laboratory manager is responsible for the contact and dialogue with DANAK prior to inspections and for management of the actions and documentation as required in order to comply with the ISO 17025 accreditation /5/.

2.5 Project management

The project manager is responsible for the management and efficient performance of the project in accordance with the contract between the client and DHI, with the QMP and with the QAPP.

The project manager's tasks include:

- Organisation and management of the project
- Meetings and other communication with the client to ensure that all necessary information is available in due time
- Preparation of the draft and final QAPP with detailed description of the project, including time schedule of activities and deliverables; the QAPP shall be made available to all staff participating in the project
- Facilitation of the process for comments and responses to the draft QAPP in dialogue with the client and the classification society
- Preparation of potential amendments and deviations to the QAPP
- Communication of the project time schedule to the classification society to enable external audit
- Participation in discussions with the classification society on important matters, particularly draft and final reports, together with the project coordinator
- Co-ordination and dialogue with the laboratory manager in relation to the practical organisation of work involving laboratory technicians; the project manager shall in due time inform the laboratory manager on the types of tests and the required capacity to enable laboratory capacity planning
- Contracts with subcontractors as appropriate for meeting the project deliverables (e.g. chemical analytical laboratory)
- Approval of initiation of the test cycles and interruption of test cycles, e.g. in case of irregularity
- Preparation of reports

2.6 Academic, laboratory and secretarial staff

The tasks of the academic, the laboratory and the secretarial staff include:

- Maintenance of materials and equipment
- Test facility technical operations
- Test co-ordinator function, i.e. co-ordination and keeping of timely records of the activities at the test facility during land-based tests
- Production of test water and monitoring of test water quality
- Sampling at the test facility
- Analysis and data processing, including data-level QC
- Contributions to test reports
- Archiving of documents and raw data
- Contributions to QAPPs and SOPs

2.7 Client

The tasks of the representative of the client include:

- Signing a Contract with DHI for the BWMS performance evaluation project
- Project management of the client's activities in the project, including the liaison with DHI and decisions in relation to the testing
- Review and comments to the draft QAPP and approval of the final QAPP
- Collaboration with DHI to establish all necessary arrangements prior to initiation of the test
- Review and comments to draft test reports
- Dismantling and removal of the BWMS from the test facility after ended testing

3 Description of testing laboratory

3.1 DHI Denmark

DHI is an independent, international consulting and research organisation established in Denmark and today represented in all regions of the world with a total of more than 1,000 employees. Our objectives are to advance technological development, governance and competence in the fields of water, environment and health. DHI works with governmental agencies and authorities, contractors, consultants and numerous industries.

DHI has no involvement, intellectual or financial, in the mechanics, design or marketing of the products and technologies that are being evaluated. To ensure that DHI's tests are uncompromised by any real or perceived individual or team bias relative to test outcomes, DHI's test activities are subject to rigorous quality assurance (QA), quality control (QC) and documentation.

DHI's quality management system is certified according to ISO 9001 by DNV (Det Norske Veritas). The certification is facilitated by the implementation of the DHI Business Management System (see Chapter 11).

3.2 DHI Environmental Laboratory

DHI's Environmental Laboratory has an accreditation according to ISO 17025 /5/, including ecotoxicological studies and analyses related to the performance evaluation of BWMS. Furthermore, the laboratory is authorized to carry out ecotoxicological studies in compliance with the OECD Principles of Good Laboratory Practice (GLP) /6/.

DHI's Environmental Laboratory and staff normally analyse all samples collected during the performance evaluation of BWMS. If required, specialized chemical analyses of, e.g., active substances or disinfection by-products, are conducted by a subcontractor identified in the section on Subcontractors.

3.3 DHI Maritime Technology Evaluation Facility

DHI holds a Certificate of Compliance issued by Lloyd's Register EMEA for the performance of land-based and shipboard testing of BWMS (Appendix A).

The travel time from the DHI Maritime Technology Evaluation Facility (hereafter the 'test facility') to the DHI Environmental Laboratory is approx. 50 min, which enables analysis or treatment of the samples within 6 hours.

The test facility is used to conduct biological evaluations of maritime technologies. The test facility is covered by the International Safety Port System (ISPS). Hundested Harbour is registered at IMO's website (Port facilities) under Port ID No. 266076DKHUN, Port facility 1651.

The test facility includes seven cylindrical tanks constructed in galvanized steel and coated with a non-toxic top coating:

- One open 750-m^3 source tank, Tank D in Figure 3.1. The source tank is equipped with a propeller, which creates a slow circulation in order to maintain the homogeneity of the test water. A bridge across the top of the source tank is established for monitoring the homogeneity.
- Six closed 250-m^3 retention tanks, Tanks A1, B1, C1, A2, B2 and C2 in Figure 3.1. Tanks A1 and A2 are also described as 'control tanks' and are used for untreated test water. Tanks B1, C1, B2 and C2 are retention tanks for treated test water. Each of the six retention tanks is equipped with a submersible agitator (with three-blade propeller), to create a slow circulation in order to maintain homogeneity of the test water.

The piping connecting source tank, control tanks, retention tanks, pump and BWMS is made of polyethylene. The diameters are 315 mm and 350 mm for the piping connecting the A1, B1 and C1 tanks and 400 mm and 500 mm for the piping connecting the A2, B2 and C2 tanks.

The piping system connecting the source tank and the retention tanks is equipped with sampling ports. The sampling ports are equipped with the following sample outlets:

1. Sample outlet for ≥1-m^3 samples (to be used for analysis of organisms ≥50 µm)
2. Sample outlet for ≥10-L samples (to be used for analysis of organisms ≥50 µm and organisms ≥10 to <50 µm)
3. Sample outlet for microbiology samples
4. Sample outlet for samples for analysis of dissolved organic carbon (DOC), particulate organic carbon (POC), total suspended solids (TSS) and transmittance

The test facility is equipped with sensors for automatic logging of flow, pressure, water levels, temperature, dissolved oxygen, pH, salinity and turbidity.

The test facility includes a main pump with a flow performance of 250-500 m^3/hour. By use of a harbour piping, this pump can be used to provide a continuous flow of brackish water directly from the harbour to the BWMS with a capacity of up to approx. 300 m^3/hour. Furthermore, the test facility includes electrical generator power supply up to 150 kVA.

If needed to fulfil the test water quality requirements, appropriate volumes of cultivated organisms can be added to the source tank by an auxiliary pump.

The exact configuration of the test facility piping and equipment may be subject to minor changes.

The procedures, guidelines or characteristics for analyses, operations or tests performed in the DHI Environmental Laboratory, at the test facility or on board a vessel are described in SOPs.

For this specific test, the retention tank C2 was modified with a central tower and tarpaulins to create appropriate barriers. The tarpaulins are fixed to the central tower and the wall of the retentions tank by use of wires.

The detailed modifications are illustrated in Figures 3.2-3.4.

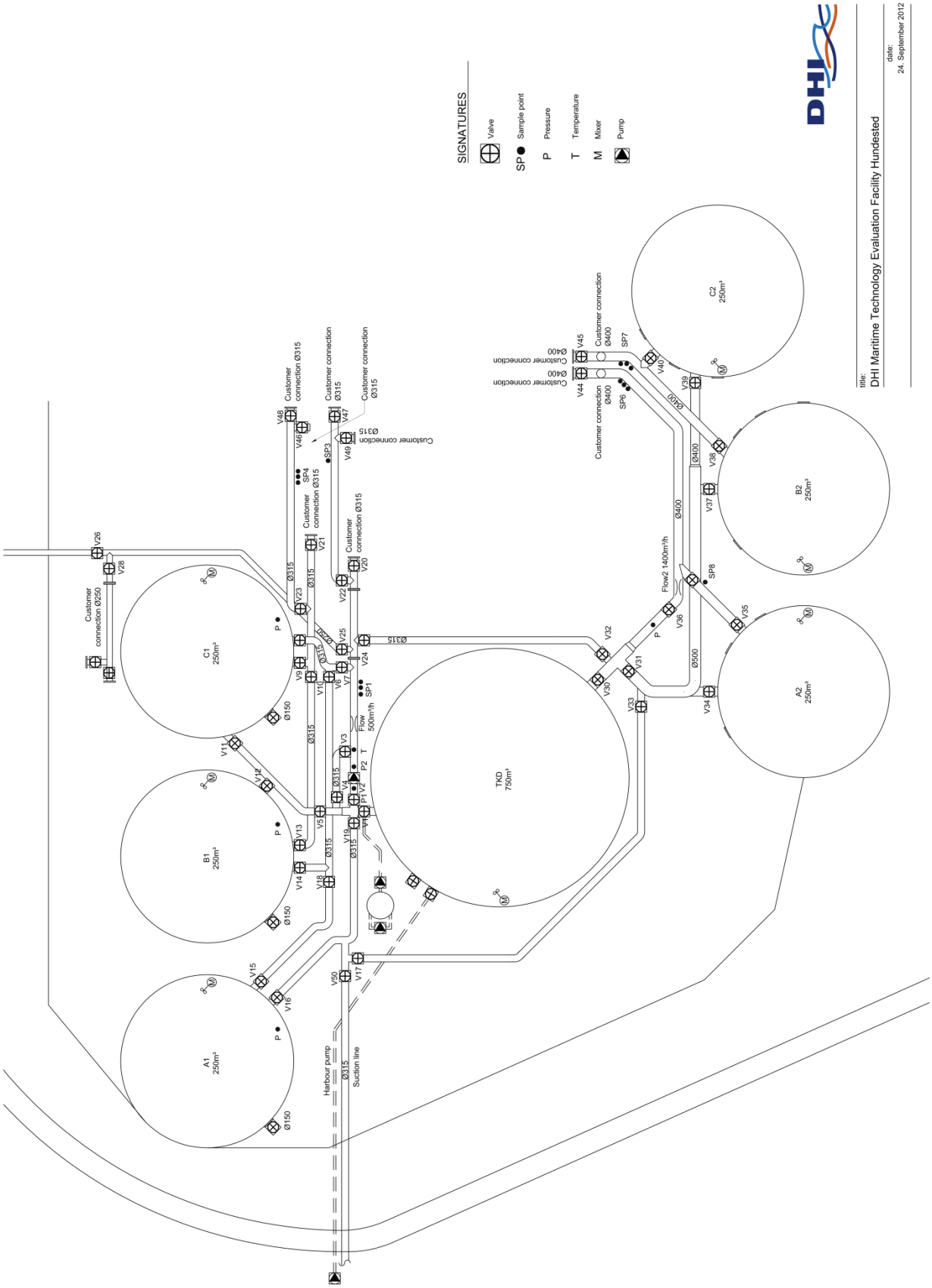

Figure 3.1 DHI Maritime Technology Evaluation Facility, Hundested, Denmark

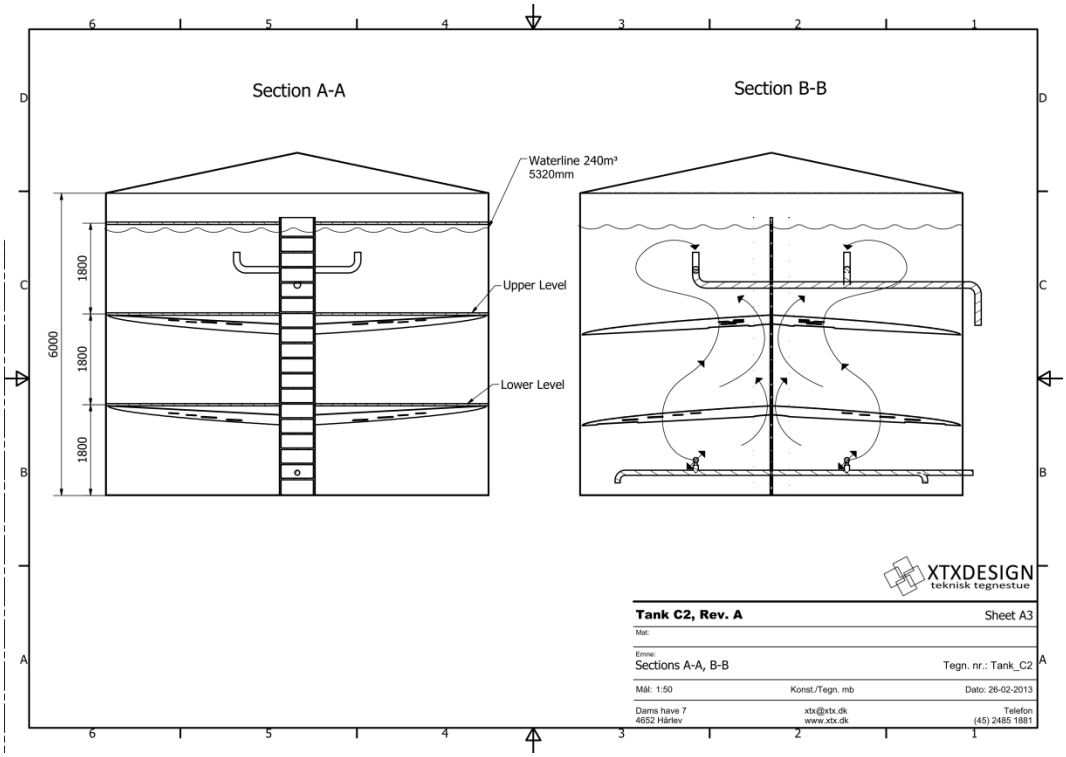

Figure 3.2 Cross sections of retention tank modifications

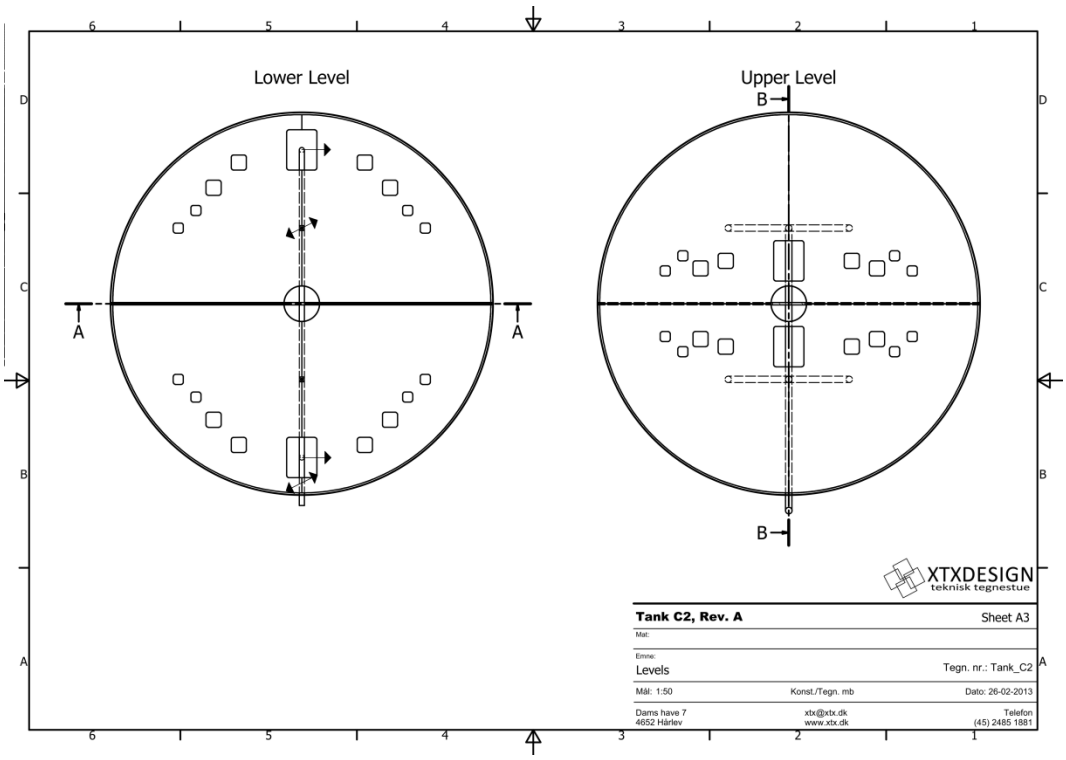

Figure 3.3 Tarpaulin design

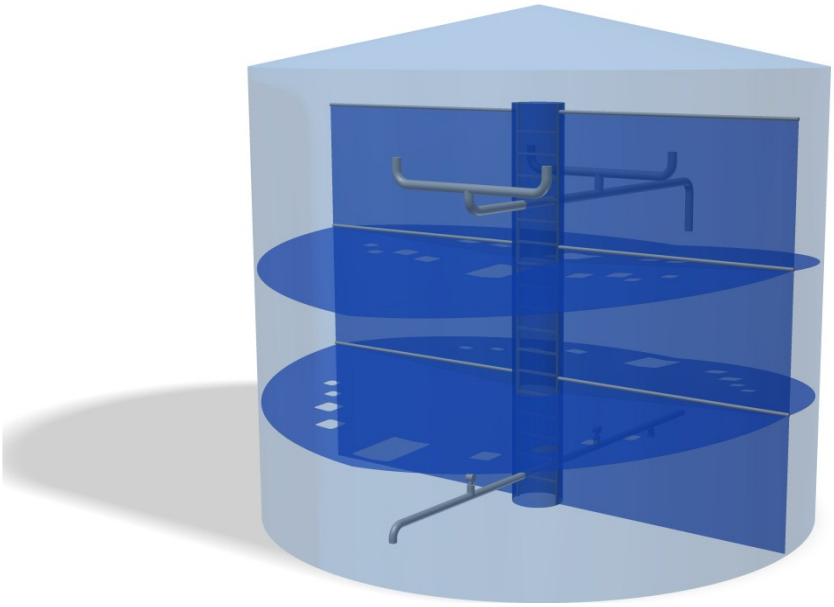

Figure 3.4 3D-view of retention tank modifications

3.4 Subcontractors

Statens Serum Institut
Artillerivej 5
DK-2300 København S

For verification of *Vibrio cholerae* according to DHI SOP 30/1707.

4 Description of ballast water management system

The description of the BWMS as provided by the client is enclosed in Appendix B.

5 Experimental design

5.1 Installation and operation of the BWMS

The BWMS shall be ready to enter the performance evaluation. Prior to the start of the performance evaluation of the BWMS, it is the client's responsibility to have met all requirements for initiation of testing set forth by the classification society appointed by the client.

The client is expected to deliver the BWMS to the test facility in due time before the initiation of the performance evaluation (see chapter on Time schedule). The BWMS shall be delivered in a container, which can protect the equipment, and installed in accordance with the directions of DHI.

The BWMS will be operated by the client during all test cycles.

5.2 Water types applied in the land-based test

The present land-based test with the BAWAT BWMS will be conducted with the following water types:

- Fresh water (salinity <3 PSU)
- Brackish water (salinity 3-32 PSU)
- Marine water (salinity > 32 PSU)

The land-based test will include three (3) sets of biological efficacy (BE) test cycles, each consisting of five (5) replicate BE test cycles with duration of at least five (5) days. Each set of BE test cycles will be conducted with test water representing one salinity range.

5.3 Biological efficacy verification testing

5.3.1 BWMS treatment process

The BE test cycles will be conducted by use of the source tank (Tank D), control tank (Tank A2) and one retention tank per test cycle (Tank C2) (Figure 3.1).

In the BWMS, the treatment of the test water will include the following steps (for definition and characterisation of test water, see Section 6.1):

1. A fraction of the test water (200-250 m^3) contained in the source tank will be transferred to the retention tank by pumping and treated by the BWMS in-tank*
2. Another fraction of the same test water (200-250 m^3) will be pumped directly into the control tank without passing the BWMS (control water). The control water serves as a control of BWMS performance*
3. Piping system and sample ports will be cleaned (DHI SOP 30/1763)

* The control and retention tanks may be filled simultaneously.

During ballasting, the flow, pressure, temperature, dissolved oxygen, pH, salinity, turbidity and water levels in the tanks will be recorded automatically (DHI SOP 30/1764).

Samples will be collected before treatment by use of relevant inlet sample ports. Sampling will be initiated when the flow rate has reached steady-state conditions, i.e. up to 5 minutes from start of operation (DHI SOPs 30/1738 and 30/1762). Samples will be labelled according to procedures described in DHI SOP 30/1750.

5.3.2 Storage of treated and untreated test water

Following the treatment of the test water with the BWMS, the treated water will be stored in the retention tank for at least five days ± 4 hours. The same storage time will be applied for the control water.

5.3.3 Discharge of test water

1. Treated water contained in the retention tank will be discharged into the harbour (treated discharge water)
2. Control water contained in the control tank will be discharged into the harbour (control discharge water)
3. The retention tanks, piping system and sample ports will be cleaned (DHI SOP 30/1763)

During de-ballasting, the flow, pressure, water temperature, dissolved oxygen, pH, salinity, turbidity and water levels in the tanks will be recorded automatically (DHI SOP 30/1764).

Samples of the treated discharge water will be collected by use of the sampling port on the BWMS discharge line whereas samples of the control discharge water will be collected on the MTEF discharge line. The samples will be collected by use of approximated isokinetic sampling methodology with fixed sample volumes according to principles described in MEPC.173(58) (G2) /7/.

6 Challenge conditions

6.1 Test water

6.1.1 Source water applied in the land-based test

Source water means the body of water from which water is drawn for the land-based test. The IMO G8 guidelines /2/ describes three distinct water types that may be applied in the land-based test:

Fresh water (salinity < 3 PSU)

Brackish water (salinity 3 - 32 PSU)

Marine water (salinity >32 PSU)

When fresh water is used, the source water will be collected from e.g. the Arresø Canal according to DHI SOP 30/1736 on collection of fresh water. Organism densities in the collected fresh water often exceed the minimum criteria for live organisms in test water with an order of magnitude allowing for dilution of the natural fresh water with potable water.

When brackish water is used, the source water will be collected immediately south of the pier adjacent to the test facility according to DHI SOP 30/1735; under normal conditions, the natural salinity of the source water will be 15-20 PSU.

When marine water is used, the source water will be collected immediately south of the pier adjacent to the test facility according to DHI SOP 30/1735, and brine will be added to achieve the required salinity.

6.1.2 Test water – water quality characteristics

Test water means the inlet water as contained in the source tank just prior to treatment. In land-based tests, source water may be adjusted to achieve the required challenge conditions.

In the source water, the natural concentrations of dissolved organic carbon (DOC), particulate organic carbon (POC) and total suspended solids (TSS) are analysed, after which the test water will be prepared to meet the water quality parameters in Table 6.1.

Table 6.1 Minimum water quality characteristics in compliance with the IMO G8 guidelines /2/.

Parameter	Test water		
	Fresh (<3 PSU)	Brackish (3-32 PSU)	Marine (>32 PSU)
Dissolved organic carbon (DOC)	>5 mg/L	>5 mg/L	>1 mg/L
Particulate organic carbon (POC)	>5 mg/L	>5 mg/L	>1 mg/L
Total suspended solid (TSS)	>50 mg/L	>50 mg/L	>1 mg/L

If necessary in order to obtain the stated water quality parameters, the concentrations of DOC, POC and mineral materials (MM) will be increased by additions of lignin sulphonate (DOC), starch (POC) and kaolin clay (MM) as described in DHI SOP 30/1737.

6.1.3 Test water – biological organism conditions

The natural densities of live organisms in the test water are analysed with reference to size classes, after which the test water will be prepared to meet the biological parameters in Table 6.2.

Table 6.2 Minimum criteria for densities of live organisms in the test water according to the IMO G8 guidelines /2/

Organism size class	Total concentration	Diversity
≥50 µm	100,000 organisms/m^3	5 species across 3 phyla
≥10 µm and <50 µm	1,000 organisms/mL	5 species across 3 phyla
<10 µm	10,000/mL as culturable aerobic heterotrophic bacteria	Not applicable

If necessary to obtain the stated minimum criteria, the densities of live organisms will be increased by addition of harvested indigenous organisms and/or cultured species as described in DHI SOP 30/1734. Addition of harvested and/or cultured species is recorded in the data logging.

Heterotrophic bacteria are typically present in the test water in densities exceeding the minimum criteria described in Table 6.2.

7 Sampling and analysis plan

7.1 Sample overview in BE verification testing

Table 7.1 Overview of sampling and purpose of samples

Parameter	Inlet water to BWMS and control tank	Treated discharge water	Control discharge water	Sample collection
Ballasting operations				
Volume	×	×	×	Continuous
Pressure	×	×	×	Continuous
Flow	×	×	×	Continuous
Other parameters*	×	×	×	Continuous
Water quality conditions				
Temperature, salinity, turbidity, pH, DO**	×	×	×	Continuous
TSS, DOC***, POC*** and UV-T****	×	×	×	Discrete grab (3 replicates; start, middle, end)
Concentrations of live organisms				
Viable organisms ≥50 µm	×******	×	×	Discrete (3 replicates; time integrated)
Viable organisms ≥10 and <50 µm	×	×	×	Discrete (3 replicates; each representing approx. a third of the operation period)
Viable organisms <10 µm (heterotrophic aerobic bacteria, *E. coli*, enterococci and *Vibrio cholerae*)	×	×	×	Discrete grab (3 replicates; start, middle, end)
Whole Effluent Toxicity (WET)*****	-	×	×	Discrete (time integrated)

* Operational parameters to ensure that the systems have been operated correctly and in accordance with the Operation and Maintenance manual
** Dissolved oxygen
*** Measured in inlet and discharge samples
**** UV-transmittance at 254 nm, 1 cm, measured in inlet samples
***** Only in BE test cycles to be decided later
****** Collected as discrete grab samples (3 replicates; start, middle, end)

Triplicate flow-integrated samples will be collected. The samples will be stored in thermo boxes with cooler bricks in the dark from the time of collection until handling of the samples in the DHI Environmental Laboratory.

7.2 Inlet water

Table 7.2 Sampling and analysis of inlet water to BWMS and control tank

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Microscopy	30/1701	DHI
Organisms <10 µm		
Heterotrophic aerobic bacteria	30/1705	DHI
E. coli and enterococci	30/1708	DHI
Physical/chemical		
Temperature, pH, O_2, salinity and turbidity	30/1764	DHI
TSS, DOC and POC	30/1768 and 30/1769	DHI
UV-transmittance at 254 nm, 1 cm	30/1770	DHI

7.3 Treated discharge water and control discharge water

Table 7.3 Sampling and analysis of treated discharge water

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Microscopy	30/1701	DHI
Organisms <10 µm		
E. coli and enterococci	30/1708	DHI
Vibrio cholerae	30/1707	DHI
Physical/chemical		
Temperature, pH, O_2, salinity and turbidity	30/1764	DHI
TSS, DOC and POC	30/1768 and 30/1769	DHI

Table 7.4 Sampling and analysis of control discharge water

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Microscopy	30/1701	DHI
Organisms <10 µm		
E. coli and enterococci	30/1708	DHI
Vibrio cholerae	30/1707	DHI
Physical/chemical		
Temperature, pH, O_2, salinity and turbidity	30/1764	DHI
TSS, DOC and POC	30/1768 and 30/1769	DHI

8 Data management, analyses and reporting

8.1 Data management

During the land-based test, logging of data related to

- Personnel participating in cleaning and maintenance at the test facility and collection of samples
- Operational procedures and monitoring
- Sampling and analysis

is performed in accordance with the data logging procedures described in the respective DHI SOPs. A complete overview of the DHI SOPs used for BWMS performance evaluation is presented in Appendix C.

An Access-based database and the procedures described in DHI SOP 30/1750 are used for storage of data generated from the BE test cycles and for marking completed QC of individual data. This data-level QC is made with reference to data quality indicators described in the DHI SOPs.

All generated data and all other records and information relevant to the quality and integrity of the performance evaluation, including a copy of the database file(s) and original raw data, will be retained in the archives of DHI for a period of five years after issue of the final report.

8.2 Analyses

8.2.1 Organism size class ≥50 µm

Compliance with the pass criterion in Chapter 10 will be verified by use of the direct count of organisms ≥50 µm in minimum dimension.

The concentrations of live organisms ≥50 µm in minimum dimension are determined by use of a stereo microscope and a counting chamber according to DHI SOP 30/1700. Viable organisms are enumerated by use of standard movement and response stimuli technique. The viable organisms are characterized according to broad taxonomic groups such as crustaceans (e.g. copepods), molluscs, rotifers, worms, etc.

8.2.2 Organism size class ≥10 µm and <50 µm

Compliance with the pass criterion in Chapter 10 will be verified by use of the total of viable organisms determined by the vital staining methodology.

To support the determination of concentrations of organisms in the ≥10 µm and <50 µm size class, a combination of the following analytical methods will be applied.

Inverted microscopy (DHI SOP 30/1701). The concentrations of organisms and the presence of taxonomic groups in the inlet water are determined by inverted microscopy.

Vital staining with fluorescein diacetate (FDA) and chloromethylfluorescein diacetate (CMFDA) (DHI SOP 30/1701). FDA and CMFDA are added to a subsample and, after incubation, the subsample is examined by use of a microscope under epifluorescence. Organisms labelled by either FDA or CMFDA are considered viable as described in DHI SOP 30/1701.

8.2.3 Organism size class <10 µm

The concentrations of heterotrophic aerobic bacteria will be determined according to DHI SOP 30/1706 (ISO 6222). *E. coli* and enterococci will be analysed according to DHI SOP 30/1708 using ISO-9308-1 for determination of *E. Coli* and ISO 7899-2 for determination of enterococci. *Vibrio cholerae* will be analysed according to the method described in DHI SOP 30/1707.

8.2.4 Physical/chemical analyses

The measurements conducted at the test facility according to DHI SOPs 30/1764 and 30/1766 will include:

- pH
- Temperature
- Salinity
- Turbidity
- Dissolved oxygen
- Ballast system pressure
- Ballast system flow rates
- Water volume in retention tanks

The analyses conducted at the DHI Environmental Laboratory will include the following measurements:

- TSS
- POC
- DOC
- UV-transmittance at 254 nm, 1 cm

8.3 Amendments, deviations and reports

Amendments are planned changes to the QAPP. Deviations are unplanned changes. Amendments and deviations will be signed by the project manager and documented in the file and the final report.

The following reports will be prepared:

- Draft final report compiling all relevant data from the test cycles, data interpretation and conclusion
- Final report

9 Validity criteria

A valid BE test cycle includes:

Concentrations of live organisms in control discharge water being (a) ≥100 organisms/m^3 for the organism size class ≥50 µm and (b) ≥100 organisms/mL for the organism size class ≥10 µm to <50 µm (IMO G8 guidelines, Annex, Part 2, Section 2.3.36 /2/)

10 Pass criteria

A valid BE test cycle is regarded as successful if it meets the performance standard for treated ballast water at discharge (IMO Regulation D-2 /1/):

1. The average density of organisms larger than or equal to 50 µm in minimum diameter in the replicate samples shall be less than 10 viable organisms per m^3 at discharge
2. The average density of organisms smaller than 50 µm and larger than or equal to 10 µm in minimum diameter in the replicate samples shall be less than 10 viable organisms per mL at discharge as determined by vital staining

3. The average density of *Vibrio cholerae* (serotypes O1 and O139) shall be less than 1 colony forming unit (CFU) per 100 mL at discharge
4. The average density of *E. coli* in the replicate samples shall be less than 250 CFU per 100 mL at discharge
5. The average density of intestinal enterococci in the replicate samples shall be less than 100 CFU per 100 mL at discharge

11 Quality assurance and control

11.1 Quality assurance

The project is conducted in accordance with the principles of ISO 9001 by using the DHI Business Management System and the procedures in the QMP /4/.

The DHI quality manager is responsible for assigning a trained internal auditor from DHI's Quality Assurance Unit to each project in accordance with the procedures for internal audit in the DHI Business Management System (Section on Quality). The internal auditor shall not be involved in solving the specific project or in any project deliverables.

The DHI Business Management System (Section on Quality; Internal Audit) describes procedures for audit and evaluation and the process of periodic internal auditing of projects and activities including audit responsibilities and planning, auditor training and competences and audit reporting.

The DHI Business Management System (Section on Quality; Correction and Prevention) describes procedures for corrective actions, i.e. how deviations identified during operation and auditing are corrected and how future occurrence of the same deviations is prevented (preventive actions).

11.2 Quality control

Quality control of individual data, or data-level QC, of BWMS operational conditions, sampling and analyses is conducted with reference to data quality indicators (DQI) in the DHI SOPs by staff appointed for this task (see Section 2.2). The data quality indicators include accuracy, precision, bias, representativeness, completeness, comparability, and sensitivity. The DQI and how they are monitored and evaluated are described in the relevant DHI SOPs.

Records of completed data-level QC are stored in an Access-based database (DHI SOP 30/1750), and a copy of the relevant database file(s) will be retained in the DHI archives for a period of five years after issue of the final report.

Quality control of the QAPP, DHI SOPs and all project proposals, deliverables and reports is conducted by management (see Section 2.2).

12 Time schedule

The testing is expected to be initiated March 2013. The biological efficacy testing will be performed with one test every week or two tests every second week throughout the spring 2013 (to the extent possible).

Table 12.1 Time schedule for the biological efficacy testing

Test cycle	Intake	Discharge
1	20 March	25 March
2	27 March	2 April
3	10 April	15 April
4	17 April	22 April
5	24 April	29 April
6-10	24 April to 21 May	-
11-15	22 May to 20 June	-

The classification society will be regularly updated by BAWAT A/S as the testing progresses.

DHI decides the applied test water salinities and the timing of the test cycles within the access period.

Dependent on weather conditions and the possibilities of preparing the right test water quality, the land-based test cycles will be conducted as outlined above. Ballasting is performed on a weekday in the morning and the de-ballasting is performed after at least 5 days from approx. 08:00 am, if at all practicable.

A draft final report will be prepared within ten (10) weeks after the successful completion of the planned test cycles.

A final report will be issued three weeks after the client's approval of the draft final report.

13 References

[1] IMO. International Convention for the Control and Management of Ships' Ballast Water and Sediments (IMO Regulation D-2). London. International Maritime Organization, 2004.

[2] MEPC. Guidelines for Approval of Ballast Water Management Systems (G8). Resolution MEPC.174(58). Adopted 10th October 2008.

[3] MEPC. Procedure for Approval of Ballast Water Management Systems that Make Use of Active Substances (G9). Resolution MEPC.169 (57). Adopted 4th April 2008.

[4] Quality management plan. Performance Evaluation of Ballast Water Management Systems. DHI Denmark. Version 3.1. June 2012.

[5] EN ISO/IEC 17025. General requirements for the competence of testing and calibration laboratories /ISO/IEC 17025, 2005.

[6] OECD Principles of Good Laboratory Practice (as revised in 1997). Organisation for Economic Co-operation and Development (OECD), Paris. ENV/MC/CHEM (98)17.

[7] Resolution MEPC.173(58). Adopted on 10 October 2008. Guidelines for approval of ballast water sampling (G2).

14 Approval of quality assurance project plan

DHI Ballast Water Centre

Project management Date: 2013.03.19

Morten Bjergstrøm

Quality control Date: 2013.03.19

Torben Madsen

This QAPP is accepted and my signature authorizes the study to proceed as described in this document.

Client Date:

Kim Diederichsen
BAWAT A/S

APPENDIX A

Certificate of compliance, ISO 9001 certificate, accreditation and GLP authorisation

COPY

Certificate no: **DS/I093222-A**
Page 1 of 1

Lloyd's Register Certificate of Compliance

Office: **Lloyd's Register EMEA**
Copenhagen Design Support Centre, Statutory Section
Strandvejen 104A, 2nd floor
DK-2900 Hellerup
Denmark

Date: **09 May 2012**

This certificate is issued to **DHI Ballast Water Centre, Denmark**

DHI Ballast Water Centre, Denmark

The Document(s) listed in paragraph 1 of the appendix have been examined for compliance with:

- Resolution MEPC.174(58), Annex part 2

and are found to comply from quality assurance and quality control aspects subject to the following:

1.1. It is required to maintain full and accurate log files in order to demonstrate correct quality measures

1.2. The Quality Assurance Project Plan is a project specific document and should as such be subject to review and commenting prior to each project start-up.

1.3. This design appraisal document is to be kept together with quality management plan.

1.4. Subject certificate is valid until 15 June 2015.

1. The documents listed below have been examined

Drawing No.	Rev.	Title	Status	Date
Date: 07 Sep 2011	**2.3**	**Quality Management Plan**	**B**	**09 May 2012**

2. The documents listed below have been considered together with the submitted documents in the appraisal

Drawing No.	Rev.	Title
11810704	**02**	**Quality Assurance Project Plan**

Appraisal Status Key

B Examined and found to comply with §2.2, Part 2 of the annex of IMO Resolution MEPC 174 (58)

Martin Schabert
Statutory Department
Copenhagen Design Support Centre
Surveyor to Lloyd's Register EMEA

LLOYD'S REGISTER EMEA
Lloyd's Register
M. Schabert
COPENHAGEN DESIGN SUPPORT CENTRE

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DNV BUSINESS ASSURANCE

MANAGEMENT SYSTEM CERTIFICATE

Certificate No. 109333-2012-AQ-DEN-DANAK

This is to certify that

DHI Group

has been found to conform to the management system standard:

DS/EN ISO 9001:2008

This certificate is valid for the following product or service ranges:

Consulting, software, research & development and laboratory testing, analysis & products within the area of water, environment & health

Locations included in the certification will appear in the appendix.

Place and date:

Hellerup, 2012-03-23

DET NORSKE VERITAS,
BUSINESS ASSURANCE, DANMARK A/S

This certificate is valid until:

2015-01-10

DANAK
SYSTEM Reg.nr. 5001

The audit has been performed under the supervision of:

Jan Carsten Schmidt
Lead Auditor

Jens Peter Høiseth
Managing Director

Lack of fulfilment of conditions as set out in the Certification Agreement may render this certificate invalid.

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DNV BUSINESS ASSURANCE

APPENDIX TO CERTIFICATE

This appendix refers to certificate no. 109333-2012-AQ-DEN-DANAK

DHI Group

Locations included in the certification are as follows:

Site Address	Scope:
Agern Allé 5 2970 Hørsholm, Denmark	Consulting, MIKE© by DHI Software Development, Sales & Support, Solutions Software Development, Research, Development & Innovation and Laboratory Analysis, Testing & Products
INCUBA Science Park, Gustav Wieds Vej 10 8000 Århus, Denmark	Consulting, Solutions Software Development and Research, Development & Innovation
Drakegatan 6, 412 50 Göteborg, Sweden	Consulting, MIKE© by DHI Software Sales & Support
Kyrkogatan 3, 222 22 Lund, Sweden	Consulting, MIKE© by DHI Software Sales & Support
Svartmangatan 18, 111 29 Stockholm, Sweden	Consulting, MIKE© by DHI Software Sales & Support
Honnörsgatan 16, Box 3287, 350 53 Växjö, Sweden	Consulting, MIKE© by DHI Software Sales & Support

This certificate is valid until:

2015-01-10

The audit has been performed under the supervision of:

Jan Carsten Schmidt
Lead Auditor

DANAK
SYSTEM Reg.nr. 5001

Place and date:

Hellerup, 2012-03-23

DET NORSKE VERITAS,
BUSINESS ASSURANCE, DANMARK A/S

Jens Peter Høiseth
Managing Director

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Accreditation to testing COPY DANAK

Company: **DHI**

Agern Allé 5
DK-2970 Hørsholm

Registration number: **26**

Valid: **24-10-2012 to 31-07-2015**

Scope:

Testing

Product

- **Biological items**
- **Chemicals and chemical products**
- **Construction products**
- **Environmental samples**

Test Type

- **Biological and biochemical testing**
- **Chemical testing**
- **Microbiological testing**
- **Ionising radiation and radiochemistry**
- **Sampling**

Testing is performed according to the current list of test methods approved by DANAK.

The company complies with the criteria in EN ISO/IEC 17025:2005 – General requirements for the competence of testing and calibration laboratories and demonstrates technical competence for the defined scope and the operation of a quality management system (refer joint ISO-ILAC-IAF Communiqué dated January 2009, www.danak.dk).

Issued the 24 October 2012

Jesper Høy / **Kirsten Jebjerg Andersen**

In case of any disputes, the Document in Danish language shall have priority.

Den Danske Akkrediterings- og Metrologifond

COPY DANAK

GOOD LABORATORY PRACTICE

STATEMENT OF COMPLIANCE

Laboratory inspection and study audits for compliance with the OECD Principles for Good Laboratory Practice were carried out at

Laboratory: DHI

on

Dates: 21st and 22nd October 2011

The laboratory inspection and study audits have been carried out in accordance with the regulation settled in Order No. 906 of 14th September 2009 from the Danish Ministry of Environment. The laboratory has been monitored for GLP Compliance within the following scope:

Type of products:

- *Industrial chemicals*
- *Pesticides*
- *Biocides*

Type of tests:

- *Environmental toxicity studies on aquatic and terrestrial organisms.*
- *Studies of behaviour in water, soil and air, bioaccumulation*

The laboratory was found to be operating in compliance with the OECD Principles of Good Laboratory Practice.

Date: 08 August 2012

Jesper Høy
Managing director, DANAK

Kirsten Jebjerg Andersen
GLP inspector, DANAK

Den Danske Akkrediterings- og Metrologifond

APPENDIX B

Description of the ballast water management system as provided by the client

Bawat A/S

BAWAT Document 2012.009, ver. E / 2013-03-18

Land-based Test
System Description
& Standard Operating Procedures

Changes from BD 2012.009, ver. D dated 2012 03 05:

1. Section 2.6.2/3 has been updated re. volume of retention section.
2. Section 2.8.2 is updated with respect to compressed air injection into the nitrogen flow.
3. Section 2.10.2: Temperature loggers are added to list of temperature sensors.
4. Section 2.10.4: Screen dump updated.
5. Section 3.2/12 re. adjustment of compressed air flow into the nitrogen flow was added.
6. Section 3.3/4 re. cooling SOP is added (consequential changes to numbering of following points).
7. Section 3.6:
    a. First line: "All process data" changed to "Main process data".
    b. Bullet points 3, 4 and 5 re. treated water volume, oxygen content and logged tank temperatures data added. (consequential changes to numbering of following points).
8. Section 5.15 added.

Changes from BD 2012.009, ver. C dated 2012 09 27:

1. In section 1.1 changes have been made to the description of the BAWAT process steps:
    a. A few editorial changes
    b. In step 2 oxygen content target has been changed to 2.0 mg/L or less.
    c. In step 3 the sentence "Shortly …… minutes" has been deleted.
2. Section 2.1:
    a. Component 2.8 added.
    b. Figure 2.1/1 updated
    c. Rationale of and description of the cooling circuit added .incl. new figure 2.1/3.
3. Fact box has been added in section 2.2.
4. In section 2.5.1 text has been updated and extended re. number of recirculations.
5. In section 2.5.2 text has been updated re. pump rate, etc.
6. In section 2.7.1 text has been updated and extended.
7. In section 2.8.2 text re. addition of oxygen to the nitrogen flow has been added.
8. Oxygen sensor added in section 2.10.2
9. In section 2.11:
    a. A fact box regarding Henry's Law has been inserted.
    b. Information re. oxygen content in nitrogen gas has been added.
    c. Target DO level has been changed to 2.0 mg/L or less.
    d. Pasteurization temperature in land-based test have changed to 72 °C.
    e. The text re. the recirculation factor has been updated and extended.
    f. A new section re. temperature in treatment tank has been added.
10. In section 3.2 instructions re. valve positions have been added.
11. New section 3.4 describing procedures re. cooling of treated water has been added. Consequently following sections have been renumbered.
12. Oxygen sensor added in section 3.5.5

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1. INTRODUCTION

The present **BAWAT Document #2012.009** describes the BAWAT Land-based Test set-up at DHI's test facilities in Hundested, Denmark, its main components and the main standard operating procedures.

1.1. BACKGROUND

The BAWAT Ballast Water Treatment System is an **In-Tank** system treating the ballast water (BW) in the ballast water tanks. Most other process systems for the same purpose are **In-Line** systems treating the water after the ballast water pumps before it enters the tanks.

Basically the BAWAT system is a recirculation system, where the BW after it has been pumped into the BW tank, is recirculated in a loop from the top of the BW tank, and re-introduced into the tank through a combination of Rotary Jet Heads (RJH) and fixed nozzles appropriately installed in the bottom section of the tank. (Please see figure 1.1/1 below.)

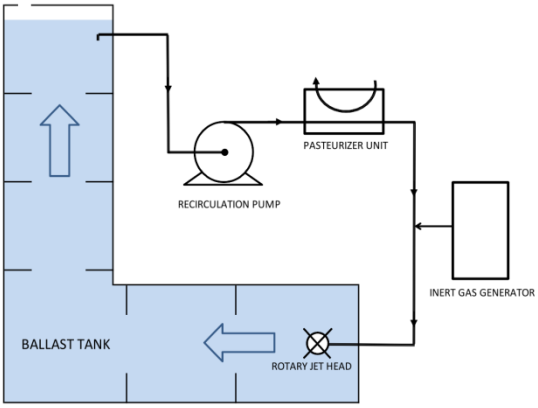


Figure 1.1/1:
Basic schematics of the BAWAT System

In the recirculation loop injection of gas such as nitrogen (N_2) or atmospheric air or a mixture of these take place on the pressure side of the pump. Further, a heat treatment system is built into the recirculation loop making it possible to apply a two-step treatment process, namely a deoxygenation of the ballast water in the tank combined with a heat treatment of the water in a pasteurizing unit.

The BAWAT System is particularly characterized by:

- The existing ballast system is operated without alterations/modifications.
- Simplicity and with a very small footprint, thereby facilitating retrofits.
- All process components have long term positive marine track records.
- No upgrade of BW pumps and associated piping and power generators are required.

It has been established, that to meet the criteria stipulated in Regulation D-2 of the 2004 Ballast Water Convention re. the content of microorganisms in the ballast water at discharge, it is necessary to apply

at least two different treatment principles. Most In-Line systems apply filtration of the incoming ballast water through 30 -50 µm filters as a first step, whereafter the filtered ballast water is exposed to either UV radiation, ultrasonic, ozone or other biocides.

Also the BAWAT System applies two distinct process principles, namely deoxygenation and pasteurization. The de-ox process effectively eradicate the zooplankton while at the same time nearly eliminate corrosion in the ballast tanks. The pasteurization process will eliminate both the phytoplankton and the bacteria to levels below the IMO requirements.

The BAWAT System normally will treat one tank at a time. Typically the system is installed allowing a port and a starboard tank to be treated simultaneously. Therefore, the system could be installed with one larger pump unit and one larger pasteurizing unit, or as a double system unit with two identical units, each having 50% capacity compared to one large system. One such system installed to handle the port side tanks, and one to handle the starboard side tanks. The treatment of the fore – and aft peak tanks, can be handled by either of these two systems.

In more details the BAWAT System will be operated as follows:

1. After the ballast water has been pumped into the ship's BW tanks and the ship has left harbor, the ship is in a situation where it has both surplus energy and waste heat available. The BAWAT System's recirculation pump(s) are started, and the recirculation of the ballast water is initiated, sucking from the top of the BW tank and reinjecting the water through Rotary Jet Heads and fixed nozzles properly installed in the lower part of the BW tanks. When recirculation has been established, heat in form of steam or hot condensate is supplied to the pasteurizer, and inert gas from the inert gas generator is injected into the recirculation line at a pressure a little higher than the pump pressure being around 2.5 – 5 bar. The inert gas injected after the pasteurizer will dissolve in the ballast water en route to the nozzles inside the BW tank. The nozzles will generate a very effective in-mixing of micro bubbles of inert gas into the ballast water by establishing a Non Stationary Flow Pattern at the entrance of the tank which effectively will be "pushing out" the oxygen from the BW.

2. The recirculation is maintained until the oxygen content in the water is below 2.0 mg/L and the total tank volume has passed at least once through the pasteurizer.
   The water is now treated to specification, and the pump is switched to start sucking from the next tank to be treated, after the valves to the just treated tank have been closed.

3. The treated water now rests in the tank until it has to be pumped overboard.

Besides effectively fulfilling the established biological treatment criteria for a BWT system, the BAWAT System further offers two important side benefits to the ship owner.

Firstly, by applying a de-ox process; the corrosion processes in the BW tanks will nearly be eliminated. Secondly, the installed Rotary Jet Heads will act as very efficient tank cleaners, which will be able to flush and clean the inlet part of the BW tanks effectively, thereby being able to exert a satisfactory sludge control of the BW tank system.

2. DESCRIPTION OF THE LAND-BASED TEST SET-UP

Contrary to other Ballast Water Treatment Systems – whether already type approved or in the type approval process – the BAWAT System utilizes various pieces of equipment already installed on the ship combined with proprietary components supplied by BAWAT.

Therefore, the BAWAT System installation will vary physically from ship to ship, however, will operate under the same principles and guidelines and controlled under identical process parameters.

In the sections below the land-based test set-up is described with reference to shipboard BAWAT System installations.

2.1. OVERVIEW

Figure 2.1/1 shows the test set-up at the DHI facilities in Hundested, the main components and measuring and sampling points in schematic form.

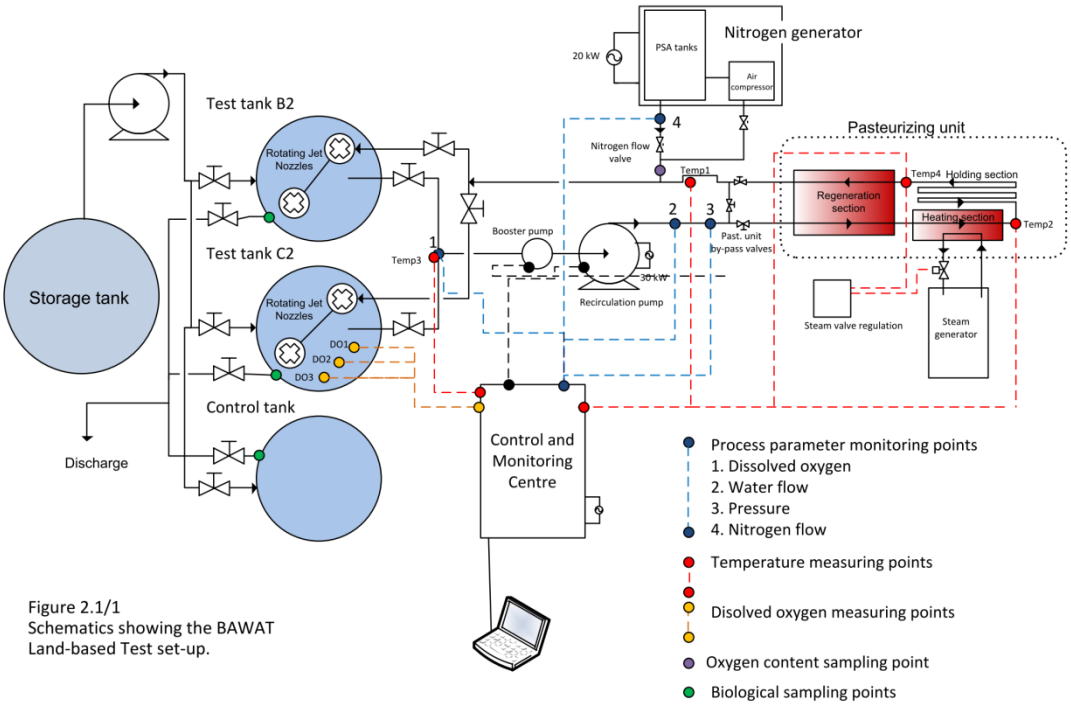


Figure 2.1/1
Schematics showing the BAWAT Land-based Test set-up.

The BAWAT System equipment has been built into three ISO containers – Figure 2.1/2:

1. A 10' container with
    - 1.1. Main pump for recirculation (Booster pump is placed outside container)
    - 1.2. Main system valve
    - 1.3. Control and Monitoring Centre

1.4. Sensors for water flow, pressure and dissolved oxygen content in the water

1.5. Connection to PC for monitoring and data logging

2. A 20' container with

2.1. Pasteurizing unit

2.2. Pasteurizing temperature regulation

2.3. Pasteurizing unit by-pass valve

2.4. Temperature sensors

2.5. Nitrogen generator

2.6. Gas flow regulation and – meter

2.7. Gas flow injection

2.8. Oxygen meter in nitrogen flow

3. A 10' foot container with the steam generator (Fuel tank and water softener are placed outside container)

The pre-insulated pipes constituting the holding section of the pasteurizing unit are placed on top of and across the two first mentioned containers.

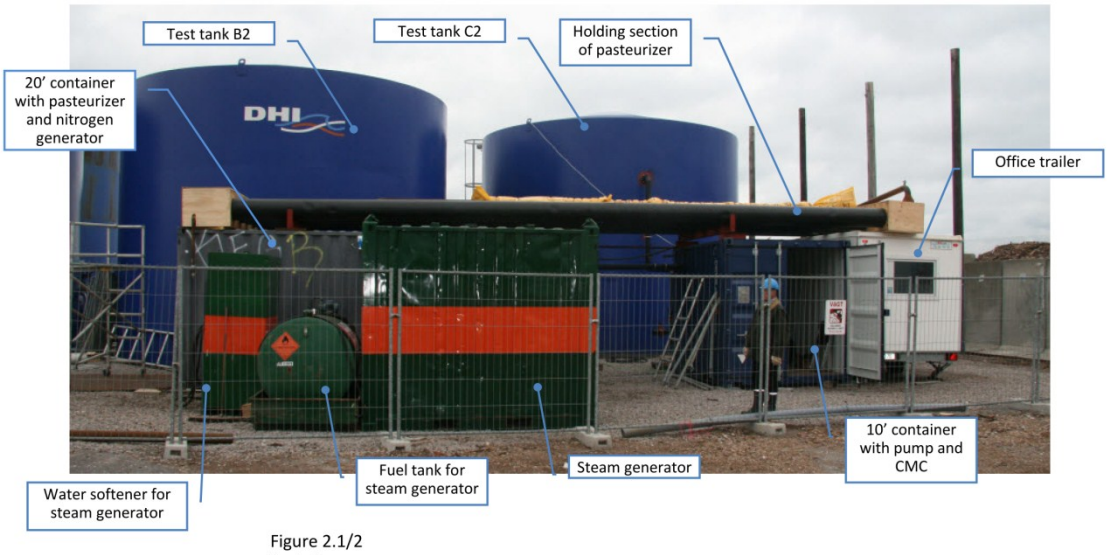


Figure 2.1/2
Test site.

The BAWAT system treatment process involves a recirculation of the water in the treatment tank through a pasteurizing unit. The ΔT (temperature increase) over the pasteurizing unit is 4 – 5 °C. This will increase the temperature in the treated tank by approximately the ΔT times the number of water recirculations during the treatment. The actual temperature increase will depend on the cooling conditions (temperature, wind, etc.) at the time of treatment. However, the temperature in the control tank will only change very slightly again depending on the actual temperature and wind condition at the time of the treatment.

The differences in after-treatment water temperatures between the treatment tank and the control tank can be considered an experimental artifact, as the temperature increase in a ship's BWT after

treatment are expected to very slight due to the efficient heat exchange through the ship's sides.

In order to mitigate the consequences of this artifact a cooling circuit has been establish in the land based test set-up in accordance with Figure 2.1/3. The plate heat exchanger utilized as the regeneration section of the pasteurizer unit is after treatment connected as a cooling heat exchanger using harbor pool water to cool the treatment tank water in accordance with section 3.4 below.

COOLING CIRCUIT INSTALLATION

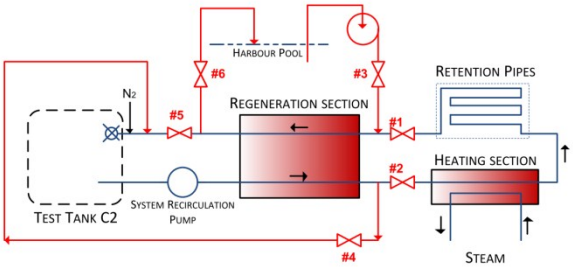


Figure 2.1/3
Cooling circuit installation.

2.2. TANKS

The BAWAT land-based tests takes place at DHI's test facilities in Hundested (Figure 2.2/1) utilizing three tanks of 250 m^3 each. Two tanks will be internally modified as described in principle below and in details in the DHI QAPP and the third tank be will used as a 'controltank' i.e. no treatment will take place in this tank.

Please observe: At present only one tank (C2) has been modified and connected to the BAWAT System equipment.

The test water is pumped into the tanks from the 750 m^3 reservoir tank, in which the test water is synthesized.

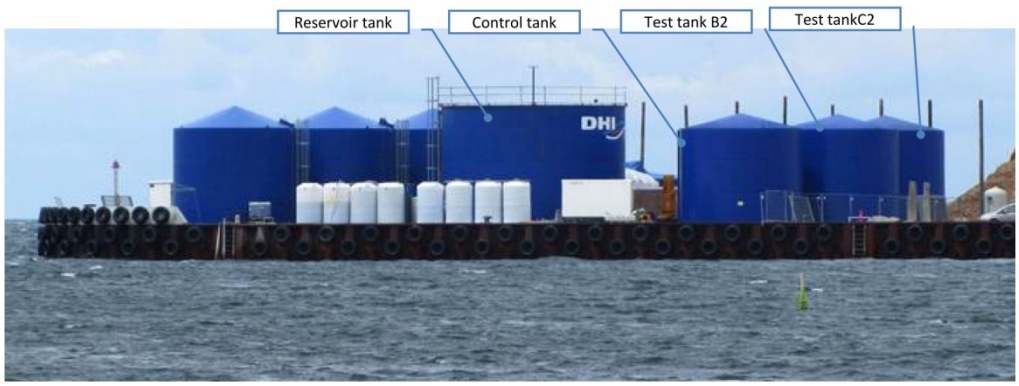


Figure 2.2/1: The DHI test installation from the sea.

The test tanks at the DHI facilities in Hundested are designed purely for the purpose of testing In–Line BWT systems, only serving as retention tanks for the treated water arriving from the BWTS. The tanks, however, in which the BAWAT System shall be tested, play an integral part of the system. The test tanks in Hundested therefore had to be modified so as to resemble normal ballast tanks as closely as possible.

In general, the recirculation system in a BAWAT System always will suck the water from right below the water surface in top of the ballast water tank, and will re-inject the water at the bottom of the ballast water tank trough the jet nozzles.

The nitrogen gas used a.o. for de-oxygenation is injected into the recirculation loop well before the tank, and will always consist of smaller and larger bubbles. The smaller bubbles primarily will facilitate the de-oxygenation of the water and will rise relatively slowly in the water, whereas the larger nitrogen bubbles will serve to agitate and mix the water in the individual compartments of the ballast water tanks. Compared to the flow of the main body of the water caused by the pumps, these larger nitrogen bubbles are travelling 4-500 times faster through the tank than the water.

Due to the basic construction of the ship and the ballast water tanks the nitrogen bubbles will always tend to move along the inner side of the ballast water tank tending to generate an upward movement of the water along the inner side of the tank.

To establish the same general movement pattern – flow regime - in the cylindrical tanks in Hundested, it was first of all necessary to establish an “inner side” in the tanks, and then ensure that the majority of the larger nitrogen bubbles ascended following this “inner side”.

The “inner side” was established by hanging a vertical tarpaulin diametrically in the tank, thus separating the tank into two equal parts.

To establish tree compartments in each half of the tank equivalent to the longitudinally decks inside a ship’s ballast water tanks, two ‘half-moon’ shaped pieces of tarpaulin were expanded from the inside cylindrical surface of the tank towards the diameter. The first half-moon positioned approx. 1/3 of the height of the tank up from the bottom and the second half moon 2/3 up from the bottom. They were positioned with a slight slope of 5 degrees towards the diameter

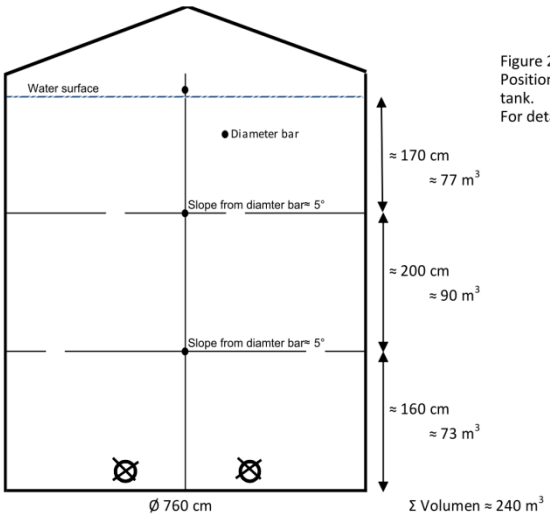


Figure 2.2/2
Positions of vertical and horizontal tarpaulins in tank.
For details please refer to the DHI description.

The intention of the tank modifications were to establish a flow pattern in the tank very similarly to what has been observed both in the 1:10 test tank at DTU, and also in the ballast water tanks of the 7.500 DWT tanker , Bro Gothenburg.

Visual inspection from the observation hatch in the top of the tank confirm that a flow pattern as intended with the main bubble flow ascending at the diameter bar seems to have been established.

Further, deoxygenation tests in the D2 test tank confirm that the deoxygenation courses observed here is qualitatively similar to analogue observations in 1:10 tank at DTU and on Bro Gothenburg.

The configuration will be optimized during pre-test runs before the land-based trials are initiated.

Please observe that the photographs in this section show the original tarpaulin setup. Hole-configuration has been modified in the present set-up.
For details please refer to the relevant QAPP section prepared by DHI.

Figure 2.2/3-4
Tarpaulin construction inside tank B2.

2.3. ROTATING JET NOZZLES

2.3.1. SHIPBOARD INSTALLATION

The BAWAT System utilizes a combination of rotating jet nozzles and fixed nozzles to introduce N_2 filled bubbles into the ballast water at the bottom of the ballast water tanks.

In a given ship's ballast tank one rotating jet nozzle will be placed in the tank segment where the ballast water is pumped into and out of the tank, and in the L-shaped tanks a series of fixed nozzles will be placed longitudinally one in each structural segment of the ballast water tank. In other tank constructions the fixed nozzles will be placed in positions creating a flow regime in the tank that agitates the ballast water in all compartments of the tank.

The water jets from the rotating jet nozzle will in addition to the introduction of nitrogen bubbles into the water remove sludge from the vicinity of the bell mouth through which the ballast water is pumped in and out of the ballast water tank and thus prevent the sludge from being washed out during the de-ballasting operation.

The relevant size of the rotating jet nozzle as well as the fixed jet nozzles will depend on required process time of the actual ballast water tank depending again on the actual tank size and the available pump capacity.

2.3.2. LAND-BASED TEST INSTALLATION

In the land based test set-up two rotating jet nozzles of the type **'IsoMix IM 25 Rotary Jet Mixer'** and two fixed Ø21 mm nozzles are installed in the tank – please see Figures 2.3.2/1 to 3.

Please see **Appendix 5.1** for specifications of the IsoMix IM 25 Rotary Jet Mixer.

Figure 2.3.2/1
Iso-Mix IM 25

Figure 2.3.2/2
Rotating Jet Nozzle and fixed jet nozzle in test tank.

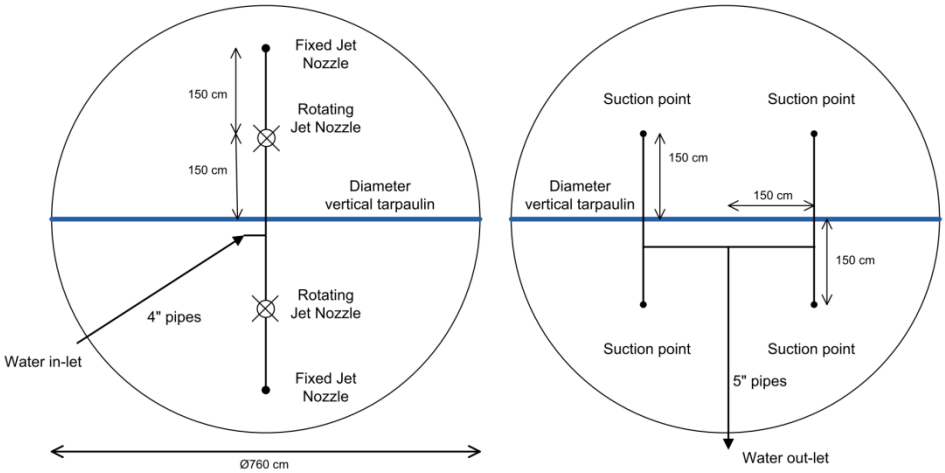


Figure 2.3.2/3
Positions of RJNs and FJNs at buttom of tank and suction points at tank top.

2.4. SUCTION POINTS

2.4.1. SHIPBOARD INSTALLATION

The BAWAT System circulates the ballast water from just below the water surface in the ballast water tanks through the treatment system to be reinjected through the nozzles at the bottom of the tanks as described above.

In the L-shaped ballast water tanks parallel suction points will be distributed longitudinally. The number of suction points, their precise placement and dimensions of the pipes will depend on the actual tank volume, the pump capacity and required process time. In other tank constructions the suction points will be placed and dimensioned to allow an unhindered water flow in the recirculation loop.

If the ballast water tanks are not filled to their maximum volume it is necessary to lower the suction point to below the actual water surface. This will be done by installing in a vertical pipe a series of floater operated valves that will open sequentially when the water level drops.

2.4.2. LAND-BASED TEST INSTALLATION

In the land-based test set-up four suction points are placed 0.5 m below the water surface as shown in figure 1.3.3/1. The pipe openings are facing upwards to avoid a direct flow of air bubbles into the pipes. Figure 1.3.3/2 shows the placement of the horizontal plane.

Please see Figure 2.3.2/3 for positioning of suction points.

Figure 2.4.2/1
Suction point in top of tank.

2.5. RECIRCULATION PUMP

2.5.1. SHIPBOARD INSTALLATION

In a ship board BAWAT System installation the existing ballast water pumps will be used as recirculation pumps and the ballast water piping will – after installation of remotely operated valves and low pressure suction piping from the top of the ballast water tanks to be attached the ballast pipes at the bottom of the tanks – be used as the low pressure suction piping in the recirculation loop.

The ballast water volume in a given ballast water tank will typically have to be recirculated between 2.5 and 4.0 times to ensure that 99.9% of the ballast water in the tank passes through the pasteurizing unit. The exact number of recirculations will primarily depend on the actual construction of the tank specifically on the number of compartments in which the tank can be considerate to be divided into.

The optimal treatment time will depend on the ship's schedule, speed, available energy for pasteurization, pump operation and nitrogen production, etc.

It is, however, expected - as a rule of thumb - that tanks in smaller ships shall be treated in 3 - 8 hours and larger ships in 16 – 24 hours. As an example: In a 30,000 DWT tanker the average ballast water tank is approximately 1,000 m^3. Running the ballast water pump as the recirculation pump in the BAWAT System at 500 m^3/h will give a process time in the tank of max. 8 hours.

2.5.2. LAND-BASED TEST INSTALLATION

In the land-based test set-up the tank size is 240 m^3. The recirculation pump system (see below) gives a pump rate of maximum 130 m^3/h allowing the BAWAT process to be carried out in less than 7 hours.

The main recirculation pump is an Iron Pumps' electrical centrifugal pump type CNLe 100/200 in series with a smaller electrical centrifugal pump (Desmi Pump PVLN, 4") serving as a 'booster' pump increasing system pressure and pump above the main pump's specification.

For specifications see **Appendix 5.4**

The pump and below described flow meter, dissolved oxygen sensor and the Control & Monitoring Centre are installed in a 10' container.

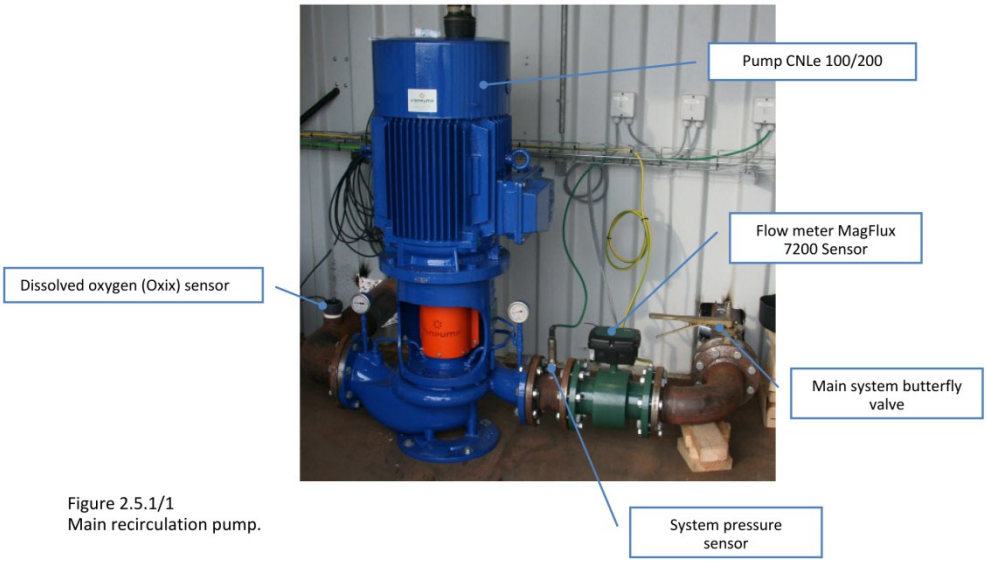


Figure 2.5.1/1
Main recirculation pump.

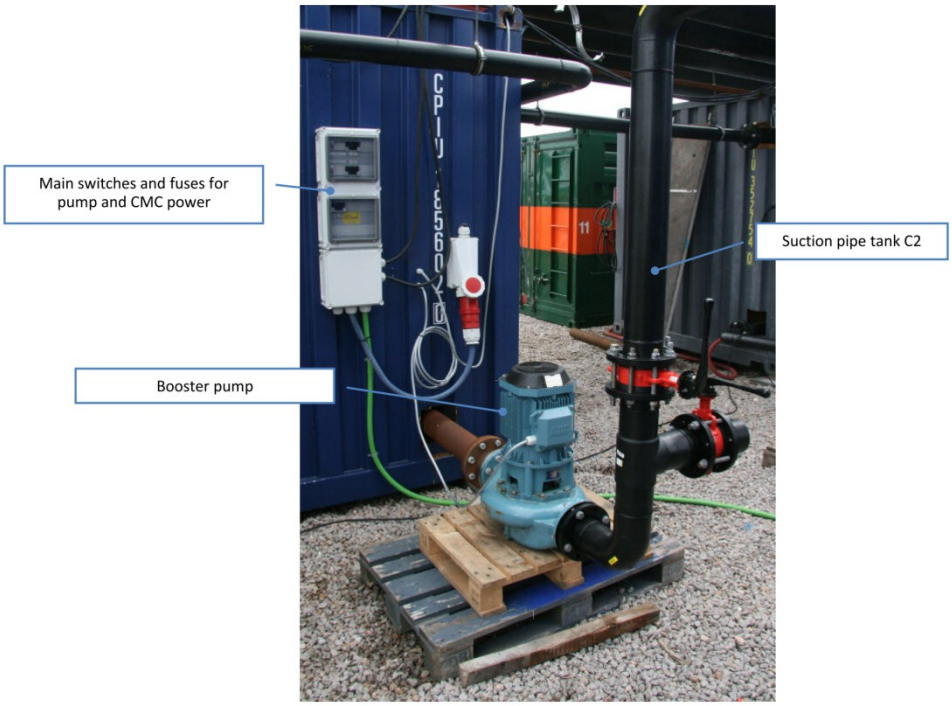


Figure 2.5.1/2
Booster pump.

2.6. PASTEURIZING UNIT

2.6.1. SHIPBOARD INSTALLATION

The BAWAT System implements a two-step process combining de-oxygenation and pasteurization. The shipboard mounted pasteurization unit consists of three parts – please see Figure 2-6-1/1:

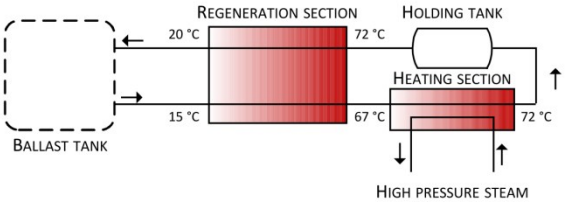


Figure 2.6.1/1
Pasteurizing unit principle

1. A Regeneration Section – a plate heat exchanger - in which in-coming water from the ballast water tank is heated by the out-going water from the holding tank.
2. A Heating Section – another plate heat exchanger – in which the water from the first heat exchanger is heated by low pressure steam supplied by the ship's existing installations, e.g. a dedicated steam generator or waste heat economizer.

3. A Holding Tank the purpose of which is to maintain the pasteurizing temperature achieved in the heating unit for a given time.

The temperatures indicated in the figure above are examples only. The temperature difference between the water flowing out of the ballast water tank and the water flowing back into the tank (ΔT) is in this example 5 °C.

The ΔT value as such has no effect on the BAWAT System efficacy and can be adjusted according to the requirements of the actual ship owner's priorities regarding capacity costs (CAPEX) and operational costs (OPEX) again depending on various issues as the actual costs of steam on a given ship.

2.6.2. LAND-BASED TEST INSTALLATION

In the land-based test set-up the pasteurizing unit comprises of

1. A Regeneration Section being a Sondex S86/200 plate heat exchanger with a ΔT of 5 °C at 150 m^3/h. (See **Appendix 5.3** for detailed specifications.)
2. A Heating Section being a Sondex S22/80 plate heat exchanger. (See **Appendix 5.3** for detailed specifications.)
3. A Holding Unit consisting of 60 m of Ø210 mm pre-insulated pipes with total water volume of 2.1 m^3+ volume of bendings, in total 2.5 m^3. The unit gives a holding time of 1 min at a flow rate of 150 m^3/h and 1,15 min at 120 m^3/h. The temperature difference measured between inlet and outlet of less than 1 °C at a flow rate of 140 m^3/h.

Figure 2-6-1/2-3
Pasteurizing unit sections

2.7. STEAM GENERATOR

2.7.1. SHIPBOARD INSTALLATION

In a shipboard mounted BAWAT installation the heating medium in the above described pasteurizing unit could be low pressure steam supplied by the ship's existing or updated installations, e.g. a dedicated steam generator, waste heat economizer or jacket cooling water heat exchange.

The heat requirement of the BAWAT System depends on the specifications of the installed pasteurization unit, but will typically be equivalent to approximately 0.02 ton of steam per 1 m^3 of ballast water treated.

As an example: A 30.000 DWT tanker holds typically 12,000 m^3 of ballast water. A full BAWAT System treatment of this volume of ballast water will require approximately 240 tons of steam over a 48 h period of time equal to 5 tons/h.

2.7.2. LAND-BASED TEST INSTALLATION

In the land-based test set-up the steam is supplied by an oil burner driven Clayton Steamgenerator Type E-150 with a capacity of 2.3 – 2.4 tons/h at 3 bar installed in a 10' container. (Specifications see **Appendix 5.2**)

The steam pressure and consequently the temperature on the hot side of the heat exchanger in the heating section of the pasteurization unit is regulated by an automatic, motorized valve operated via an electronic circuit with temperature sensors in the water flow at the inlet and outlet of the holding section of the pasteurizing unit. The water temperature can be held within ±1 °C of the set temperature.

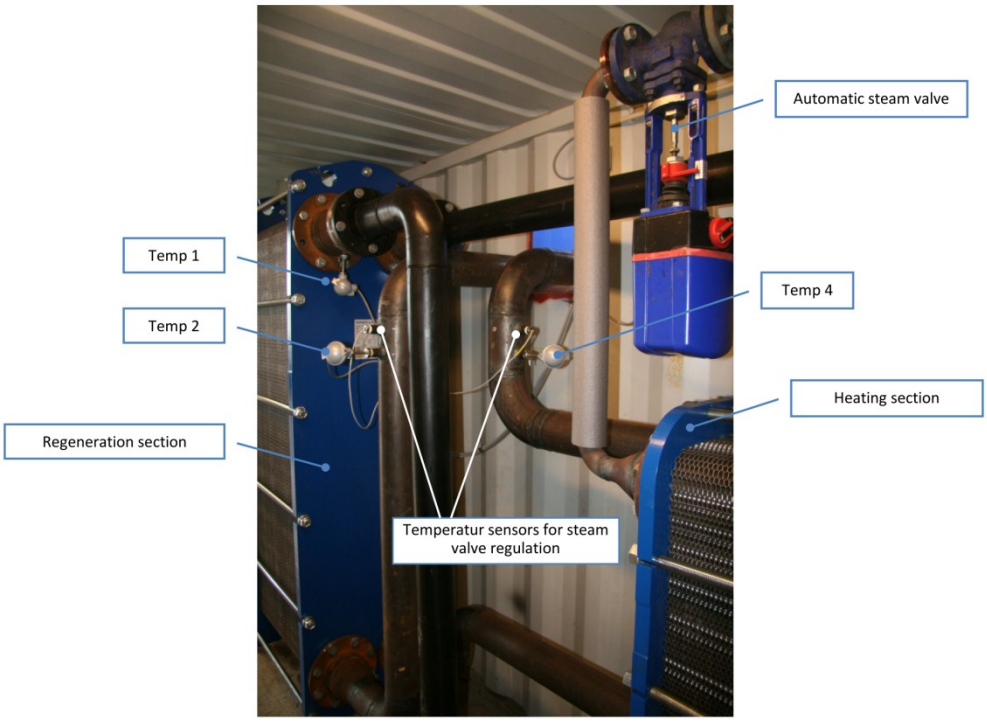


Figure 2.7.2/1: Temperature sensors in pasteurizer unit

Figure 2.7.2/2: Control panel for setting and control of Pasteurizing temperature located in 20' container.

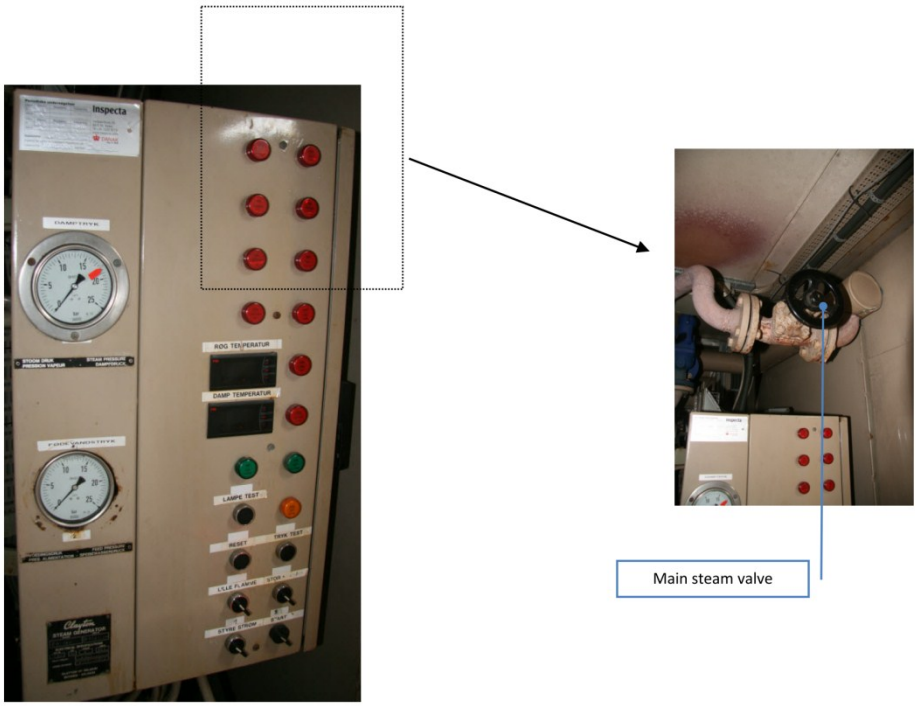


Figure 2.7.2/3-4: Location of main steam valve in steam container.

2.8. NITROGEN GENERATOR

2.8.1. SHIPBOARD INSTALLATION

In a ship board mounted BAWAT installation the required nitrogen flow will either be supplied from an already installed nitrogen generator system used for tank blanketing or from a dedicated BAWAT System installation.

Nitrogen for marine applications is for the main part produced either by the Membrane Technology or by the Pressure Swing Adsorption (PSA) Technology.

2.8.2. LAND-BASED TEST INSTALLATION

In the land-based test set-up a PSA generator from Gazcon with a capacity of 21 Nm^3/h is installed. The nitrogen flow rate necessary for the upcoming tests will be approx. 12 m^3/h. (See **Appendix 5.5** for specifications.)

The purity of the nitrogen is dependent on the flow rate and at 18 m^3/h the purity will - according to the manufacturer's specifications - be 99.7% N_2, the balance being argon and O_2. The oxygen concentration in the nitrogen determines the minimum obtainable dissolved oxygen level in the treated water. In shipboard installations the oxygen content can vary from 0.01 % to 2.00 % oxygen depending on the actual nitrogen flow.

In order to run the tests under the most challenging conditions oxygen in the form of compressed atmospheric air is injected into the nitrogen stream. The oxygen content of the gas is measured before injection into the water piping and manually held at 2.00 % oxygen as this value will be the most challenging situation compared to a shipboard installation as indicated above.

Figure 2.8.2/1-3
Nitrogen generator

Figure 2.8.3/4
Nitrogen injection

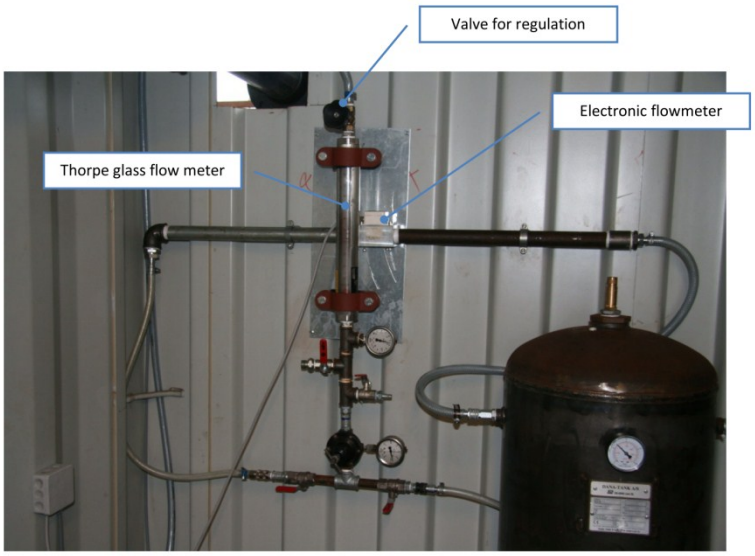


Figure 2.8.3/5
Nitrogen flow regulation

2.9. PIPING AND VALVES

2.9.1. SHIPBOARD INSTALLATION

In a ship board BAWAT installation the ballast water pipes will be used on the suction side of the recirculation pump

2.9.2. LAND-BASED TEST INSTALLATION

In the land-based test set-up suction side pipes are 5" PE pipes and pressure side pipes are 4" PE pipes apart from high temperature pipes between the regeneration and the heating sections of the pasteurizing unit, where the pipes are made of steel.

All valves are manually operated butterfly-valves.

A coarse strainer (1 mm openings) is placed on the pressure side of the pump to withhold welding debris, etc. originating from the assembly of the piping. The sieve is removed again before operation of the system.

2.10. CONTROL AND MONITORING CENTRE AND SENSOR PLACEMENTS

2.10.1. SHIPBOARD INSTALLATION

In a ship board BAWAT installation all control, monitoring and data logging functions in the BAWAT System will handled by a Control and Monitoring Centre (CMC) most likely placed with the ship's ballasting system controls and most likely interfaced with this system. Apart from the basic functionality of controlling the BAWAT process in one ballast water tank the shipboard CMC will among other routines have preprogrammed routines for running the entire treatment process in all tanks automatically switching from one tank to the next when treatment in the first tank has been completed.

2.10.2. LAND-BASED TEST INSTALLATION

In the land-based test set-up a prototype of the coming CMC is applied, however, only containing features relevant to the land-based test set-up. The CMC is basically identical to the CMC used in the 1:10 tank tests (See **Appendix 5.12**: BAWAT Document 2012.007 entitled "1:10 Test Tank Description & Standard Operating Procedures") modified to control the equipment applied in general and to log temperature data, also.

The CMC is built around SCADA (**S**upervisory **C**ontrol **A**nd **D**ata **A**cquisition) equipment and software supplied by MJK Automation A/S.

The CMC consists of

- Datalogger and software: (Specifications in **Appendix 5.9**)
  - Connect base (MJK)
  - MJK Monitors
  - IGSS (Interactive Graphic SCADA System) software (7-Technologies)
- Switches, automatic fuses, relays, etc.
- The main pump is running at max speed, but the speed of the booster pump can be regulated by a frequency converter,

and receives data from the following sensors:

- Dissolved oxygen: (Specifications in **Appendix 5.6**)
  - SuSix/Oxix converter (MJK)
  - Oxix sensors
    - Three sensors are placed in tank C2 one in each vertical segment (See figure 3.1.9/1) of the tank (DO 1, DO 2 and DO 3)
    - A fourth sensor (DO 0) is placed in the water flow just before the main recirculation pump thus in effect measuring the dissolved oxygen content at the suction points at the top of the tank.
- Oxygen sensor : (Specifications in **Appendix5.14**)
- Pressure: (Specifications in **Appendix 5.7**)
  - Pressure transmitter (0-6 bar) (MJK)
    - The pressure sensor is placed after the main pump.
- Water flow: (Specifications in **Appendix 5.8**)
  - MagFlux 7200 Sensor DN32EN/PN40 (MJK)
  - MagFlux converter (MJK)
    - The water flow is measured just after the main recirculation pump.
- Temperature sensors
  - The temperature is measured
    - in all dissolved oxygen sensors (Only temperature in the DO 0 sensor is logged (Temp 3)),
    - at the outlet from the pasteurizing unit (Temp 1) and at the inlet and outlet of the holding section of the pasteurizing unit (Temp 2 and Temp 4, respectively.
    - The pasteurizing temperature, T_{Past}, is defined as (Temp 2+ Temp 4)/2.
    - A temperature logger is placed in both the treatment tank and in the control tank prior to initiation of the treatment logging the temperatures in the tanks before and during treatment as well as during the retention time following the treatment. (Specifications in **Appendix 5.15)**

- Nitrogen flow:
  - Two types of flow sensors are applied
    - A Thorpe type glass flow meter
    - An electronic flow meter the output of which is logged in the Connect Base **(Appendix 5.10)**

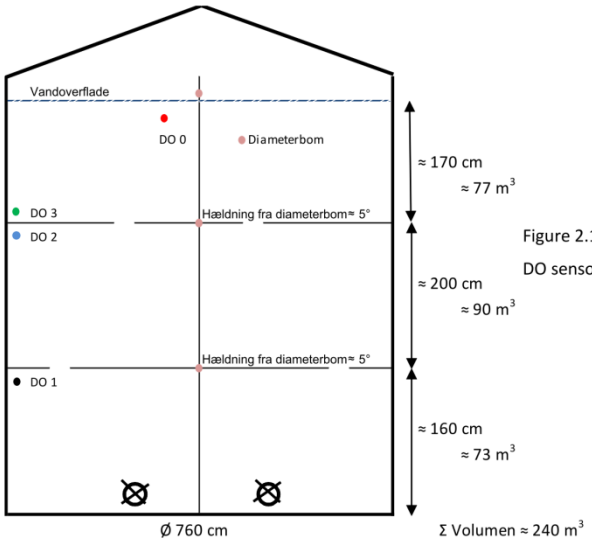


Figure 2.10.2/1

DO sensors in tank C2

2.10.3. Control and monitoring centre (CMC)

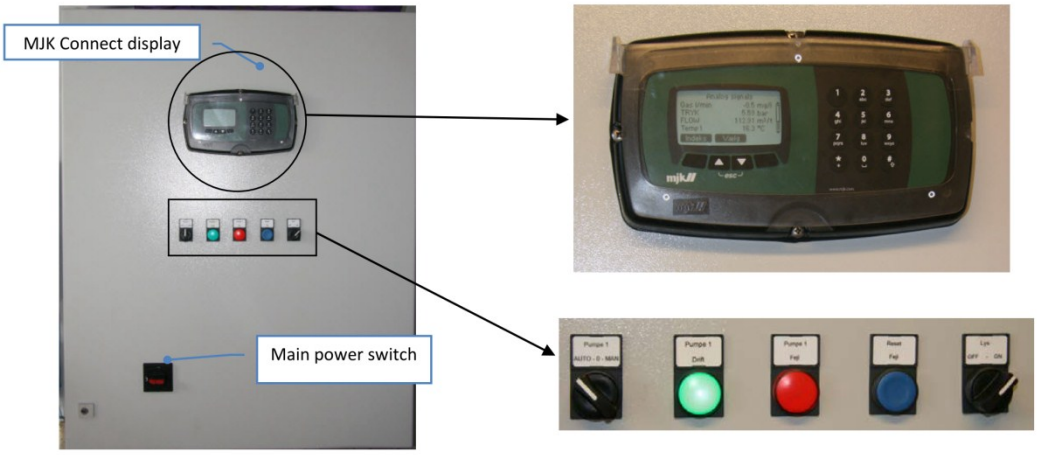


Figure 2.10.3/1-3 CMC Main panel

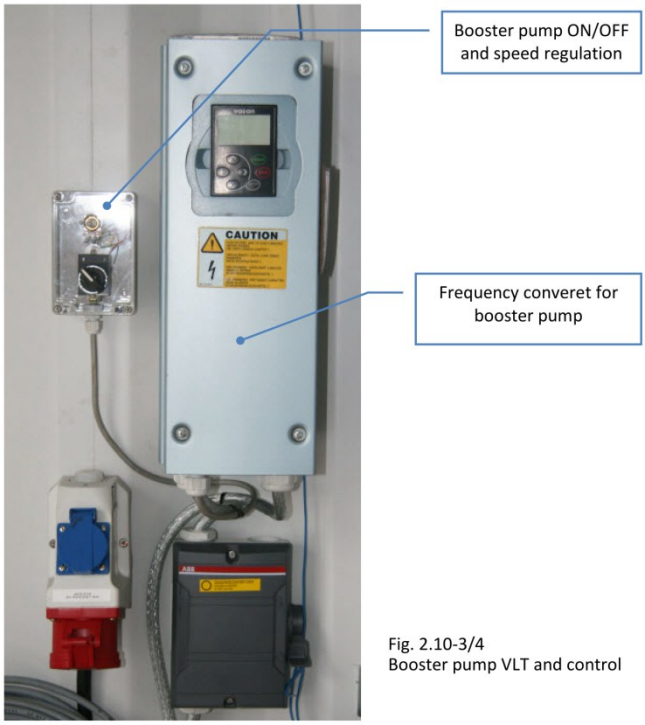


Fig. 2.10-3/4
Booster pump VLT and control

2.10.4. IGSS SCREEN

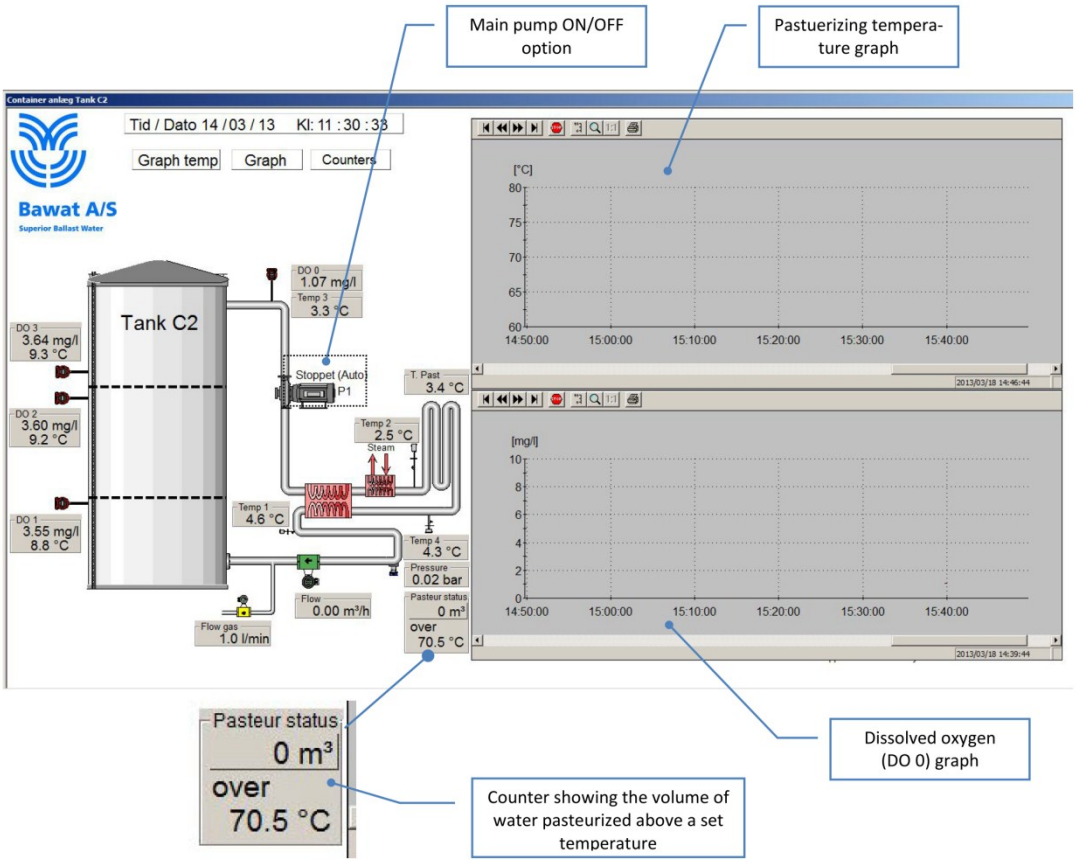


Figure 2.10.4/1: IGSS screen picture. Graphs not shown as system not in operation

2.11. PROCESS PARAMETERS

2.11.1. Main process parameters

The three main process parameters in the BAWAT System are:

1) The content of dissolved oxygen in the treated water = $\mathbf{DO_{treated}}$.

> The dexoygenation follows Henry's Law: "At a constant temperature, the amount of a given gas that dissolves in a given type and volume of liquid is directly proportional to the partial pressure of that gas in equilibrium with that liquid."
> Through the surface of the micro bubbles created by the injection of nitrogen under pressure into the water the nitrogen in the bubbles is exchanged with the oxygen dissolved in the water and thus reducing the dissolved oxygen content of the water. The level to which the dissolved oxygen can be dissolved is dependent on the oxygen content of the nitrogen gas injected.

2) The level of Pasteurization Units (PU) applied in the pasteurization process = $\mathbf{PU_{applied}}$.

> The destructive effect on micro-organisms of pasteurization is determined by the retention time and the temperature applied. It is calculated in terms of pasteurization units (PU) and is a measure for the microbiological effect of the heat treatment.
> It is calculated as follows:
> **PU = 'Retention time at temperature' ∗ 1.393**$^{(\text{Temperature} - 60\ °C)}$

3) The $\boldsymbol{\rho_{min}}$**-factor.**

> For a given pump rate the ρ-factor tells how many times a water volume equal to the water volume in the ballast water tank has passed through the pump.
> ρ_{min} is defined as the minimum number of times the ballast tank volume must pumped through the pump to ensure that a minimum of 99.9% of the water elements has passed the pump and consequently also the pasteurizing unit.

Re 1. Deoxygenation level

In the land-based test the dissolved oxygen content in the test water will be reduced to 2.0 mg/L or less.

Further, in the land-based tests the oxygen level in the nitrogen flow will be kept at 2 %.

Re.2. Pasteurization

In the land-based test a pasteurization temperature of 72 °C and a retention time of not less than 1 min will be applied.

Re 3. The Recirculation Factor.

Since an important part of the annihilation process in the BAWAT System takes place outside the ballast tank during the treatment process, namely the pasteurization, it is important to ensure that essentially all part of the ballast water (99.9%) passes through the pasteurization unit.

If a "plug flow" could be established in the recirculation loop, the ballast water volume would need to be pumped through the pasteurizer one time only. However, due to the internal mixing of the water in the ballast water tank taking place during the process, more than one recirculation is required to ensure that all water volume elements are passing through the pasteurizer at least one time.

In general, a ballast tank is constructed as a number of parallel sections each consisting of a number compartments in series which in most tanks form an L-shaped volume stretching longitudinally. The ballast water during the BAWAT treatment, will be recirculated from the top of the tank and reintroduced at the bottom of the tank mixed with the nitrogen. The water then moves slowly up through the tank towards the top.

A mathematical model describing the water flow in typical ballast water tanks have been developed at Denmark's Technical University[1].The models show that the de-oxygenation of the water takes place very quickly in the lower compartment at the introduction of the nitrogen micro bubbles through the nozzles.

The de-oxygenated water then moves slowly from compartment to compartment and is agitated by the larger bubbles of nitrogen. These bubbles are rising through the tank primarily along the inside of the tank structure, generating a mixing of the water in each compartment facilitating that all water elements are moved around and mixed into the main flow passing upwards towards the top. The speed of the rising bubbles relative to the slow moving water is in the order of 4-500 times faster.

The mathematical models indicate that in a typical L-shaped ballast water tank a recirculation factor (ρ_{min}) of between 2.0 and 5.5 should ensure that at least 99.99% of the water has passes through the pasteurizer.

A series of pasteurizing tests with biological sampling in the 1:10 tank at DTU, BAWAT A/S have shown that a ρ_{min} factor of between 2.0 and 2.5 results in satisfactory reduction of zooplancton, phytoplancton and bacteria meeting the D2 criteria. (Please see **Appendix 5.10**)

In several tests it has further been shown, that a deoxygenation to below 2.0 mg/L will reduce the zooplankton content to well below the D2 criteria and there are strong indications that deoxygenation to this level results in a substantial reduction of the phytoplankton concentration as well. The remaining phytoplankton and the bacteria are killed by pasteurization.

Before deciding finally on which ρ_{min} factor will be used in the land-based tests in Hundested, a number of tests will be performed in the 250 m^3 tanks, partly with de-oxygenation only, and partly in a pilot test also involving analysis of the full spectre of zooplankton phytoplankton and bacteria.

Based on the mathematical model and the deoxygenation experiments mentioned, it has been decided to recirculate the water 4 times in the land-based tests in Hundested.

2.11.2. Water temperature in treated tank

As mentioned above the BAWAT system treatment process involves a recirculation of the water in the treatment tank through a pasteurizing unit. The ΔT (temperature increase) over the pasteurizing unit is 4 – 5 °C. This will increase the temperature in the treated tank by approximately the ΔT times the number of water recirculations during the treatment. The actual temperature increase will depend on the cooling conditions (temperature, wind, etc.) at the time of treatment. However, the temperature in the control tank will only change very slightly again depending on the actual temperature and wind condition at the time of the treatment.

[1] Jakob K. Huusom and John Villadsen, Department of Chemical and Biochemical Engineering, DTU: Treatment of Ballast Tank Water in different scales – modelling of the ballast tank, and experimental validation of the model. (Included as **Appendix 5.13**)

The differences in after-treatment water temperatures between the treatment tank and the control tank can be considered an experimental artifact, as the temperature increase in a ship's BWT after treatment are expected to be very slight due to the efficient heat exchange through the ship's sides.

In order to mitigate the consequences of this test artifact a cooling circuit has been establish in the land based test set-up in accordance with Figure 2.1/3. The plate heat exchanger utilized as the regeneration section of the pasteurizer unit is after treatment connected as a cooling heat exchanger using harbor pool water to cool the treatment tank water in accordance with section 3.4.

The treated tank will be cooled to approximately 3 – 4 °C above the water temperature in the control tank. However, cooling will only take place if the water temperature in the treated tank is above 15 °C as below this temperature biological activity in both tanks will be low and more or less identical.

3. STANDARD OPERATING PROCEDURES

The Standard Operating Procedures implemented in the Land-based Test Series follow the principles of the SOPs implemented in the 1:10 tank test outlined in BAWAT Document 2012.007 entitled "1:10 Test Tank Description & Standard Operating Procedures" (**Appendix 5.12**), however, duly modified to reflect the installed equipment and interfaces to the DHI installations and the DHI sampling procedures to be followed.

For convenience the main routines are included below.

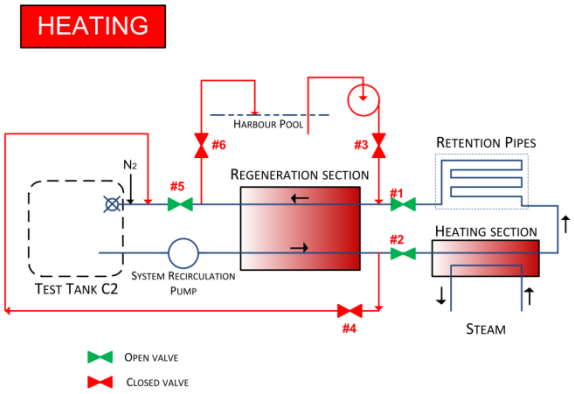
3.1. FILLING AND EMPYING OF TANKS

The tanks are filled and emptied according to the SOPs implemented by DHI and by DHI personnel.

3.2. SYSTEM START-UP

To start-up the system the following steps are required:

1) Valvepositions in the cooling circuit must be as follows:



2) The on-site diesel driven electric generator is turned on according to the SOPs implemented by DHI and by DHI personnel.
3) Main power and system on-off switches are turned to ON. **Figure 2.10.3/1**.
4) The laptop is connected to the CMC and the IGSS (Interactive Graphical SCADA System) program is opened on laptop. Figure 2.4.10/1 shows the screen picture.
5) The steam generator is turned on and adjusted to deliver the necessary steam volume in accordance with the Operational Manual supplied by Clayton, Inc. See **Appendix 5.2**.
6) The requested pasteurization temperature is entered into the keypad on the steam pressure regulation unit in accordance with the Operational Manual supplied by the manufacturer. See **Appendix5.2** and **Figure 2.7.2/2**.

7) When the required steam pressure is established the main steam valve is opened. The valve is located above the control panel in the steam generator container. **Figure 2.7.2/3-4**.
8) Pumps are switched on and regulated to the required flow on the CMC control box and the booster pump VLT. See **Figure 2.10.3/1-4.** Main pump can also be switched on via IGSS program **– figure 2.10.4/1.**
9) The main water flow valve is opened. See **figure 2.5.1/1**.
10) The nitrogen generator is turned on in accordance with the Operational Manual supplied by Gazcon A/S. See **Figures 2.8.2/1-3**.
11) The nitrogen injection valve is opened and nitrogen flow established by manual adjustment of the gas valve. See **Figure 2.8.3/5**.
12) The flow of compressed air into the nitrogen flow is manually adjusted to the required oxygen content measured on the oxygen meter installed in line.

3.3. SYSTEM SHUT-DOWN

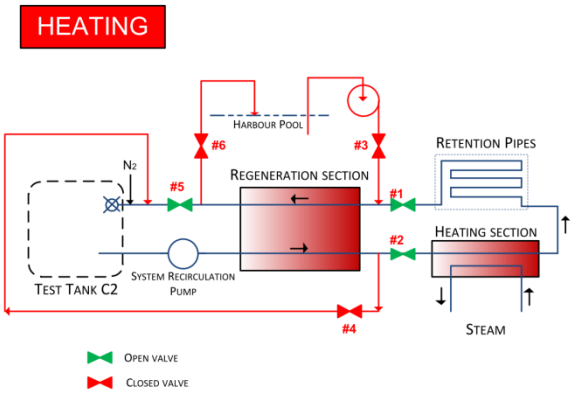
To shut-down the system the following steps are required:

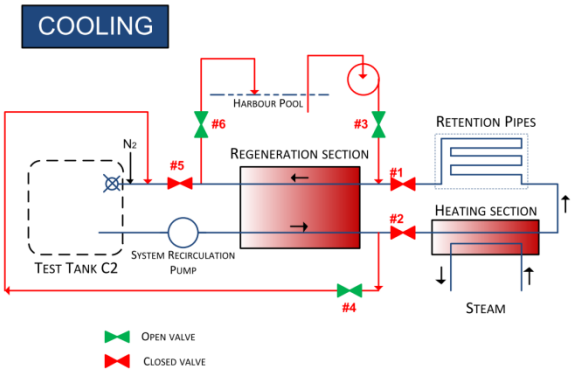
1) The steam generator is switched off in accordance with the Operational Manual supplied by Clayton, Inc. See **Appendix 5.2**
2) Main water flow valve is closed and the pumps are switched off. See **figures 2.5.1/1; 2.10.3/1-4; 2.10.4/1.**
3) Nitrogen injection valve is closed and nitrogen generator is switched off in accordance with the Operational Manual supplied by Clayton, Inc. See **Figures 2.8.3/5;2.8.2/1-3.**
4) **If cooling of the treated water is required (See section 2.11.2) procedure 3.4 below is applied.**
5) Main power and system on-off switches are turned to OFF. **Figure 2.10.3/1.**
6) IGSS program is closed.
7) Data log file is copied to hard drive and USB stick.
8) Laptop is disconnected.

3.4. COOLING OF TREATED WATER

Steps described in section 3.3, 1) through 3) are carried out and the following procedure is followed:

1) Pump is lowered into harbor pool and connected to power supply.
2) Valve position are changed according to the following:





3) Harbor pump is switched on.
4) Temperatures in test tank are monitored on CMC and when the target temperature has been reached the harbor pump is switched off and valves #3 and #6 are closed.

3.5. MEASUREMENTS

3.5.1. WATER FLOW

Water flow data are recorded in the data logging system and can continuously be read on the IGSS co sole and on the MJK Connect display (Fig. 1.3.7/3).

3.5.2. PRESSURE

System water data are recorded in the data logging system and can continuously be read on the IGSS console and on the MJK Connect display (Fig. 1.3.7/3).

3.5.3. TEMPERATURES

Temperatures are recorded in the data logging system and can continuously be read on the IGSS console and on the MJK Connect display (Fig. 1.3.7/3).

3.5.4. DISSOLVED OXYGEN

Dissolved oxygen content in the water are recorded in the data logging system and can continuously be read on the IGSS console and on the MJK Connect display (Fig. 1.3.7/3).

3.5.5. GAS FLOW

The N_2 flow is are recorded in the data logging system and can continuously be read on the IGSS console and on the MJK Connect display (Fig. 1.3.7/3).

3.5.6. BIOLOGICAL SAMPLING AND MEASUREMENTS

Biological samples are collected according to relevant DHI SOPs.

3.6. DATA RECORDING AND PROCESSING

Main process data are automatically recorded in the MJK Datalogging system:

1) Data points

   {Absolute time; Dissolved Oxygen at DO 0 [mg/L]; Dissolved Oxygen at DO 1 [mg/L]; Dissolved Oxygen at DO 2 [mg/L]; Dissolved Oxygen at DO 3 [mg/L]; Water Flow [m^3/h]; Pressure [bar]; Gas Flow [NL/min]; Temperature #1 [°C]; Temperature #2 [°C]; Temperature #3 [°C]; Temperature #4 [°C]}

   are collected every 30 seconds.

2) Selected, recorded data is continuously presented on screen by the IGSS software package.
3) Volume of water [m^3] above a set temperature [°C] is continuously presented on the screen and logged.
4) Oxygen content in nitrogen flow is manually recorded approx. every 15 min. during treatment.
5) Logged temperatures in treatment tank and control tank are saved to main data file after retention period (120 h).
6) The data are transferred into a Microsoft Excel spreadsheet for data processing.
7) The 'Raw data' and the subsequent Excel data processing files are stored (i) on the attached laptop, (ii) on a USB data storage stick, (iii) on a separate laptop and (iv) on a Drop-Box data storage facility.

Data are processed in Microsoft Excel and presented in graphical form. Figure 3.5 shows an example from the preliminary tests in the D2 test tank.

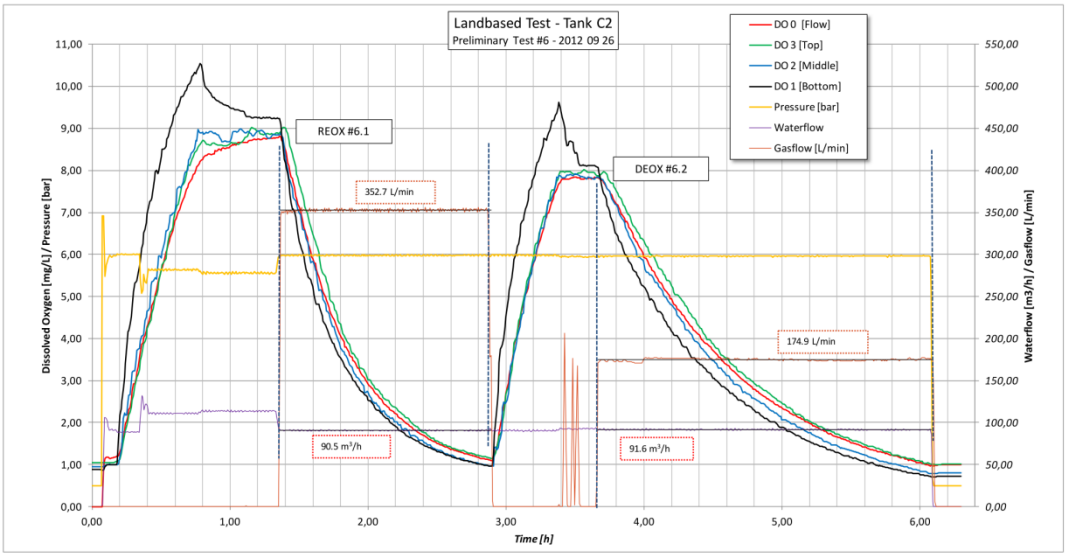


Figure 3.5: Example of graphic data presentation

4. EMERGENCY PROCEDURES

4.1. SHIPBOARD INSTALLATION

In shipboard BAWAT System installations existing equipment will part of the installations, e.g. the ballast pump and the nitrogen generator. For these the ship's emergency procedures will apply.

The proprietary BAWAT components to be installed will be equipped with emergency stops where appropriate and emergency procedures will be established.

It should be observed that ballast water tanks after treatment with the BAWAT System and after de-ballasting might contain a higher level of nitrogen than the content in 'normal' atmospheric air. Therefore in the procedures for entering a ballast water tank, special attention should be paid to ensure that after the normal and customary aeration procedure, the oxygen content is acceptable for entering.

As a side remark it should be kept in mind, that nitrogen in itself is slightly lighter than air. Therefore it will not pose the same problem as CO_2 , which might accumulate in the bottom of the tank, because its specific gravity is 50% higher than it is for air.

4.2. LAND-BASED TEST INSTALLATION

In the land-based test installation the following emergency procedures will apply:

4.2.1. STEAM GENERATOR

The steam generator is equipped with an emergency stop switch located as shown in figure 4.2.1/1.

In case of any malfunction of the steam generator, rupture of a steam pipe or connection in the steam generator container, in the 20' container with the pasteurizer or outside any of the containers the emergency switch must be activated and personnel evacuated from the vicinity of the system until the steam pressure has subsided.

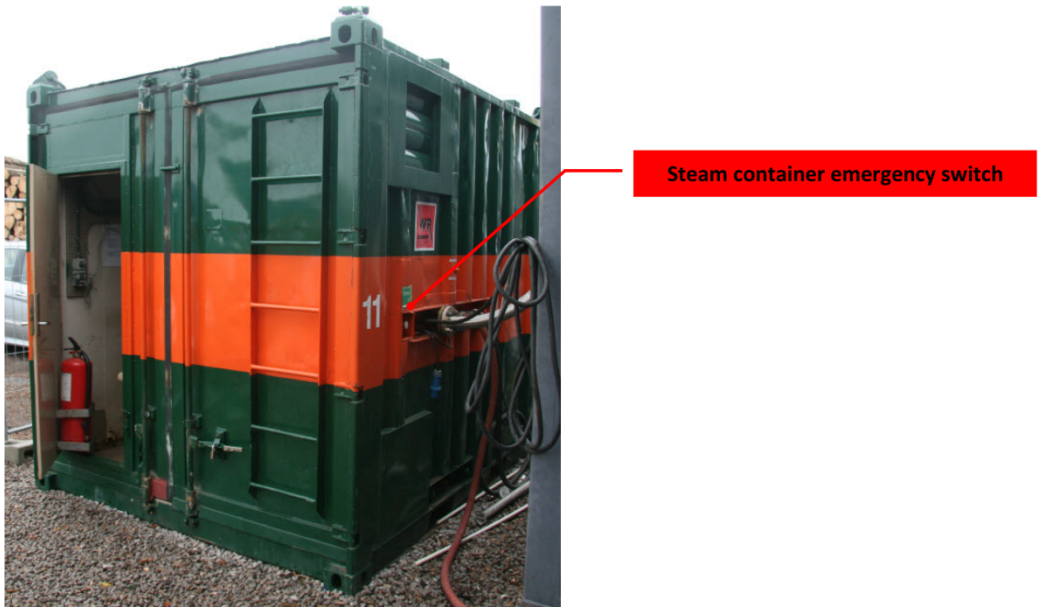


Figure 4.2.1/1: Location of steam generator emergency switch.

4.2.2. 20' CONTAINER

In case of escape of high pressure steam caused by a steam pipe rupture please refer to section 4.2.1 above.

The 20' container houses the nitrogen generator. In case of a generator malfunction there is a risk of increased nitrogen content in the air inside the container. Therefore, during operation of the generator at least one of the container doors must be fully open. Further, the feed-through openings of the various pipes through the container walls are constantly kept open to allow ventilation.

The compressor is equipped with an emergency switch located as shown in figure 4.2.2/1.

In case of malfunction of the nitrogen generator the emergency switch must be activated.

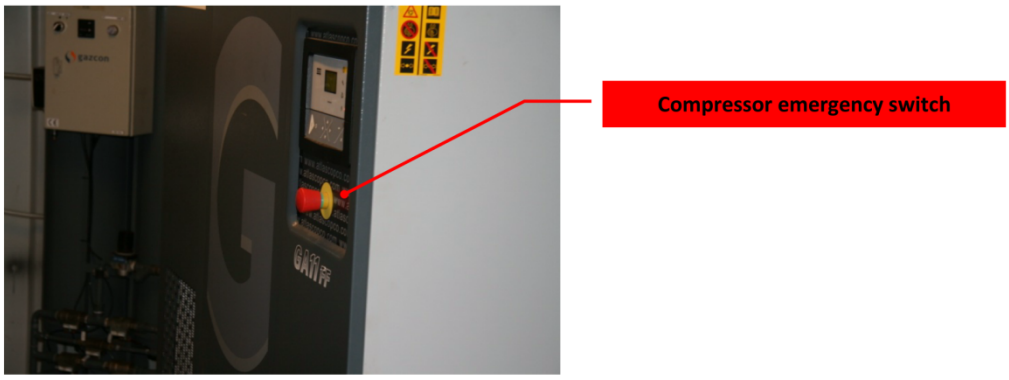


Figure 4.2.2/1: Location of compressor emergency switch.

4.2.3. 10' CONTAINER

The 10' container houses the BAWAT Control and Monitoring Centre (CMC) and the main recirculation pump.

The main fuse box with Residual Current Circuit Breakers is located outside on the back wall of the container – figure 4.2.3/1. In case of a malfunction in the pumps or the CMC that requires immediate power-down the power can be cut in the shown fuse box or on by turning the power switch to OFF on the front of the CMC unit inside the container - figure 4.2.3/2.

Figure 4.2.3/1: Main fuse box with Residual Current Circuit Breakers is located outside on the back wall of the 10' container.

5. APPENDICES

Appendices are available in digital form on a DVD or for download.

5.1. ISOMIX IM 25 ROTARY JET MIXER SPECIFICATIONS
5.2. STEAM GENERATOR SYSTEM
5.3. PASTEURIZER UNIT
5.4. IRON PUMPS CENTRIFUGAL PUMP
5.5. NITROGEN GENERATOR
5.6. DISSOLVED OXYGEN MEASUREMENT
5.7. PRESSURE MEASUREMENT
5.8. WATER FLOW MEASUREMENT
5.9. DATALOGGER AND SOFTWARE
5.10. NITROGEN FLOW INSTRUMENTATI
5.11. BIOLOGICAL TESTS (DHI)
5.12. BAWAT DOCUMENT 2012.007 ENTITLED "1:10 TEST TANK DESCRIPTION & STANDARD OPERATING PROCEDURES"
5.13. JAKOB K. HUUSOM AND JOHN VILLADSEN, DEPARTMENT OF CHEMICAL AND BIO-CHEMICAL ENGINEERING, DTU: TREATMENT OF BALLAST TANK WATER IN DIFFERENT SCALES – MODELLING OF THE BALLAST TANK, AND EXPERIMENTAL VALIDATION OF THE MODEL.
5.14. OXYGEN SENSOR
5.15. TEMPERATURE LOGGER

APPENDIX C

Overview of DHI SOPs

SUBJECT/SUBSUBJECT	DHI SOP NO.
ANALYTICAL METHOD DETERMINATION OF VIABLE ORGANISMS ≥50 µm	30/1700
ANALYTICAL METHOD DETERMINATION OF VIABLE ORGANISMS ≥10 µm AND < 50 µm	30/1701
ANALYTICAL METHOD DETERMINATION OF PRIMARY PRODUCTION OF MICROALGAE	30/1702
ANALYTICAL METHOD DETERMINATION OF VIABLE ALGAE BY RE-GROWTH ASSAY	30/1704
MICROBIOLOGICAL TESTS DETERMINATION OF TOTAL NUMBER OF BACTERIA BY EPIFLUORESCENCE MICROSCOPY	30/1705
MICROBIOLOGICAL TESTS DETERMINATION OF HETEROTROPHIC PLATE COUNT	30/1706
MICROBIOLOGICAL TESTS DETERMINATION OF *VIBRIO CHOLERAE* IN WATER	30/1707
MICROBIOLOGICAL TESTS DETERMINATION OF TOTAL COLIFORM, E.COLI AND ENTEROCOCCI	30/1708
MEASUREMENT METHOD TRO MEASUREMENT IN WATER	30/1732
HARVESTING, CULTURING AND ADDITION OF ORGANISMS	30/1734
COLLECTION OF SEAWATER	30/1735
COLLECTION OF FRESH WATER	30/1736
CRITERIA FOR TEST WATER ADDITION OF DOC, POC, MM AND BRINE	30/1737
SAMPLING PREPARATION, SUBSAMPLING AND TRANSPORTATION OF SAMPLES	30/1738
DATABASE SAMPLES, LABELS AND DATA SHEETS	30/1750
OPERATION OF THE DHI MTEF	30/1762
CLEANING RETENTION TANKS; PIPINGS AND OTHER EQUIPMENT AT TEST SITE	30/1763
MEASUREMENT METHOD ON-LINE MONITORING OF PRESSURE, TEMPERATURE, FLOW RATES AND QUALITY PARAMETERS AT TEST SITE	30/1764
MEASUREMENT METHOD FLUORESCENCE	30/1765
MEASUREMENT METHOD TURBIDITY	30/1766
DHI MTEF HEALTH AND SAFETY	30/1767
MEASUREMENT METHOD DETERMINATION OF TSS	30/1768
MEASUREMENT METHOD DETERMINATION OF DOC AND POC	30/1769
MEASUREMENT METHOD DETERMINATION OF TRANSMITTANCE	30/1770

Quality assurance project plan Version 3

Performance evaluation in land-based test facility of BAWAT ballast water management system

BAWAT

Quality assurance project plan

January 2014

Performance evaluation in land-based test facility of BAWAT ballast water management system

Prepared for	**BAWAT**
Represented by	**Mr Kim Diederichsen**

DHI land-based test facility in Hundested

This report has been prepared under the DHI Business Management System certified by DNV and specifically for ballast water management system testing certified by Lloyd's Register	
Quality Management	BWMS Testing
ISO 9001	IMO Resolution MEPC.174(58) Annex part 2
Quality Management System certified according to DS/EN ISO 9001 by Det Norske Veritas, Business Assurance, Danmark A/S	Lloyd's Register

Project No	11812682
Classification	Confidential

Author	Morten Bjergstrøm	

QC	Torben Madsen	

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B Description of the ballast water management system as provided by the client
C Overview of DHI SOPs

Abbreviations

Abbreviation	Description
BE	Biological efficacy
BWMS	Ballast water management system
CFU	Colony forming units
CMFDA	Chloromethylfluorescein diacetate
DNV	Det Norske Veritas
DO	Dissolved oxygen
DOC	Dissolved organic carbon
DQI	Data quality indicator
FDA	Fluorescein diacetate
IMO	International Maritime Organization
kVA	Kilovolt-ampere
MEPC	Marine Environment Protection Committee
POC	Particulate organic carbon
PSU	Practical salinity units
QA	Quality assurance
QAPP	Quality assurance project plan
QC	Quality control
QMP	Quality management plan
SOP	Standard operating procedure
TRO	Total residual oxidants
TSS	Total suspended solids
UV-T	UV transmittance
WET	Whole effluent toxicity

1 Project description and treatment performance objectives

1.1 Background and objectives

For an application for final approval, the IMO International Convention for the Control and Management of Ships' Ballast Water and Sediments /1/ requires a performance evaluation of ballast water management systems (BWMS) according to the principles laid down in Resolution MEPC.174(58) /2/, generally referred to as IMO G8 guidelines, and, for systems that make use of active substances, also Resolution MEPC.169(57) /3/, generally referred to as IMO G9 guidelines. The purpose of the performance evaluation is to assure that BWMS approved by administrations are capable of meeting the ballast water performance standard in Regulation D-2 /1/, also known as the IMO D-2 standard, in land-based and shipboard evaluations and do not cause unacceptable harm to the vessel, crew, environment or public health.

The objective of the project is to conduct a performance evaluation of the BWMS in a land-based test facility with the aim to meet the testing requirements in Resolution MEPC.174(58) /2/.

1.2 Client and ballast water management system

The client requesting the performance evaluation is:

BAWAT A/S
Diplomvej 381
DK-2800 Kongens Lyngby

The client is the manufacturer of the BAWAT BWMS.

1.3 Classification society

The classification society appointed by the client for inspection and certification of the project is:

Det Norske Veritas A/S (DNV)
Mariesvej 30
NO-1363 Høvik
Norway

1.4 Testing laboratory

The project is conducted by DHI Denmark (www.dhigroup.com) with the following facilities:

Mailing address:

DHI
Agern Allé 5
DK-2970 Hørsholm
Denmark
Att. Torben Madsen

DHI Maritime Technology Evaluation Facility
Færgevejen
DK-3390 Hundested
Denmark

DHI Denmark and its facilities are described in detail in Chapter 3.

The project manager for this project is Morten Bjergstrøm, M.Sc.

2 Project organisation and personnel responsibilities

The project organisation is illustrated in Figure 2.1.

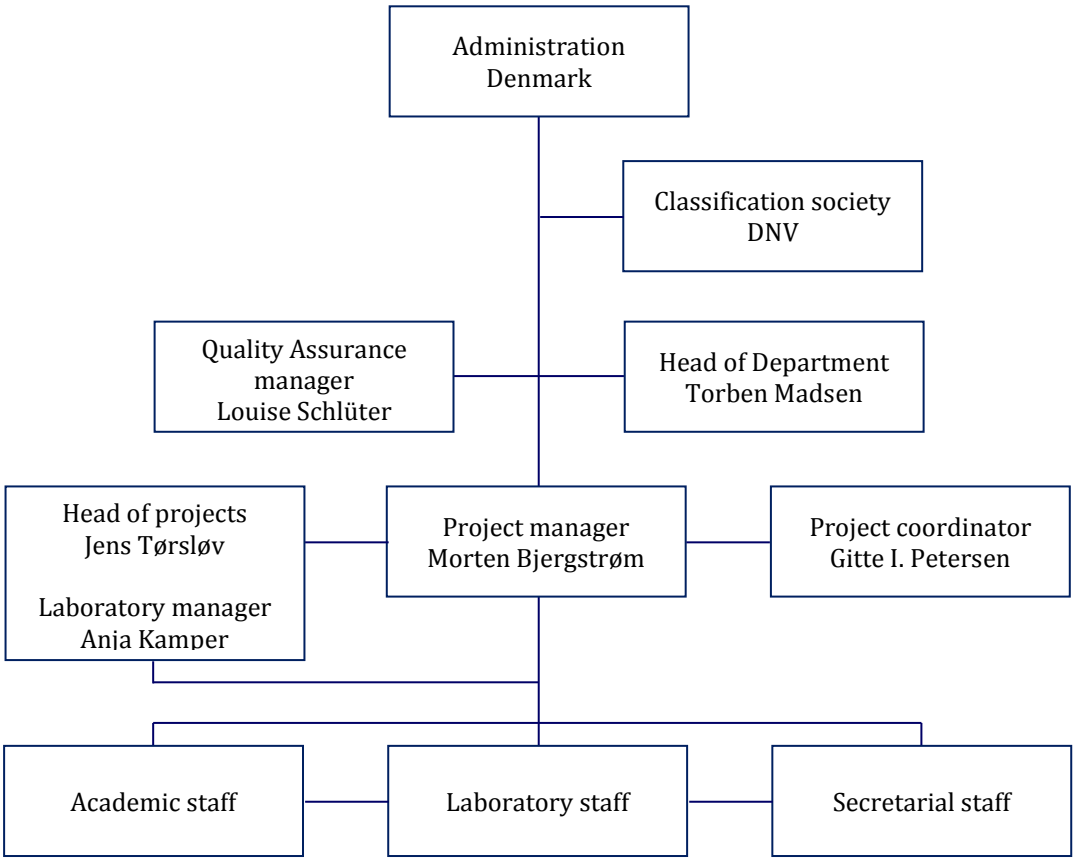

Figure 2.1 The DHI project organisation

2.1 Quality assurance

Senior biologist Louise Schlüter (Ph.D.) is assigned by DHI's Quality Assurance (QA) Unit as internal auditor (see Chapter 11). This includes the following tasks:

- Drafting of a plan for quality assurance
- Monitoring of compliance with the quality management plan (QMP), the quality assurance project plan (QAPP) and the standard operating procedures (SOPs) by audit including the project manager and the laboratory staff
- Monitoring compliance with the appropriate guidelines by audit including the project manager
- Verification of the presence of applicable staff training records
- Drafting of audit reports and verification that audit responses are appropriate and that corrective action has been implemented effectively
- Verification that the final product complies with DHIs standards for QA (Chapter 11) and, particularly, the QMP, the QAPP and the guidelines and standards.

2.2 Management and quality control

Head of department Torben Madsen (Ph.D.) is quality supervisor for all projects and has the overall responsibility for the services related to performance evaluation of BWMS provided by DHI Denmark. This includes the following tasks:

- Member of the Ballast Water Test Facility Board for DHI Ballast Water Centre, a coordinating structure between DHI Denmark and DHI Singapore
- Overall responsibility for the liaison and contractual relations between DHI and Lloyds Register EMEA (certification of test facility), between DHI and the Danish Accreditation and Metrology Fund, DANAK (accreditation of analyses), and between DHI and the Independent Laboratory (subcontractor agreement)
- Negotiation of contracts with clients
- Appointment of project managers and staff responsible for quality control (QC) of individual data (data-level QC) and maintenance of staff experience records (allocation of project managers for specific projects is the responsibility of the head of projects)
- Maintenance of the QMP /4/ with updated versions as appropriate
- Quality control of the QAPP, SOPs and all project proposals, deliverables and reports
- Documentation in relation to
    - Staff training and experience
    - Facilities and their maintenance
    - Records of complaints

2.3 Project coordinator

Business area manager Gitte I. Petersen (Ph.D.) is responsible for the coordination, timely execution and the overall scientific quality of the services. This includes the following tasks:

- Business development and marketing
- Contact and dialogue with Lloyds Register EMEA prior to inspections and for management of the actions and documentation, in collaboration with the laboratory manager, as required to comply with the Certificate of Compliance issued by Lloyds Register EMEA
- Contact and dialogue with the Independent Laboratory prior to inspections and for management of the actions and documentation, in collaboration with the laboratory manager, as required to comply with the agreement between DHI and the Independent Laboratory
- Coordination of the services to ensure optimal logistics at the test facility, including decisions related to the practical installation of clients and their technology and timing of tests
- Maintenance of the test facility including routine technical maintenance and dialogue with the head of department in relation to investments and maintenance expenses
- Instruction of staff with responsibility for specific tasks such as test facility technical operations and production of test water
- Principal scientific expert with responsibility for the overall scientific quality of the services, including compliance with official guidelines, standards, protocols and requirements from classification societies and Independent Laboratories; this implies input to the QAPP and the Test Plan, revisions and implementation of SOPs, and contributions to data interpretation and reporting in collaboration with the project manager
- Participation in discussions with the classification society or the Independent Laboratory on important matters, particularly draft and final reports, together with the project manager

2.4 Staffing, planning and project execution

Head of projects Jens Tørsløv (Ph.D.) has the overall responsibility for allocation of staff, planning and project execution in coordination with the business area manager or the project manager as appropriate.

Laboratory manager Anja Kamper (M.Sc.) allocates laboratory technicians for a specific project as part of the laboratory capacity planning by allocation of responsibility from the head of projects. Furthermore, the laboratory manager appoints one or more test co-ordinators among the laboratory technicians or the academic staff for on-site co-ordination of land-based test cycles.

The laboratory manager is responsible for the contact and dialogue with DANAK prior to inspections and for management of the actions and documentation as required in order to comply with the ISO 17025 accreditation /5/.

2.5 Project management

The project manager is responsible for the management and efficient performance of the project in accordance with the contract between the client and DHI, with the QMP and with the QAPP.

The project manager's tasks include:

- Organisation and management of the project
- Meetings and other communication with the client to ensure that all necessary information is available in due time
- Preparation of the draft and final QAPP with detailed description of the project, including time schedule of activities and deliverables; the QAPP shall be made available to all staff participating in the project
- Facilitation of the process for comments and responses to the draft QAPP in dialogue with the client and the classification society
- Preparation of potential amendments and deviations to the QAPP
- Communication of the project time schedule to the classification society to enable external audit
- Participation in discussions with the classification society on important matters, particularly draft and final reports, together with the project coordinator
- Co-ordination and dialogue with the laboratory manager in relation to the practical organisation of work involving laboratory technicians; the project manager shall in due time inform the laboratory manager on the types of tests and the required capacity to enable laboratory capacity planning
- Contracts with subcontractors as appropriate for meeting the project deliverables (e.g. chemical analytical laboratory)
- Approval of initiation of the test cycles and interruption of test cycles, e.g. in case of irregularity
- Preparation of reports

2.6 Academic, laboratory and secretarial staff

The tasks of the academic, the laboratory and the secretarial staff include:

- Maintenance of materials and equipment
- Test facility technical operations
- Test co-ordinator function, i.e. co-ordination and keeping of timely records of the activities at the test facility during land-based tests
- Production of test water and monitoring of test water quality
- Sampling at the test facility
- Analysis and data processing, including data-level QC
- Contributions to test reports
- Archiving of documents and raw data
- Contributions to QAPPs and SOPs

2.7 Client

The tasks of the representative of the client include:

- Signing a Contract with DHI for the BWMS performance evaluation project
- Project management of the client's activities in the project, including the liaison with DHI and decisions in relation to the testing
- Review and comments to the draft QAPP and approval of the final QAPP
- Collaboration with DHI to establish all necessary arrangements prior to initiation of the test
- Review and comments to draft test reports
- Dismantling and removal of the BWMS from the test facility after ended testing

3 Description of testing laboratory

3.1 DHI Denmark

DHI is an independent, international consulting and research organisation established in Denmark and today represented in all regions of the world with a total of more than 1,000 employees. Our objectives are to advance technological development, governance and competence in the fields of water, environment and health. DHI works with governmental agencies and authorities, contractors, consultants and numerous industries.

DHI has no involvement, intellectual or financial, in the mechanics, design or marketing of the products and technologies that are being evaluated. To ensure that DHI's tests are uncompromised by any real or perceived individual or team bias relative to test outcomes, DHI's test activities are subject to rigorous quality assurance (QA), quality control (QC) and documentation.

DHI's quality management system is certified according to ISO 9001 by DNV (Det Norske Veritas). The certification is facilitated by the implementation of the DHI Business Management System (see Chapter 11).

3.2 DHI Environmental Laboratory

DHI's Environmental Laboratory has an accreditation according to ISO 17025 /5/, including ecotoxicological studies and analyses related to the performance evaluation of BWMS. Furthermore, the laboratory is authorized to carry out ecotoxicological studies in compliance with the OECD Principles of Good Laboratory Practice (GLP) /6/.

DHI's Environmental Laboratory and staff normally analyse all samples collected during the performance evaluation of BWMS. If required, specialized chemical analyses of, e.g., active substances or disinfection by-products, are conducted by a subcontractor identified in the section on Subcontractors.

3.3 DHI Maritime Technology Evaluation Facility

DHI holds a Certificate of Compliance issued by Lloyd's Register EMEA for the performance of land-based and shipboard testing of BWMS (Appendix A).

The travel time from the DHI Maritime Technology Evaluation Facility (hereafter the 'test facility') to the DHI Environmental Laboratory is approx. 50 min, which enables analysis or treatment of the samples within 6 hours.

The test facility is used to conduct biological evaluations of maritime technologies. The test facility is covered by the International Safety Port System (ISPS). Hundested Harbour is registered at IMO's website (Port facilities) under Port ID No. 266076DKHUN, Port facility 1651.

The test facility includes seven cylindrical tanks constructed in galvanized steel and coated with a non-toxic top coating:

- One open 750-m^3 source tank, Tank D in Figure 3.1. The source tank is equipped with a propeller, which creates a slow circulation in order to maintain the homogeneity of the test water. A bridge across the top of the source tank is established for monitoring the homogeneity.
- Six closed 250-m^3 retention tanks, Tanks A1, B1, C1, A2, B2 and C2 in Figure 3.1. Tanks A1 and A2 are also described as 'control tanks' and are used for untreated test water. Tanks B1, C1, B2 and C2 are retention tanks for treated test water. Each of the six retention tanks is equipped with a submersible agitator (with three-blade propeller), to create a slow circulation in order to maintain homogeneity of the test water.

The piping connecting source tank, control tanks, retention tanks, pump and BWMS is made of polyethylene. The diameters are 315 mm and 350 mm for the piping connecting the A1, B1 and C1 tanks and 400 mm and 500 mm for the piping connecting the A2, B2 and C2 tanks.

The piping system connecting the source tank and the retention tanks is equipped with sampling ports. The sampling ports are equipped with the following sample outlets:

1. Sample outlet for ≥1-m^3 samples (to be used for analysis of organisms ≥50 µm)
2. Sample outlet for ≥10-L samples (to be used for analysis of organisms ≥50 µm and organisms ≥10 to <50 µm)
3. Sample outlet for microbiology samples
4. Sample outlet for samples for analysis of dissolved organic carbon (DOC), particulate organic carbon (POC), total suspended solids (TSS) and transmittance

The test facility is equipped with sensors for automatic logging of flow, pressure, water levels, temperature, dissolved oxygen, pH, salinity and turbidity.

The test facility includes a main pump with a flow performance of 250-500 m^3/hour. By use of a harbour piping, this pump can be used to provide a continuous flow of brackish water directly from the harbour to the BWMS with a capacity of up to approx. 300 m^3/hour. Furthermore, the test facility includes electrical generator power supply up to 150 kVA.

If needed to fulfil the test water quality requirements, appropriate volumes of cultivated organisms can be added to the source tank by an auxiliary pump.

The exact configuration of the test facility piping and equipment may be subject to minor changes.

The procedures, guidelines or characteristics for analyses, operations or tests performed in the DHI Environmental Laboratory, at the test facility or on board a vessel are described in SOPs.

For this specific test, the retention tank C2 was modified with a central tower and tarpaulins to create appropriate barriers. The tarpaulins are fixed to the central tower and the wall of the retentions tank by use of wires.

The detailed modifications are illustrated in Figures 3.2-3.4.

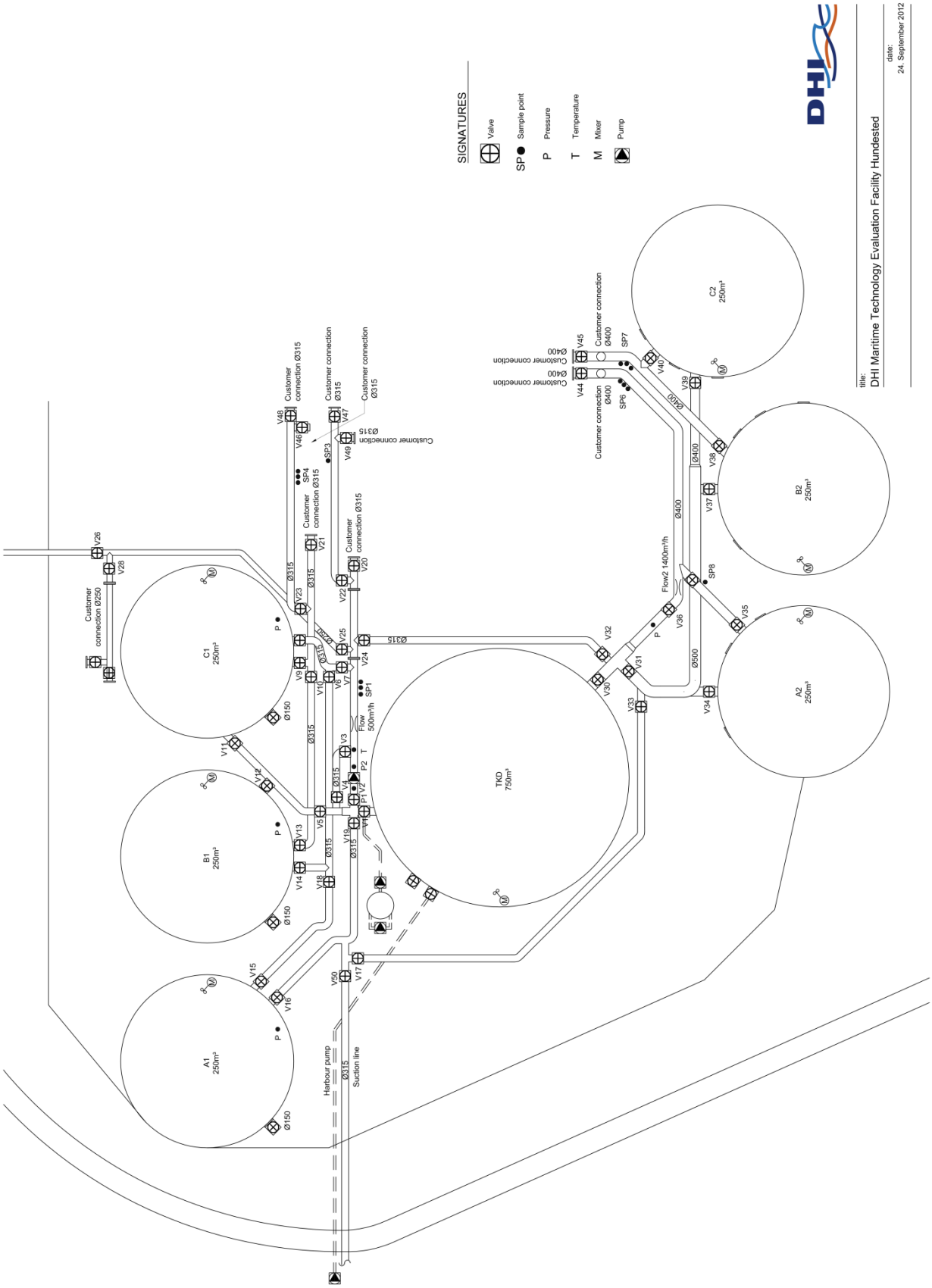

Figure 3.1 DHI Maritime Technology Evaluation Facility, Hundested, Denmark

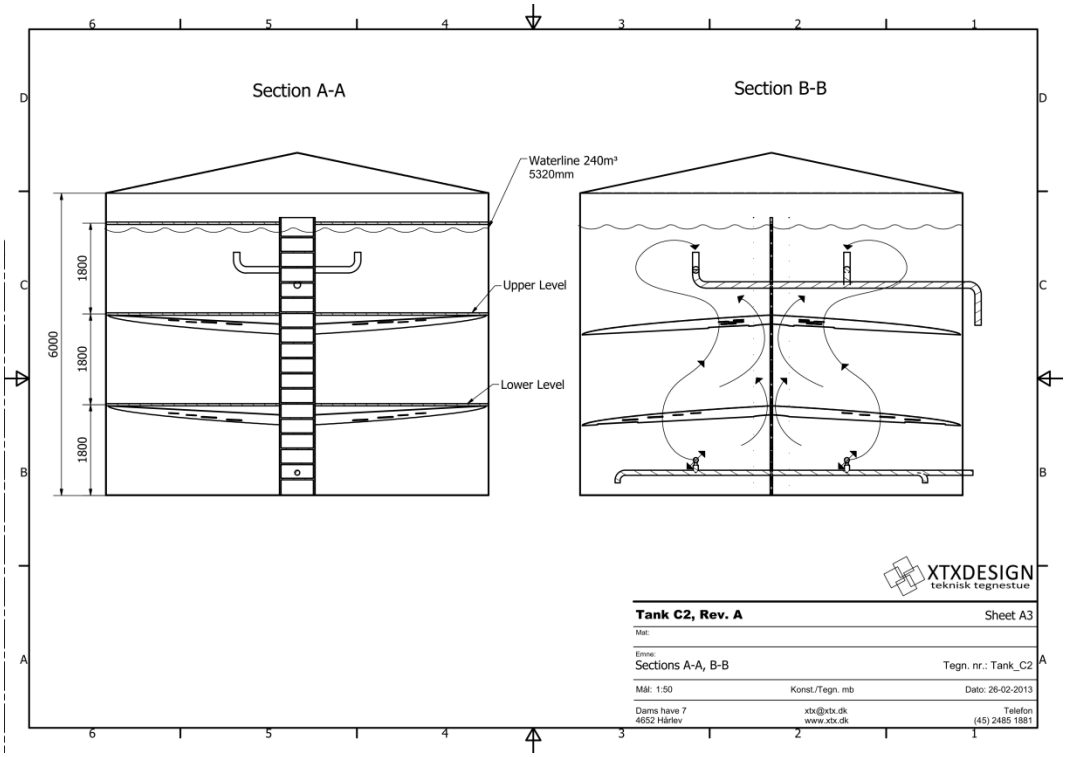

Figure 3.2 Cross sections of retention tank modifications

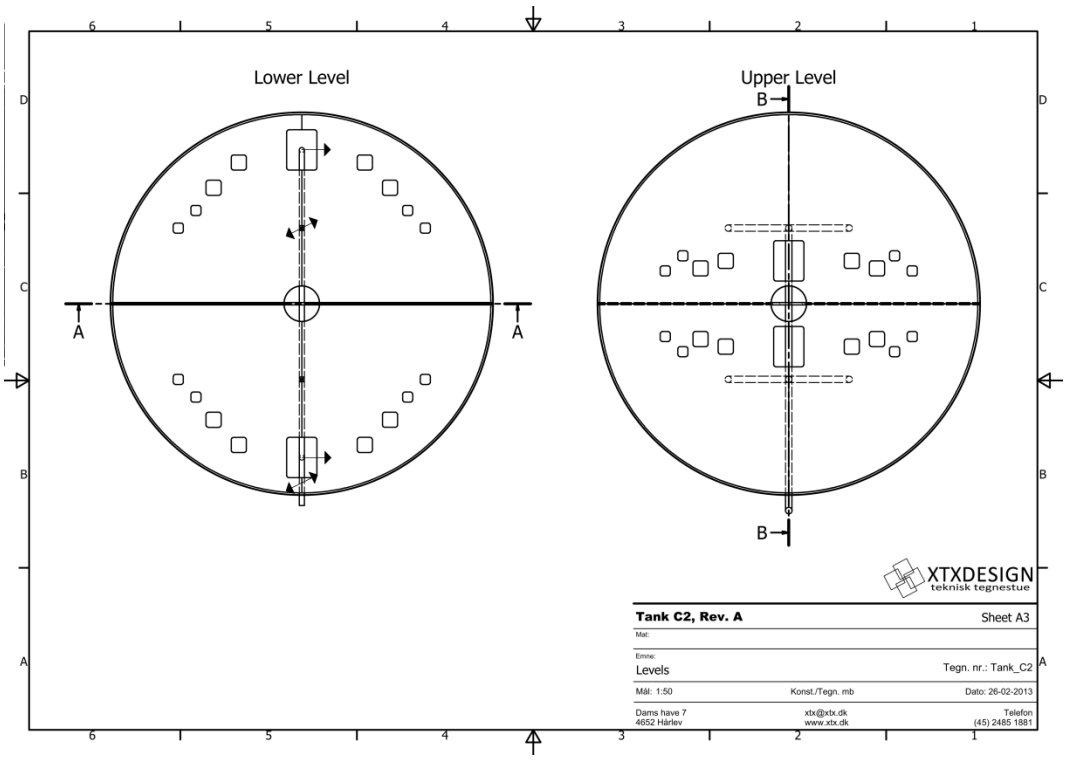

Figure 3.3 Tarpaulin design

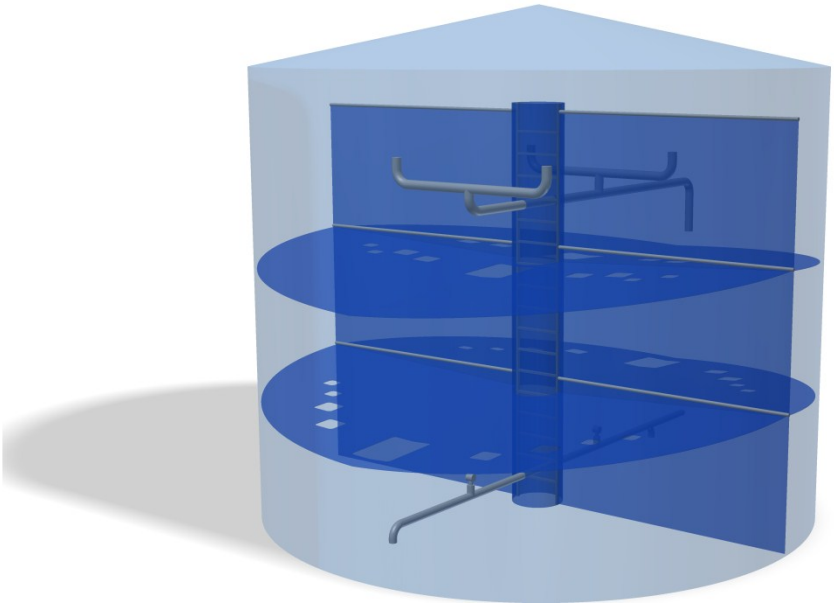

Figure 3.4 3D-view of retention tank modifications

3.4 Subcontractors

Statens Serum Institut
Artillerivej 5
DK-2300 København S

For verification of *Vibrio cholerae* according to DHI SOP 30/1707.

4 Description of ballast water management system

The description of the BWMS as provided by the client is enclosed in Appendix B.

5 Experimental design

5.1 Installation and operation of the BWMS

The BWMS shall be ready to enter the performance evaluation. Prior to the start of the performance evaluation of the BWMS, it is the client's responsibility to have met all requirements for initiation of testing set forth by the classification society appointed by the client.

The client is expected to deliver the BWMS to the test facility in due time before the initiation of the performance evaluation (see chapter on Time schedule). The BWMS shall be delivered in a container, which can protect the equipment, and installed in accordance with the directions of DHI.

The BWMS will be operated by the client during all test cycles.

5.2 Water types applied in the land-based test

The present land-based test with the BAWAT BWMS will be conducted with the following water types:

- Fresh water (salinity <3 PSU)
- Brackish water (salinity 3-32 PSU)
- Marine water (salinity > 32 PSU)

The land-based test will include three (3) sets of biological efficacy (BE) test cycles, each consisting of five (5) replicate BE test cycles with duration of at least five (5) days. Each set of BE test cycles will be conducted with test water representing one salinity range.

5.3 Biological efficacy verification testing

5.3.1 BWMS treatment process

The BE test cycles will be conducted by use of the source tank (Tank D), control tank (Tank A2) and one retention tank per test cycle (Tank C2) (Figure 3.1).

In the BWMS, the treatment of the test water will include the following steps (for definition and characterisation of test water, see Section 6.1):

1. A fraction of the test water (200-250 m^3) contained in the source tank will be transferred to the retention tank by pumping and treated by the BWMS in-tank*
2. Another fraction of the same test water (200-250 m^3) will be pumped directly into the control tank without passing the BWMS (control water). The control water serves as a control of BWMS performance*
3. Piping system and sample ports will be cleaned (DHI SOP 30/1763)

* The control and retention tanks may be filled simultaneously.

During ballasting, the flow, pressure, temperature, dissolved oxygen, pH, salinity, turbidity and water levels in the tanks will be recorded automatically (DHI SOP 30/1764).

Samples will be collected before treatment by use of relevant inlet sample ports. Sampling will be initiated when the flow rate has reached steady-state conditions, i.e. up to 5 minutes from start of operation (DHI SOPs 30/1738 and 30/1762). Samples will be labelled according to procedures described in DHI SOP 30/1750.

5.3.2 Storage of treated and untreated test water

Following the treatment of the test water with the BWMS, the treated water will be stored in the retention tank for at least five days ± 4 hours. The same storage time will be applied for the control water.

5.3.3 Discharge of test water

1. Treated water contained in the retention tank will be discharged into the harbour (treated discharge water)
2. Control water contained in the control tank will be discharged into the harbour (control discharge water)
3. The retention tanks, piping system and sample ports will be cleaned (DHI SOP 30/1763)

During de-ballasting, the flow, pressure, water temperature, dissolved oxygen, pH, salinity, turbidity and water levels in the tanks will be recorded automatically (DHI SOP 30/1764).

Samples of the treated discharge water will be collected by use of the sampling port on the BWMS discharge line whereas samples of the control discharge water will be collected on the MTEF discharge line. The samples will be collected by use of approximated isokinetic sampling methodology with fixed sample volumes according to principles described in MEPC.173(58) (G2) /7/.

6 Challenge conditions

6.1 Test water

6.1.1 Source water applied in the land-based test

Source water means the body of water from which water is drawn for the land-based test. The IMO G8 guidelines /2/ describes three distinct water types that may be applied in the land-based test:

Fresh water (salinity < 3 PSU)

Brackish water (salinity 3 - 32 PSU)

Marine water (salinity >32 PSU)

When fresh water is used, the source water will be collected from e.g. the Arresø Canal according to DHI SOP 30/1736 on collection of fresh water. Organism densities in the collected fresh water often exceed the minimum criteria for live organisms in test water with an order of magnitude allowing for dilution of the natural fresh water with potable water.

When brackish water is used, the source water will be collected immediately south of the pier adjacent to the test facility according to DHI SOP 30/1735; under normal conditions, the natural salinity of the source water will be 15-20 PSU.

When marine water is used, the source water will be collected immediately south of the pier adjacent to the test facility according to DHI SOP 30/1735, and brine will be added to achieve the required salinity.

6.1.2 Test water – water quality characteristics

Test water means the inlet water as contained in the source tank just prior to treatment. In land-based tests, source water may be adjusted to achieve the required challenge conditions.

In the source water, the natural concentrations of dissolved organic carbon (DOC), particulate organic carbon (POC) and total suspended solids (TSS) are analysed, after which the test water will be prepared to meet the water quality parameters in Table 6.1.

Table 6.1 Minimum water quality characteristics in compliance with the IMO G8 guidelines /2/.

Parameter	Test water		
	Fresh (<3 PSU)	Brackish (3-32 PSU)	Marine (>32 PSU)
Dissolved organic carbon (DOC)	>5 mg/L	>5 mg/L	>1 mg/L
Particulate organic carbon (POC)	>5 mg/L	>5 mg/L	>1 mg/L
Total suspended solid (TSS)	>50 mg/L	>50 mg/L	>1 mg/L

If necessary in order to obtain the stated water quality parameters, the concentrations of DOC, POC and mineral materials (MM) will be increased by additions of lignin sulphonate (DOC), starch (POC) and kaolin clay (MM) as described in DHI SOP 30/1737.

6.1.3 Test water – biological organism conditions

The natural densities of live organisms in the test water are analysed with reference to size classes, after which the test water will be prepared to meet the biological parameters in Table 6.2.

Table 6.2 Minimum criteria for densities of live organisms in the test water according to the IMO G8 guidelines /2/

Organism size class	Total concentration	Diversity
≥50 µm	100,000 organisms/m^3	5 species across 3 phyla
≥10 µm and <50 µm	1,000 organisms/mL	5 species across 3 phyla
<10 µm	10,000/mL as culturable aerobic heterotrophic bacteria	Not applicable

If necessary to obtain the stated minimum criteria, the densities of live organisms will be increased by addition of harvested indigenous organisms and/or cultured species as described in DHI SOP 30/1734. Addition of harvested and/or cultured species is recorded in the data logging.

Heterotrophic bacteria are typically present in the test water in densities exceeding the minimum criteria described in Table 6.2.

7 Sampling and analysis plan

7.1 Sample overview in BE verification testing

Table 7.1 Overview of sampling and purpose of samples

Parameter	Inlet water to BWMS and control tank	Treated discharge water	Control discharge water	Sample collection
Ballasting operations				
Volume	×	×	×	Continuous
Pressure	×	×	×	Continuous
Flow	×	×	×	Continuous
Other parameters*	×	×	×	Continuous
Water quality conditions				
Temperature, salinity, turbidity, pH, DO**	×	×	×	Continuous
TSS, DOC***, POC*** and UV-T****	×	×	×	Discrete grab (3 replicates; start, middle, end)
Concentrations of live organisms				
Viable organisms ≥50 µm	×******	×	×	Discrete (3 replicates; time integrated)
Viable organisms ≥10 and <50 µm	×	×	×	Discrete (3 replicates; each representing approx. a third of the operation period)
Viable organisms <10 µm (heterotrophic aerobic bacteria, *E. coli*, enterococci and *Vibrio cholerae*)	×	×	×	Discrete grab (3 replicates; start, middle, end)
Whole Effluent Toxicity (WET)*****	-	×	×	Discrete (time integrated)

* Operational parameters to ensure that the systems have been operated correctly and in accordance with the Operation and Maintenance manual
** Dissolved oxygen
*** Measured in inlet and discharge samples
**** UV-transmittance at 254 nm, 1 cm, measured in inlet samples
***** Only in BE test cycles to be decided later
****** Collected as discrete grab samples (3 replicates; start, middle, end)

Triplicate flow-integrated samples will be collected. The samples will be stored in thermo boxes with cooler bricks in the dark from the time of collection until handling of the samples in the DHI Environmental Laboratory.

7.2 Inlet water

Table 7.2 Sampling and analysis of inlet water to BWMS and control tank

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Microscopy	30/1701	DHI
Organisms <10 µm		
Heterotrophic aerobic bacteria	30/1705	DHI
E. coli and enterococci	30/1708	DHI
Physical/chemical		
Temperature, pH, O_2, salinity and turbidity	30/1764	DHI
TSS, DOC and POC	30/1768 and 30/1769	DHI
UV-transmittance at 254 nm, 1 cm	30/1770	DHI

7.3 Treated discharge water and control discharge water

Table 7.3 Sampling and analysis of treated discharge water

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Microscopy	30/1701	DHI
Organisms <10 µm		
E. coli and enterococci	30/1708	DHI
Vibrio cholerae	30/1707	DHI
Physical/chemical		
Temperature, pH, O_2, salinity and turbidity	30/1764	DHI
TSS, DOC and POC	30/1768 and 30/1769	DHI

Table 7.4 Sampling and analysis of control discharge water

Parameter	DHI SOP	Laboratory
Organisms ≥50 µm	30/1700	DHI
Organisms ≥10 µm and <50 µm		
Microscopy	30/1701	DHI
Organisms <10 µm		
E. coli and enterococci	30/1708	DHI
Vibrio cholerae	30/1707	DHI
Physical/chemical		
Temperature, pH, O_2, salinity and turbidity	30/1764	DHI
TSS, DOC and POC	30/1768 and 30/1769	DHI

8 Data management, analyses and reporting

8.1 Data management

During the land-based test, logging of data related to

- Personnel participating in cleaning and maintenance at the test facility and collection of samples
- Operational procedures and monitoring
- Sampling and analysis

is performed in accordance with the data logging procedures described in the respective DHI SOPs. A complete overview of the DHI SOPs used for BWMS performance evaluation is presented in Appendix C.

An Access-based database and the procedures described in DHI SOP 30/1750 are used for storage of data generated from the BE test cycles and for marking completed QC of individual data. This data-level QC is made with reference to data quality indicators described in the DHI SOPs.

All generated data and all other records and information relevant to the quality and integrity of the performance evaluation, including a copy of the database file(s) and original raw data, will be retained in the archives of DHI for a period of five years after issue of the final report.

8.2 Analyses

8.2.1 Organism size class ≥50 µm

Compliance with the pass criterion in Chapter 10 will be verified by use of the direct count of organisms ≥50 µm in minimum dimension.

The concentrations of live organisms ≥50 µm in minimum dimension are determined by use of a stereo microscope and a counting chamber according to DHI SOP 30/1700. Viable organisms are enumerated by use of standard movement and response stimuli technique. The viable organisms are characterized according to broad taxonomic groups such as crustaceans (e.g. copepods), molluscs, rotifers, worms, etc.

8.2.2 Organism size class ≥10 µm and <50 µm

Compliance with the pass criterion in Chapter 10 will be verified by use of the total of viable organisms determined by the vital staining methodology.

To support the determination of concentrations of organisms in the ≥10 µm and <50 µm size class, a combination of the following analytical methods will be applied.

Inverted microscopy (DHI SOP 30/1701). The concentrations of organisms and the presence of taxonomic groups in the inlet water are determined by inverted microscopy.

Vital staining with fluorescein diacetate (FDA) and chloromethylfluorescein diacetate (CMFDA) (DHI SOP 30/1701). FDA and CMFDA are added to a subsample and, after incubation, the subsample is examined by use of a microscope under epifluorescence. Organisms labelled by either FDA or CMFDA are considered viable as described in DHI SOP 30/1701.

8.2.3 Organism size class <10 µm

The concentrations of heterotrophic aerobic bacteria will be determined according to DHI SOP 30/1706 (ISO 6222). *E. coli* and enterococci will be analysed according to DHI SOP 30/1708 using ISO-9308-1 for determination of *E. Coli* and ISO 7899-2 for determination of enterococci. *Vibrio cholerae* will be analysed according to the method described in DHI SOP 30/1707.

8.2.4 Physical/chemical analyses

The measurements conducted at the test facility according to DHI SOPs 30/1764 and 30/1766 will include:

- pH
- Temperature
- Salinity
- Turbidity
- Dissolved oxygen
- Ballast system pressure
- Ballast system flow rates
- Water volume in retention tanks

The analyses conducted at the DHI Environmental Laboratory will include the following measurements:

- TSS
- POC
- DOC
- UV-transmittance at 254 nm, 1 cm

8.3 Amendments, deviations and reports

Amendments are planned changes to the QAPP. Deviations are unplanned changes. Amendments and deviations will be signed by the project manager and documented in the file and the final report.

The following reports will be prepared:

- Draft final report compiling all relevant data from the test cycles, data interpretation and conclusion
- Final report

9 Validity criteria

A valid BE test cycle includes:

Concentrations of live organisms in control discharge water being (a) ≥100 organisms/m^3 for the organism size class ≥50 µm and (b) ≥100 organisms/mL for the organism size class ≥10 µm to <50 µm (IMO G8 guidelines, Annex, Part 2, Section 2.3.36 /2/)

10 Pass criteria

A valid BE test cycle is regarded as successful if it meets the performance standard for treated ballast water at discharge (IMO Regulation D-2 /1/):

1. The average density of organisms larger than or equal to 50 µm in minimum diameter in the replicate samples shall be less than 10 viable organisms per m^3 at discharge
2. The average density of organisms smaller than 50 µm and larger than or equal to 10 µm in minimum diameter in the replicate samples shall be less than 10 viable organisms per mL at discharge as determined by vital staining

3. The average density of *Vibrio cholerae* (serotypes O1 and O139) shall be less than 1 colony forming unit (CFU) per 100 mL at discharge
4. The average density of *E. coli* in the replicate samples shall be less than 250 CFU per 100 mL at discharge
5. The average density of intestinal enterococci in the replicate samples shall be less than 100 CFU per 100 mL at discharge

11 Quality assurance and control

11.1 Quality assurance

The project is conducted in accordance with the principles of ISO 9001 by using the DHI Business Management System and the procedures in the QMP /4/.

The DHI quality manager is responsible for assigning a trained internal auditor from DHI's Quality Assurance Unit to each project in accordance with the procedures for internal audit in the DHI Business Management System (Section on Quality). The internal auditor shall not be involved in solving the specific project or in any project deliverables.

The DHI Business Management System (Section on Quality; Internal Audit) describes procedures for audit and evaluation and the process of periodic internal auditing of projects and activities including audit responsibilities and planning, auditor training and competences and audit reporting.

The DHI Business Management System (Section on Quality; Correction and Prevention) describes procedures for corrective actions, i.e. how deviations identified during operation and auditing are corrected and how future occurrence of the same deviations is prevented (preventive actions).

11.2 Quality control

Quality control of individual data, or data-level QC, of BWMS operational conditions, sampling and analyses is conducted with reference to data quality indicators (DQI) in the DHI SOPs by staff appointed for this task (see Section 2.2). The data quality indicators include accuracy, precision, bias, representativeness, completeness, comparability, and sensitivity. The DQI and how they are monitored and evaluated are described in the relevant DHI SOPs.

Records of completed data-level QC are stored in an Access-based database (DHI SOP 30/1750), and a copy of the relevant database file(s) will be retained in the DHI archives for a period of five years after issue of the final report.

Quality control of the QAPP, DHI SOPs and all project proposals, deliverables and reports is conducted by management (see Section 2.2).

12 Time schedule

The testing is expected to be initiated March 2013. The biological efficacy testing will be performed with one test every week or two tests every second week throughout the spring 2013 (to the extent possible).

Table 12.1 Time schedule for the biological efficacy testing

Test cycle	Intake	Discharge
1	20 March	25 March
2	27 March	2 April
3	10 April	15 April
4	17 April	22 April
5	24 April	29 April
6-10	24 April to 21 May	-
11-15	22 May to 20 June	-

The classification society will be regularly updated by BAWAT A/S as the testing progresses.

DHI decides the applied test water salinities and the timing of the test cycles within the access period.

Dependent on weather conditions and the possibilities of preparing the right test water quality, the land-based test cycles will be conducted as outlined above. Ballasting is performed on a weekday in the morning and the de-ballasting is performed after at least 5 days from approx. 08:00 am, if at all practicable.

A draft final report will be prepared within ten (10) weeks after the successful completion of the planned test cycles.

A final report will be issued three weeks after the client's approval of the draft final report.

13 References

[1] IMO. International Convention for the Control and Management of Ships' Ballast Water and Sediments (IMO Regulation D-2). London. International Maritime Organization, 2004.

[2] MEPC. Guidelines for Approval of Ballast Water Management Systems (G8). Resolution MEPC.174(58). Adopted 10th October 2008.

[3] MEPC. Procedure for Approval of Ballast Water Management Systems that Make Use of Active Substances (G9). Resolution MEPC.169 (57). Adopted 4th April 2008.

[4] Quality management plan. Performance Evaluation of Ballast Water Management Systems. DHI Denmark. Version 3.1. June 2012.

[5] EN ISO/IEC 17025. General requirements for the competence of testing and calibration laboratories /ISO/IEC 17025, 2005.

[6] OECD Principles of Good Laboratory Practice (as revised in 1997). Organisation for Economic Co-operation and Development (OECD), Paris. ENV/MC/CHEM (98)17.

[7] Resolution MEPC.173(58). Adopted on 10 October 2008. Guidelines for approval of ballast water sampling (G2).

14 Approval of quality assurance project plan

DHI Ballast Water Centre

Project management Date: 2014.01.30

Morten Bjergstrøm

Quality control Date: 2014.01.30

Torben Madsen

This QAPP is accepted and my signature authorizes the study to proceed as described in this document.

Client Date:

Kim Diederichsen
BAWAT A/S

APPENDIX A

Certificate of compliance, ISO 9001 certificate, accreditation and GLP authorisation

COPY

Certificate no: **DS/I093222-A**
Page 1 of 1

Lloyd's Register Certificate of Compliance

Office: **Lloyd's Register EMEA**
Copenhagen Design Support Centre, Statutory Section
Strandvejen 104A, 2nd floor
DK-2900 Hellerup
Denmark

Date: **09 May 2012**

This certificate is issued to **DHI Ballast Water Centre, Denmark**

DHI Ballast Water Centre, Denmark

The Document(s) listed in paragraph 1 of the appendix have been examined for compliance with:

- Resolution MEPC.174(58), Annex part 2

and are found to comply from quality assurance and quality control aspects subject to the following:

1.1. It is required to maintain full and accurate log files in order to demonstrate correct quality measures

1.2. The Quality Assurance Project Plan is a project specific document and should as such be subject to review and commenting prior to each project start-up.

1.3. This design appraisal document is to be kept together with quality management plan.

1.4. Subject certificate is valid until 15 June 2015.

1. The documents listed below have been examined

Drawing No.	Rev.	Title	Status	Date
Date: 07 Sep 2011	**2.3**	**Quality Management Plan**	**B**	**09 May 2012**

2. The documents listed below have been considered together with the submitted documents in the appraisal

Drawing No.	Rev.	Title
11810704	**02**	**Quality Assurance Project Plan**

Appraisal Status Key

B Examined and found to comply with §2.2, Part 2 of the annex of IMO Resolution MEPC 174 (58)

Martin Schabert
Statutory Department
Copenhagen Design Support Centre
Surveyor to Lloyd's Register EMEA

LLOYD'S REGISTER EMEA
Lloyd's Register
M. Schabert
COPENHAGEN DESIGN SUPPORT CENTRE

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DNV BUSINESS ASSURANCE

MANAGEMENT SYSTEM CERTIFICATE

Certificate No. 109333-2012-AQ-DEN-DANAK

This is to certify that

DHI Group

has been found to conform to the management system standard:

DS/EN ISO 9001:2008

This certificate is valid for the following product or service ranges:

Consulting, software, research & development and laboratory testing, analysis & products within the area of water, environment & health

Locations included in the certification will appear in the appendix.

Place and date:

Hellerup, 2012-03-23

DET NORSKE VERITAS,
BUSINESS ASSURANCE, DANMARK A/S

This certificate is valid until:

2015-01-10

The audit has been performed under the supervision of:

Jan Carsten Schmidt
Lead Auditor

DANAK
SYSTEM Reg.nr. 5001

Jens Peter Høiseth
Managing Director

Lack of fulfilment of conditions as set out in the Certification Agreement may render this certificate invalid.

ACCREDITED UNIT: DET NORSKE VERITAS, BUSINESS ASSURANCE, DANMARK A/S, TUBORG PARKVEJ 8, 2., DK-2900, HELLERUP, DANMARK, TEL:+45 39 45 48 00, WWW.DNVBA.COM

DNV BUSINESS ASSURANCE

APPENDIX TO CERTIFICATE

This appendix refers to certificate no. 109333-2012-AQ-DEN-DANAK

DHI Group

Locations included in the certification are as follows:

Site Address	Scope:
Agern Allé 5 2970 Hørsholm, Denmark	Consulting, MIKE© by DHI Software Development, Sales & Support, Solutions Software Development, Research, Development & Innovation and Laboratory Analysis, Testing & Products
INCUBA Science Park, Gustav Wieds Vej 10 8000 Århus, Denmark	Consulting, Solutions Software Development and Research, Development & Innovation
Drakegatan 6, 412 50 Göteborg, Sweden	Consulting, MIKE© by DHI Software Sales & Support
Kyrkogatan 3, 222 22 Lund, Sweden	Consulting, MIKE© by DHI Software Sales & Support
Svartmangatan 18, 111 29 Stockholm, Sweden	Consulting, MIKE© by DHI Software Sales & Support
Honnörsgatan 16, Box 3287, 350 53 Växjö, Sweden	Consulting, MIKE© by DHI Software Sales & Support

This certificate is valid until:

2015-01-10

The audit has been performed under the supervision of:

Jan Carsten Schmidt
Lead Auditor

DANAK
SYSTEM Reg.nr. 5001

Place and date:

Hellerup, 2012-03-23

DET NORSKE VERITAS,
BUSINESS ASSURANCE, DANMARK A/S

Jens Peter Høiseth
Managing Director

Lack of fulfilment of conditions as set out in the Certification Agreement may render this certificate invalid.

ACCREDITED UNIT: DET NORSKE VERITAS, BUSINESS ASSURANCE, DANMARK A/S, TUBORG PARKVEJ 8, 2., DK-2900, HELLERUP, DANMARK, TEL:+45 39 45 48 00, WWW.DNVBA.COM

Accreditation to testing COPY DANAK

Company: **DHI**

Agern Allé 5
DK-2970 Hørsholm

Registration number: **26**

Valid: **24-10-2012 to 31-07-2015**

Scope:

Testing

Product

- **Biological items**
- **Chemicals and chemical products**
- **Construction products**
- **Environmental samples**

Test Type

- **Biological and biochemical testing**
- **Chemical testing**
- **Microbiological testing**
- **Ionising radiation and radiochemistry**
- **Sampling**

Testing is performed according to the current list of test methods approved by DANAK.

The company complies with the criteria in EN ISO/IEC 17025:2005 – General requirements for the competence of testing and calibration laboratories and demonstrates technical competence for the defined scope and the operation of a quality management system (refer joint ISO-ILAC-IAF Communiqué dated January 2009, www.danak.dk).

Issued the 24 October 2012

Jesper Høy / **Kirsten Jebjerg Andersen**

In case of any disputes, the Document in Danish language shall have priority.

Den Danske Akkrediterings- og Metrologifond

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GOOD LABORATORY PRACTICE

STATEMENT OF COMPLIANCE

Laboratory inspection and study audits for compliance with the OECD Principles for Good Laboratory Practice were carried out at

Laboratory: DHI

on

Dates: 21st and 22nd October 2011

The laboratory inspection and study audits have been carried out in accordance with the regulation settled in Order No. 906 of 14th September 2009 from the Danish Ministry of Environment. The laboratory has been monitored for GLP Compliance within the following scope:

Type of products:

- *Industrial chemicals*
- *Pesticides*
- *Biocides*

Type of tests:

- *Environmental toxicity studies on aquatic and terrestrial organisms.*
- *Studies of behaviour in water, soil and air, bioaccumulation*

The laboratory was found to be operating in compliance with the OECD Principles of Good Laboratory Practice.

Date: 08 August 2012

Jesper Høy
Managing director, DANAK

Kirsten Jebjerg Andersen
GLP inspector, DANAK

Den Danske Akkrediterings- og Metrologifond

APPENDIX B

Description of the ballast water management system as provided by the client

The “BAWAT Land-Based Test - System Description & Standard Operating Procedures” has been updated by the client to reflect the following changes:

- Test 01 – Test 04 were performed with 4 recirculations. From test 05 and onwards the tests have been performed with 5 recirculations
- Test 01 – Test 06 were performed with cooling of the treated water after treatment. From test 07 and onwards the tests have been performed with in-line cooling during treatment

Bawat A/S

BAWAT Document 2012.009, ver. F / 2014-01-28

Land-based Test
System Description
& Standard Operating Procedures

Changes from BD 2012.009, ver. E dated 2013.03.18

1. Section 2.1: Figure 2.1/3 has been changed to show actual installation of in-line cooling heat exchanger.
2. Preceding text has been updated in accordance with change in installation.
3. Foot-note page 10 was added.
4. Section 2.11.1: Last paragraph was updated reflecting that the number of recirculations was changed from 4 to 5.
5. Foot note page 28 was added.
6. Section 2.11.2: Last two paragraphs deleted and new paragraph re. in-line cooling inserted.
7. Section 3.2: Item 1) deleted. Consequently following items have been renumbered.
8. Section 3.4 (Colling of Treated Water) deleted. Consequently following subsections in chapter 3 have been renumbered.

Changes from BD 2012.009, ver. D dated 2012 03 05:

9. Section 2.6.2/3 has been updated re. volume of retention section.
10. Section 2.8.2 is updated with respect to compressed air injection into the nitrogen flow.
11. Section 2.10.2: Temperature loggers are added to list of temperature sensors.
12. Section 2.10.4: Screen dump updated.
13. Section 3.2/12 re. adjustment of compressed air flow into the nitrogen flow was added.
14. Section 3.3/4 re. cooling SOP is added (consequential changes to numbering of following points).
15. Section 3.6:
    a. First line: “All process data” changed to “Main process data”.
    b. Bullet points 3, 4 and 5 re. treated water volume, oxygen content and logged tank temperatures data added. (consequential changes to numbering of following points).
16. Section 5.15 added.

Changes from BD 2012.009, ver. C dated 2012 09 27:

1. In section 1.1 changes have been made to the description of the BAWAT process steps:
    a. A few editorial changes
    b. In step 2 oxygen content target has been changed to 2.0 mg/L or less.
    c. In step 3 the sentence “Shortly …… minutes” has been deleted.
2. Section 2.1:
    a. Component 2.8 added.
    b. Figure 2.1/1 updated
    c. Rationale of and description of the cooling circuit added .incl. new figure 2.1/3.
3. Fact box has been added in section 2.2.
4. In section 2.5.1 text has been updated and extended re. number of recirculations.
5. In section 2.5.2 text has been updated re. pump rate, etc.
6. In section 2.7.1 text has been updated and extended.
7. In section 2.8.2 text re. addition of oxygen to the nitrogen flow has been added.

8. Oxygen sensor added in section 2.10.2
9. In section 2.11:
    a. A fact box regarding Henry's Law has been inserted.
    b. Information re. oxygen content in nitrogen gas has been added.
    c. Target DO level has been changed to 2.0 mg/L or less.
    d. Pasteurization temperature in land-based test have changed to 72 °C.
    e. The text re. the recirculation factor has been updated and extended.
    f. A new section re. temperature in treatment tank has been added.
10. In section 3.2 instructions re. valve positions have been added.
11. New section 3.4 describing procedures re. cooling of treated water has been added. Consequently following sections have been renumbered.
12. Oxygen sensor added in section 3.5.5

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1. INTRODUCTION

The present **BAWAT Document #2012.009** describes the BAWAT Land-based Test set-up at DHI's test facilities in Hundested, Denmark, its main components and the main standard operating procedures.

1.1. BACKGROUND

The BAWAT Ballast Water Treatment System is an **In-Tank** system treating the ballast water (BW) in the ballast water tanks. Most other process systems for the same purpose are **In-Line** systems treating the water after the ballast water pumps before it enters the tanks.

Basically the BAWAT system is a recirculation system, where the BW after it has been pumped into the BW tank, is recirculated in a loop from the top of the BW tank, and re-introduced into the tank through a combination of Rotary Jet Heads (RJH) and fixed nozzles appropriately installed in the bottom section of the tank. (Please see figure 1.1/1 below.)

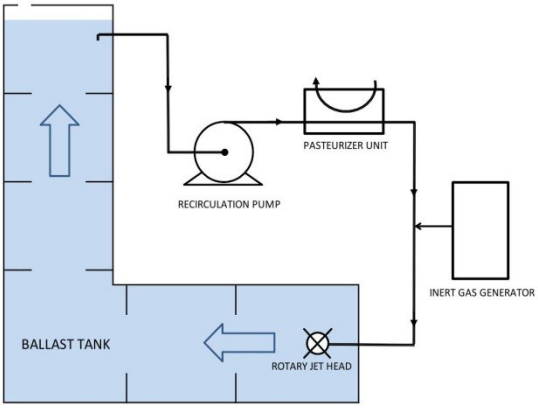

Figure 1.1/1:
Basic schematics of the BAWAT System

In the recirculation loop injection of gas such as nitrogen (N_2) or atmospheric air or a mixture of these take place on the pressure side of the pump. Further, a heat treatment system is built into the recirculation loop making it possible to apply a two-step treatment process, namely a deoxygenation of the ballast water in the tank combined with a heat treatment of the water in a pasteurizing unit.

The BAWAT System is particularly characterized by:

- The existing ballast system is operated without alterations/modifications.
- Simplicity and with a very small footprint, thereby facilitating retrofits.
- All process components have long term positive marine track records.
- No upgrade of BW pumps and associated piping and power generators are required.

It has been established, that to meet the criteria stipulated in Regulation D-2 of the 2004 Ballast Water Convention re. the content of microorganisms in the ballast water at discharge, it is necessary to apply

at least two different treatment principles. Most In-Line systems apply filtration of the incoming ballast water through 30 -50 µm filters as a first step, whereafter the filtered ballast water is exposed to either UV radiation, ultrasonic, ozone or other biocides.

Also the BAWAT System applies two distinct process principles, namely deoxygenation and pasteurization. The de-ox process effectively eradicate the zooplankton while at the same time nearly eliminate corrosion in the ballast tanks. The pasteurization process will eliminate both the phytoplankton and the bacteria to levels below the IMO requirements.

The BAWAT System normally will treat one tank at a time. Typically the system is installed allowing a port and a starboard tank to be treated simultaneously. Therefore, the system could be installed with one larger pump unit and one larger pasteurizing unit, or as a double system unit with two identical units, each having 50% capacity compared to one large system. One such system installed to handle the port side tanks, and one to handle the starboard side tanks. The treatment of the fore – and aft peak tanks, can be handled by either of these two systems.

In more details the BAWAT System will be operated as follows:

1. After the ballast water has been pumped into the ship's BW tanks and the ship has left harbor, the ship is in a situation where it has both surplus energy and waste heat available. The BAWAT System's recirculation pump(s) are started, and the recirculation of the ballast water is initiated, sucking from the top of the BW tank and reinjecting the water through Rotary Jet Heads and fixed nozzles properly installed in the lower part of the BW tanks. When recirculation has been established, heat in form of steam or hot condensate is supplied to the pasteurizer, and inert gas from the inert gas generator is injected into the recirculation line at a pressure a little higher than the pump pressure being around 2.5 – 5 bar. The inert gas injected after the pasteurizer will dissolve in the ballast water en route to the nozzles inside the BW tank. The nozzles will generate a very effective in-mixing of micro bubbles of inert gas into the ballast water by establishing a Non Stationary Flow Pattern at the entrance of the tank which effectively will be "pushing out" the oxygen from the BW.

2. The recirculation is maintained until the oxygen content in the water is below 2.0 mg/L and the total tank volume has passed at least once through the pasteurizer.
   The water is now treated to specification, and the pump is switched to start sucking from the next tank to be treated, after the valves to the just treated tank have been closed.

3. The treated water now rests in the tank until it has to be pumped overboard.

Besides effectively fulfilling the established biological treatment criteria for a BWT system, the BAWAT System further offers two important side benefits to the ship owner.

Firstly, by applying a de-ox process; the corrosion processes in the BW tanks will nearly be eliminated. Secondly, the installed Rotary Jet Heads will act as very efficient tank cleaners, which will be able to flush and clean the inlet part of the BW tanks effectively, thereby being able to exert a satisfactory sludge control of the BW tank system.

2. DESCRIPTION OF THE LAND-BASED TEST SET-UP

Contrary to other Ballast Water Treatment Systems – whether already type approved or in the type approval process – the BAWAT System utilizes various pieces of equipment already installed on the ship combined with proprietary components supplied by BAWAT.

Therefore, the BAWAT System installation will vary physically from ship to ship, however, will operate under the same principles and guidelines and controlled under identical process parameters.

In the sections below the land-based test set-up is described with reference to shipboard BAWAT System installations.

2.1. OVERVIEW

Figure 2.1/1 shows the test set-up at the DHI facilities in Hundested, the main components and measuring and sampling points in schematic form.

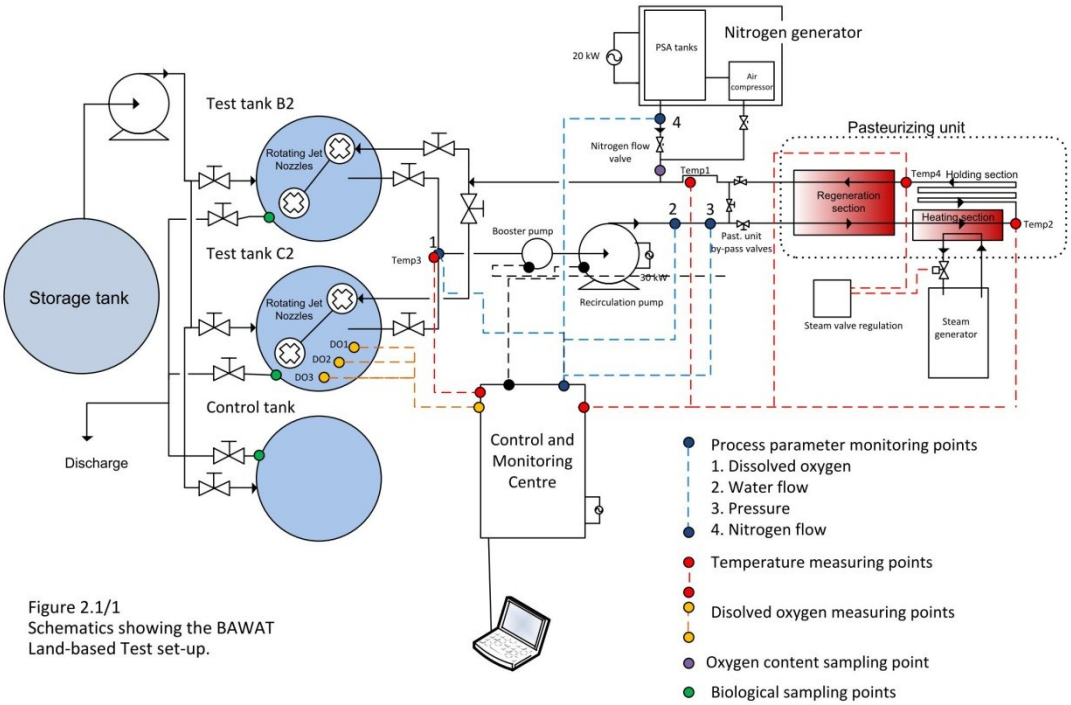

Figure 2.1/1
Schematics showing the BAWAT Land-based Test set-up.

The BAWAT System equipment has been built into three ISO containers – Figure 2.1/2:

1. A 10' container with
    - 1.1. Main pump for recirculation (Booster pump is placed outside container)
    - 1.2. Main system valve
    - 1.3. Control and Monitoring Centre

1.4. Sensors for water flow, pressure and dissolved oxygen content in the water

1.5. Connection to PC for monitoring and data logging

2. A 20' container with

2.1. Pasteurizing unit

2.2. Pasteurizing temperature regulation

2.3. Pasteurizing unit by-pass valve

2.4. Temperature sensors

2.5. Nitrogen generator

2.6. Gas flow regulation and – meter

2.7. Gas flow injection

2.8. Oxygen meter in nitrogen flow

3. A 10' foot container with the steam generator (Fuel tank and water softener are placed outside container)

The pre-insulated pipes constituting the holding section of the pasteurizing unit are placed on top of and across the two first mentioned containers.

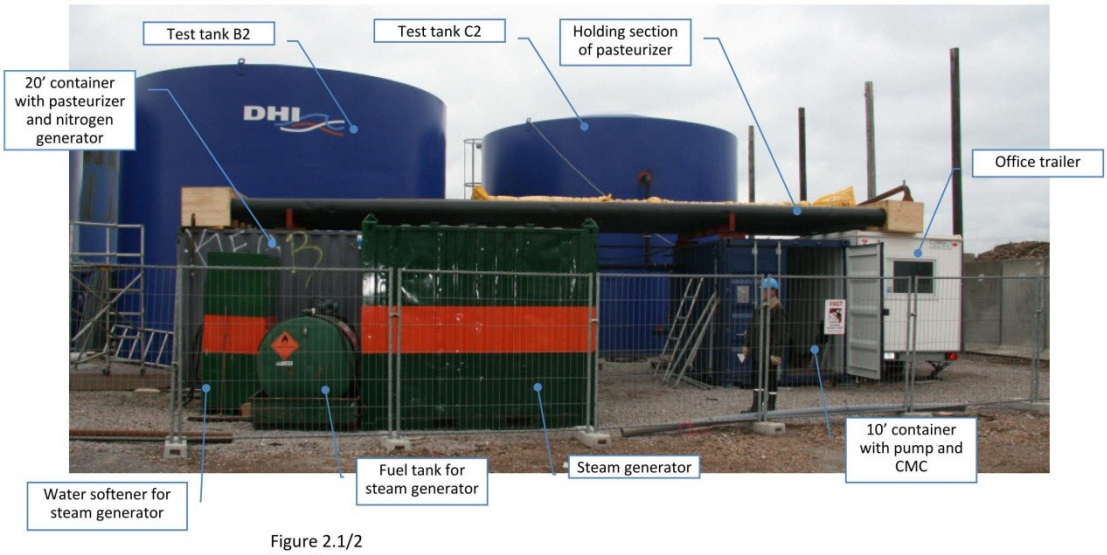

Figure 2.1/2
Test site.

The BAWAT system treatment process involves a recirculation of the water in the treatment tank through a pasteurizing unit. The ΔT (temperature increase) over the pasteurizing unit is 4 – 5 °C. This will increase the temperature in the treated tank by approximately the ΔT times the number of water recirculations during the treatment. The actual temperature increase will depend on the cooling conditions (temperature, wind, etc.) at the time of treatment. However, the temperature in the control tank will only change very slightly again depending on the actual temperature and wind condition at the time of the treatment.

The differences in after-treatment water temperatures between the treatment tank and the control tank can be considered an experimental artifact, as the temperature increase in a ship's BWT after

treatment are expected to very slight due to the efficient heat exchange through the ship's sides.

In order to mitigate the consequences of this artifact an-line cooling heat exchanger has been installed in accordance with Figure 2.1/3. [1]

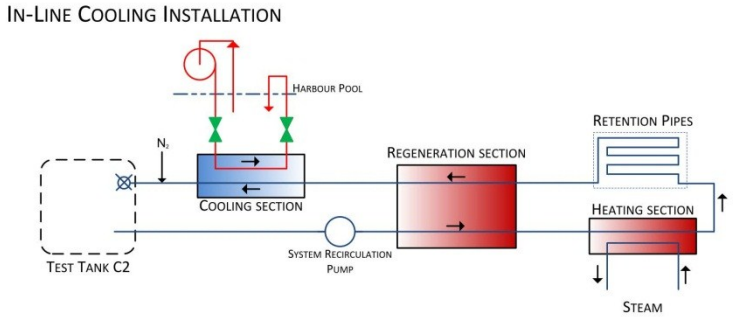

Figure 2.1/3
In-line cooling installation.

2.2. TANKS

The BAWAT land-based tests takes place at DHI's test facilities in Hundested (Figure 2.2/1) utilizing three tanks of 250 m^3 each. Two tanks will be internally modified as described in principle below and in details in the DHI QAPP and the third tank be will used as a 'controltank' i.e. no treatment will take place in this tank.

Please observe: At present only one tank (C2) has been modified and connected to the BAWAT System equipment.

The test water is pumped into the tanks from the 750 m^3 reservoir tank, in which the test water is synthesized.

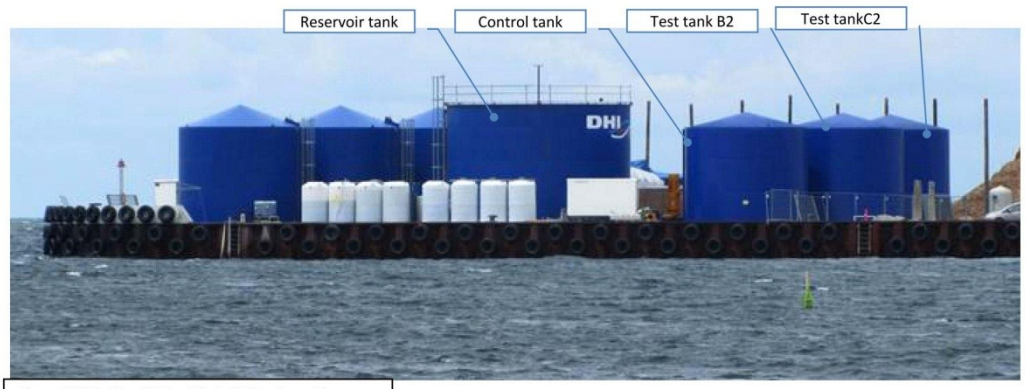

Figure 2.2/1: The DHI test installation from the sea.

[1] Please observe that in land-based tests #1 through #6 an 'After-treatment cooling procedure' were implemented.

The test tanks at the DHI facilities in Hundested are designed purely for the purpose of testing In–Line BWT systems, only serving as retention tanks for the treated water arriving from the BWTS. The tanks, however, in which the BAWAT System shall be tested, play an integral part of the system. The test tanks in Hundested therefore had to be modified so as to resemble normal ballast tanks as closely as possible.

In general, the recirculation system in a BAWAT System always will suck the water from right below the water surface in top of the ballast water tank, and will re-inject the water at the bottom of the ballast water tank trough the jet nozzles.

The nitrogen gas used a.o. for de-oxygenation is injected into the recirculation loop well before the tank, and will always consist of smaller and larger bubbles. The smaller bubbles primarily will facilitate the de-oxygenation of the water and will rise relatively slowly in the water, whereas the larger nitrogen bubbles will serve to agitate and mix the water in the individual compartments of the ballast water tanks. Compared to the flow of the main body of the water caused by the pumps, these larger nitrogen bubbles are travelling 4-500 times faster through the tank than the water.

Due to the basic construction of the ship and the ballast water tanks the nitrogen bubbles will always tend to move along the inner side of the ballast water tank tending to generate an upward movement of the water along the inner side of the tank.

To establish the same general movement pattern – flow regime - in the cylindrical tanks in Hundested, it was first of all necessary to establish an “inner side” in the tanks, and then ensure that the majority of the larger nitrogen bubbles ascended following this “inner side”.

The “inner side” was established by hanging a vertical tarpaulin diametrically in the tank, thus separating the tank into two equal parts.

To establish tree compartments in each half of the tank equivalent to the longitudinally decks inside a ship’s ballast water tanks, two ‘half-moon’ shaped pieces of tarpaulin were expanded from the inside cylindrical surface of the tank towards the diameter. The first half-moon positioned approx. 1/3 of the height of the tank up from the bottom and the second half moon 2/3 up from the bottom. They were positioned with a slight slope of 5 degrees towards the diameter

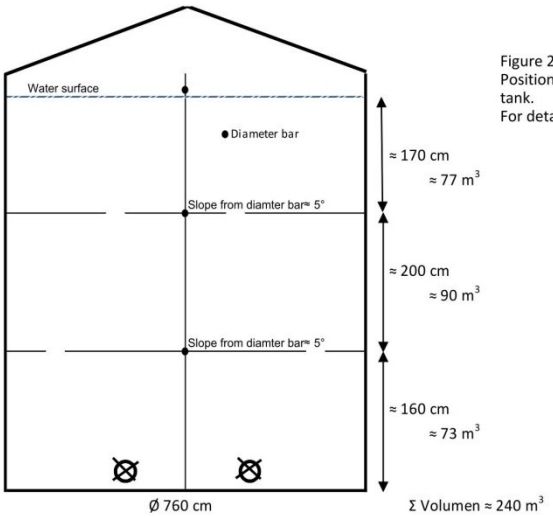

Figure 2.2/2
Positions of vertical and horizontal tarpaulins in tank.
For details please refer to the DHI description.

The intention of the tank modifications were to establish a flow pattern in the tank very similarly to what has been observed both in the 1:10 test tank at DTU, and also in the ballast water tanks of the 7.500 DWT tanker , Bro Gothenburg.

Visual inspection from the observation hatch in the top of the tank confirm that a flow pattern as intended with the main bubble flow ascending at the diameter bar seems to have been established.

Further, deoxygenation tests in the D2 test tank confirm that the deoxygenation courses observed here is qualitatively similar to analogue observations in 1:10 tank at DTU and on Bro Gothenburg.

The configuration will be optimized during pre-test runs before the land-based trials are initiated.

Please observe that the photographs in this section show the original tarpaulin setup. Hole-configuration has been modified in the present set-up.
For details please refer to the relevant QAPP section prepared by DHI.

Figure 2.2/3-4
Tarpaulin construction inside tank B2.

2.3. ROTATING JET NOZZLES

2.3.1. SHIPBOARD INSTALLATION

The BAWAT System utilizes a combination of rotating jet nozzles and fixed nozzles to introduce N_2 filled bubbles into the ballast water at the bottom of the ballast water tanks.

In a given ship's ballast tank one rotating jet nozzle will be placed in the tank segment where the ballast water is pumped into and out of the tank, and in the L-shaped tanks a series of fixed nozzles will be placed longitudinally one in each structural segment of the ballast water tank. In other tank constructions the fixed nozzles will be placed in positions creating a flow regime in the tank that agitates the ballast water in all compartments of the tank.

The water jets from the rotating jet nozzle will in addition to the introduction of nitrogen bubbles into the water remove sludge from the vicinity of the bell mouth through which the ballast water is pumped in and out of the ballast water tank and thus prevent the sludge from being washed out during the de-ballasting operation.

The relevant size of the rotating jet nozzle as well as the fixed jet nozzles will depend on required process time of the actual ballast water tank depending again on the actual tank size and the available pump capacity.

2.3.2. LAND-BASED TEST INSTALLATION

In the land based test set-up two rotating jet nozzles of the type **'IsoMix IM 25 Rotary Jet Mixer'** and two fixed Ø21 mm nozzles are installed in the tank – please see Figures 2.3.2/1 to 3.

Please see **Appendix 5.1** for specifications of the IsoMix IM 25 Rotary Jet Mixer.

Figure 2.3.2/1
Iso-Mix IM 25

Figure 2.3.2/2
Rotating Jet Nozzle and fixed jet nozzle in test tank.

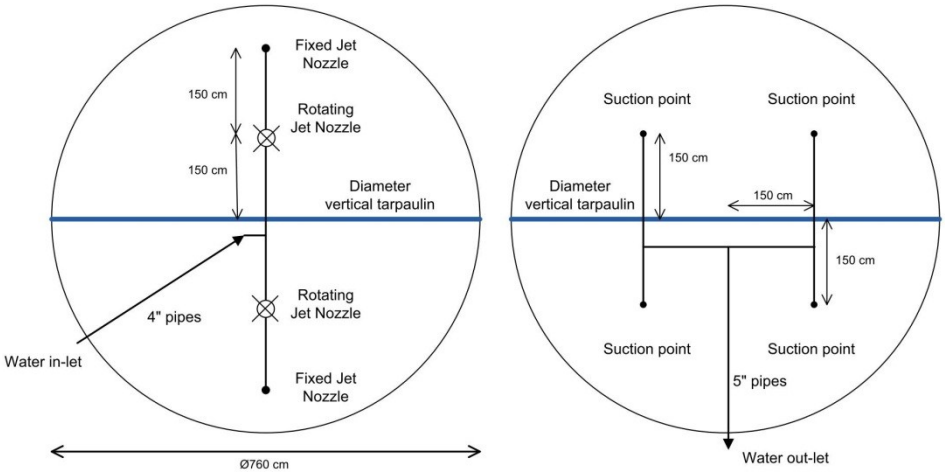

Figure 2.3.2/3
Positions of RJNs and FJNs at buttom of tank and suction points at tank top.

2.4. SUCTION POINTS

2.4.1. SHIPBOARD INSTALLATION

The BAWAT System circulates the ballast water from just below the water surface in the ballast water tanks through the treatment system to be reinjected through the nozzles at the bottom of the tanks as described above.

In the L-shaped ballast water tanks parallel suction points will be distributed longitudinally. The number of suction points, their precise placement and dimensions of the pipes will depend on the actual tank volume, the pump capacity and required process time. In other tank constructions the suction points will be placed and dimensioned to allow an unhindered water flow in the recirculation loop.

If the ballast water tanks are not filled to their maximum volume it is necessary to lower the suction point to below the actual water surface. This will be done by installing in a vertical pipe a series of floater operated valves that will open sequentially when the water level drops.

2.4.2. LAND-BASED TEST INSTALLATION

In the land-based test set-up four suction points are placed 0.5 m below the water surface as shown in figure 1.3.3/1. The pipe openings are facing upwards to avoid a direct flow of air bubbles into the pipes. Figure 1.3.3/2 shows the placement of the horizontal plane.

Please see Figure 2.3.2/3 for positioning of suction points.

Figure 2.4.2/1
Suction point in top of tank.

2.5. RECIRCULATION PUMP

2.5.1. SHIPBOARD INSTALLATION

In a ship board BAWAT System installation the existing ballast water pumps will be used as recirculation pumps and the ballast water piping will – after installation of remotely operated valves and low pressure suction piping from the top of the ballast water tanks to be attached the ballast pipes at the bottom of the tanks – be used as the low pressure suction piping in the recirculation loop.

The ballast water volume in a given ballast water tank will typically have to be recirculated between 2.5 and 4.0 times to ensure that 99.9% of the ballast water in the tank passes through the pasteurizing unit. The exact number of recirculations will primarily depend on the actual construction of the tank specifically on the number of compartments in which the tank can be considerate to be divided into.

The optimal treatment time will depend on the ship's schedule, speed, available energy for pasteurization, pump operation and nitrogen production, etc.

It is, however, expected - as a rule of thumb - that tanks in smaller ships shall be treated in 3 - 8 hours and larger ships in 16 – 24 hours. As an example: In a 30,000 DWT tanker the average ballast water tank is approximately 1,000 m^3. Running the ballast water pump as the recirculation pump in the BAWAT System at 500 m^3/h will give a process time in the tank of max. 8 hours.

2.5.2. LAND-BASED TEST INSTALLATION

In the land-based test set-up the tank size is 240 m^3. The recirculation pump system (see below) gives a pump rate of maximum 130 m^3/h allowing the BAWAT process to be carried out in less than 7 hours.

The main recirculation pump is an Iron Pumps' electrical centrifugal pump type CNLe 100/200 in series with a smaller electrical centrifugal pump (Desmi Pump PVLN, 4") serving as a 'booster' pump increasing system pressure and pump above the main pump's specification.

For specifications see **Appendix 5.4**

The pump and below described flow meter, dissolved oxygen sensor and the Control & Monitoring Centre are installed in a 10' container.

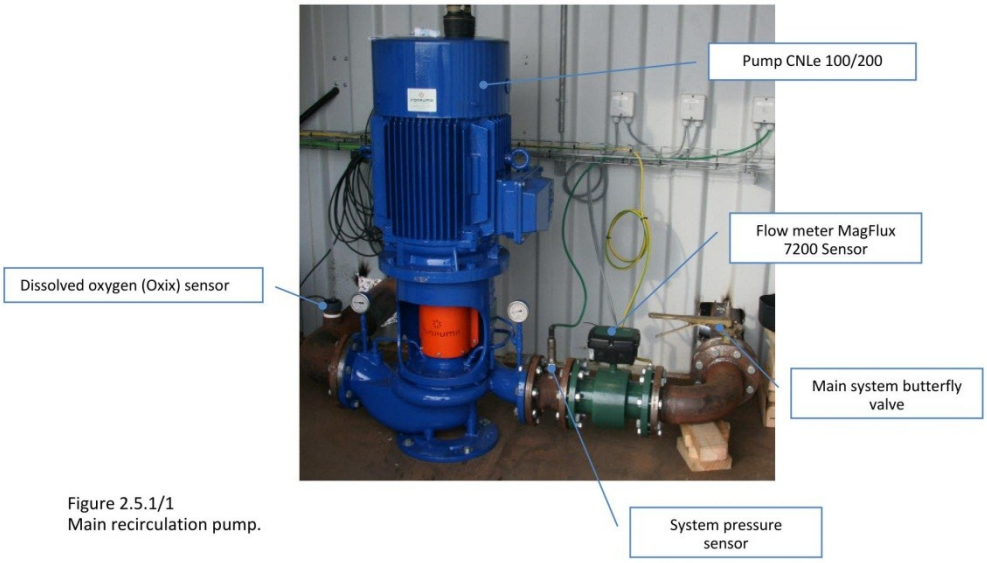

Figure 2.5.1/1
Main recirculation pump.

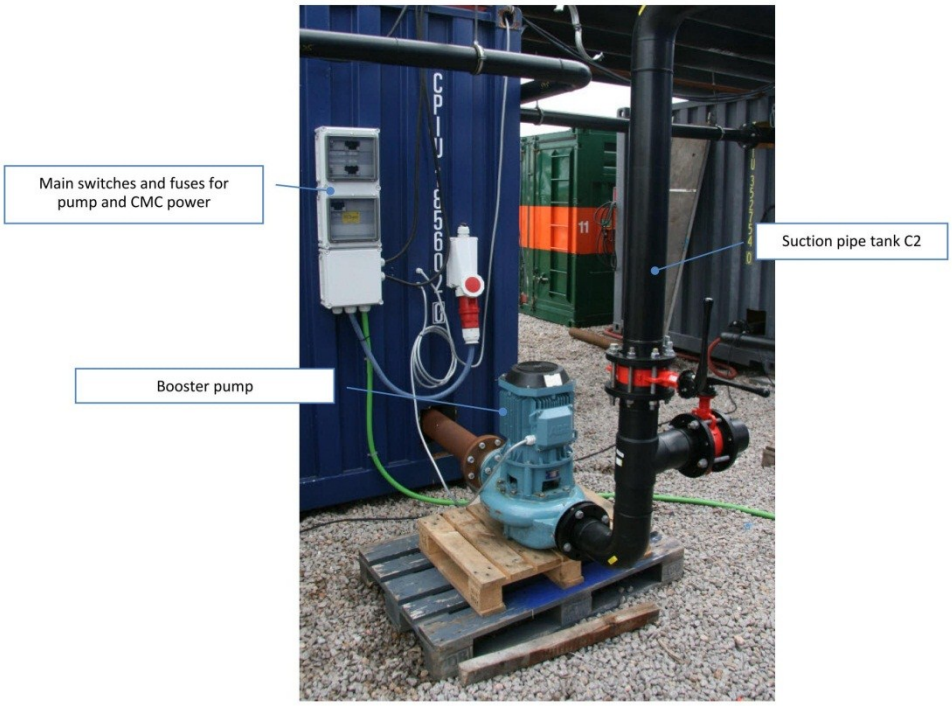

Figure 2.5.1/2
Booster pump.

2.6. PASTEURIZING UNIT

2.6.1. SHIPBOARD INSTALLATION

The BAWAT System implements a two-step process combining de-oxygenation and pasteurization. The shipboard mounted pasteurization unit consists of three parts – please see Figure 2-6-1/1:

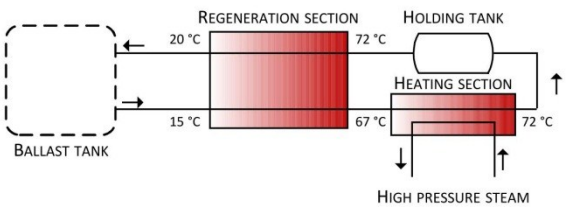

Figure 2.6.1/1
Pasteurizing unit principle

1. A Regeneration Section – a plate heat exchanger - in which in-coming water from the ballast water tank is heated by the out-going water from the holding tank.
2. A Heating Section – another plate heat exchanger – in which the water from the first heat exchanger is heated by low pressure steam supplied by the ship's existing installations, e.g. a dedicated steam generator or waste heat economizer.

3. A Holding Tank the purpose of which is to maintain the pasteurizing temperature achieved in the heating unit for a given time.

The temperatures indicated in the figure above are examples only. The temperature difference between the water flowing out of the ballast water tank and the water flowing back into the tank (ΔT) is in this example 5 °C.

The ΔT value as such has no effect on the BAWAT System efficacy and can be adjusted according to the requirements of the actual ship owner's priorities regarding capacity costs (CAPEX) and operational costs (OPEX) again depending on various issues as the actual costs of steam on a given ship.

2.6.2. LAND-BASED TEST INSTALLATION

In the land-based test set-up the pasteurizing unit comprises of

1. A Regeneration Section being a Sondex S86/200 plate heat exchanger with a ΔT of 5 °C at 150 m^3/h. (See **Appendix 5.3** for detailed specifications.)
2. A Heating Section being a Sondex S22/80 plate heat exchanger. (See **Appendix 5.3** for detailed specifications.)
3. A Holding Unit consisting of 60 m of Ø210 mm pre-insulated pipes with total water volume of 2.1 m^3+ volume of bendings, in total 2.5 m^3. The unit gives a holding time of 1 min at a flow rate of 150 m^3/h and 1,15 min at 120 m^3/h. The temperature difference measured between inlet and outlet of less than 1 °C at a flow rate of 140 m^3/h.

Figure 2-6-1/2-3
Pasteurizing unit sections

2.7. STEAM GENERATOR

2.7.1. SHIPBOARD INSTALLATION

In a shipboard mounted BAWAT installation the heating medium in the above described pasteurizing unit could be low pressure steam supplied by the ship's existing or updated installations, e.g. a dedicated steam generator, waste heat economizer or jacket cooling water heat exchange.

The heat requirement of the BAWAT System depends on the specifications of the installed pasteurization unit, but will typically be equivalent to approximately 0.02 ton of steam per 1 m^3 of ballast water treated.

As an example: A 30.000 DWT tanker holds typically 12,000 m^3 of ballast water. A full BAWAT System treatment of this volume of ballast water will require approximately 240 tons of steam over a 48 h period of time equal to 5 tons/h.

2.7.2. LAND-BASED TEST INSTALLATION

In the land-based test set-up the steam is supplied by an oil burner driven Clayton Steamgenerator Type E-150 with a capacity of 2.3 – 2.4 tons/h at 3 bar installed in a 10' container. (Specifications see **Appendix 5.2**)

The steam pressure and consequently the temperature on the hot side of the heat exchanger in the heating section of the pasteurization unit is regulated by an automatic, motorized valve operated via an electronic circuit with temperature sensors in the water flow at the inlet and outlet of the holding section of the pasteurizing unit. The water temperature can be held within ±1 °C of the set temperature.

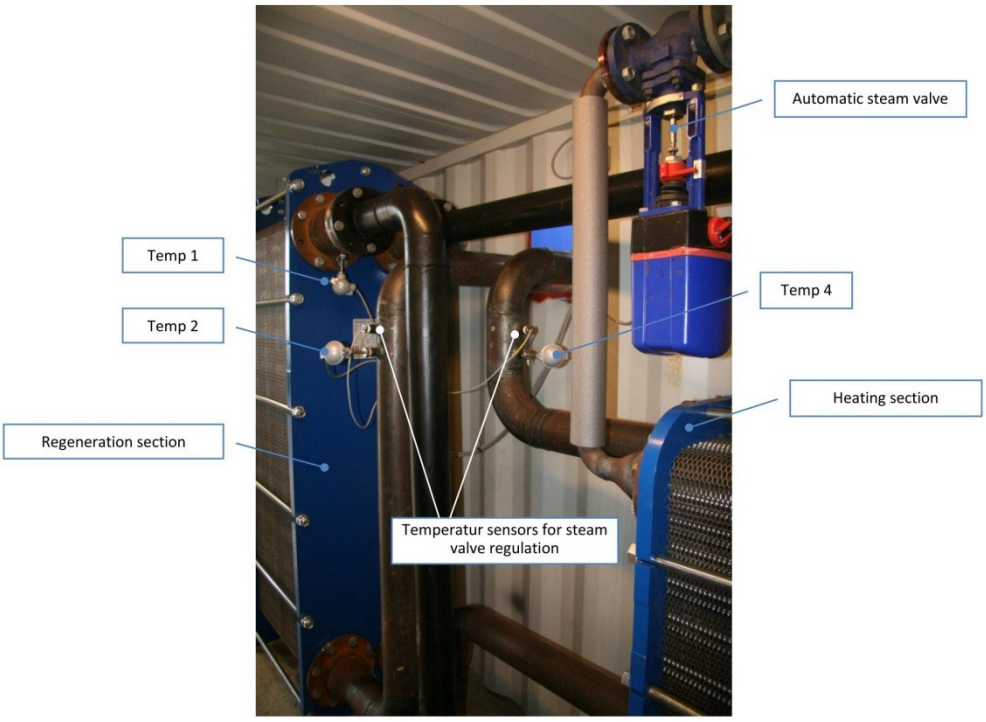

Figure 2.7.2/1: Temperature sensors in pasteurizer unit

Figure 2.7.2/2: Control panel for setting and control of Pasteurizing temperature located in 20' container.

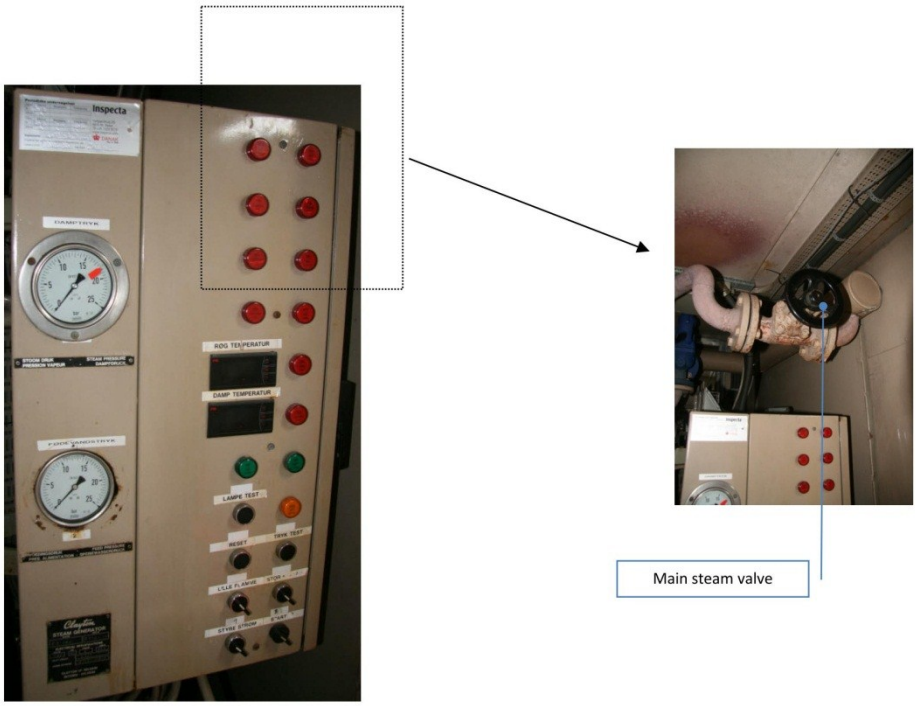

Figure 2.7.2/3-4: Location of main steam valve in steam container.

2.8. NITROGEN GENERATOR

2.8.1. SHIPBOARD INSTALLATION

In a ship board mounted BAWAT installation the required nitrogen flow will either be supplied from an already installed nitrogen generator system used for tank blanketing or from a dedicated BAWAT System installation.

Nitrogen for marine applications is for the main part produced either by the Membrane Technology or by the Pressure Swing Adsorption (PSA) Technology.

2.8.2. LAND-BASED TEST INSTALLATION

In the land-based test set-up a PSA generator from Gazcon with a capacity of 21 Nm^3/h is installed. The nitrogen flow rate necessary for the upcoming tests will be approx. 12 m^3/h. (See **Appendix 5.5** for specifications.)

The purity of the nitrogen is dependent on the flow rate and at 18 m^3/h the purity will - according to the manufacturer's specifications - be 99.7% N_2, the balance being argon and O_2. The oxygen concentration in the nitrogen determines the minimum obtainable dissolved oxygen level in the treated water. In shipboard installations the oxygen content can vary from 0.01 % to 2.00 % oxygen depending on the actual nitrogen flow.

In order to run the tests under the most challenging conditions oxygen in the form of compressed atmospheric air is injected into the nitrogen stream. The oxygen content of the gas is measured before injection into the water piping and manually held at 2.00 % oxygen as this value will be the most challenging situation compared to a shipboard installation as indicated above.

Figure 2.8.2/1-3
Nitrogen generator

Figure 2.8.3/4
Nitrogen injection

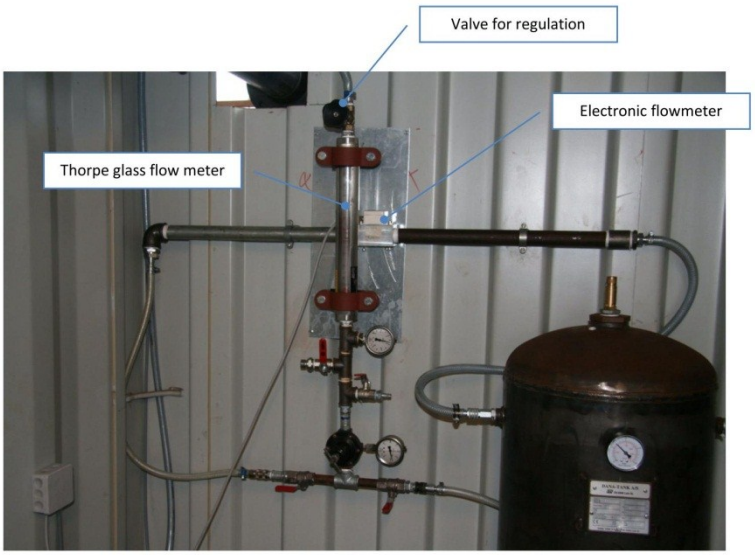

Figure 2.8.3/5
Nitrogen flow regulation

2.9. PIPING AND VALVES

2.9.1. SHIPBOARD INSTALLATION

In a ship board BAWAT installation the ballast water pipes will be used on the suction side of the recirculation pump

2.9.2. LAND-BASED TEST INSTALLATION

In the land-based test set-up suction side pipes are 5" PE pipes and pressure side pipes are 4" PE pipes apart from high temperature pipes between the regeneration and the heating sections of the pasteurizing unit, where the pipes are made of steel.

All valves are manually operated butterfly-valves.

A coarse strainer (1 mm openings) is placed on the pressure side of the pump to withhold welding debris, etc. originating from the assembly of the piping. The sieve is removed again before operation of the system.

2.10. CONTROL AND MONITORING CENTRE AND SENSOR PLACEMENTS

2.10.1. SHIPBOARD INSTALLATION

In a ship board BAWAT installation all control, monitoring and data logging functions in the BAWAT System will handled by a Control and Monitoring Centre (CMC) most likely placed with the ship's ballasting system controls and most likely interfaced with this system. Apart from the basic functionality of controlling the BAWAT process in one ballast water tank the shipboard CMC will among other routines have preprogrammed routines for running the entire treatment process in all tanks automatically switching from one tank to the next when treatment in the first tank has been completed.

2.10.2. LAND-BASED TEST INSTALLATION

In the land-based test set-up a prototype of the coming CMC is applied, however, only containing features relevant to the land-based test set-up. The CMC is basically identical to the CMC used in the 1:10 tank tests (See **Appendix 5.12**: BAWAT Document 2012.007 entitled "1:10 Test Tank Description & Standard Operating Procedures") modified to control the equipment applied in general and to log temperature data, also.

The CMC is built around SCADA (**S**upervisory **C**ontrol **A**nd **D**ata **A**cquisition) equipment and software supplied by MJK Automation A/S.

The CMC consists of

- Datalogger and software: (Specifications in **Appendix 5.9**)
  - Connect base (MJK)
  - MJK Monitors
  - IGSS (Interactive Graphic SCADA System) software (7-Technologies)
- Switches, automatic fuses, relays, etc.
- The main pump is running at max speed, but the speed of the booster pump can be regulated by a frequency converter,

and receives data from the following sensors:

- Dissolved oxygen: (Specifications in **Appendix 5.6**)
  - SuSix/Oxix converter (MJK)
  - Oxix sensors
    - Three sensors are placed in tank C2 one in each vertical segment (See figure 3.1.9/1) of the tank (DO 1, DO 2 and DO 3)
    - A fourth sensor (DO 0) is placed in the water flow just before the main recirculation pump thus in effect measuring the dissolved oxygen content at the suction points at the top of the tank.
- Oxygen sensor : (Specifications in **Appendix5.14**)
- Pressure: (Specifications in **Appendix 5.7**)
  - Pressure transmitter (0-6 bar) (MJK)
    - The pressure sensor is placed after the main pump.
- Water flow: (Specifications in **Appendix 5.8**)
  - MagFlux 7200 Sensor DN32EN/PN40 (MJK)
  - MagFlux converter (MJK)
    - The water flow is measured just after the main recirculation pump.
- Temperature sensors
  - The temperature is measured
    - in all dissolved oxygen sensors (Only temperature in the DO 0 sensor is logged (Temp 3)),
    - at the outlet from the pasteurizing unit (Temp 1) and at the inlet and outlet of the holding section of the pasteurizing unit (Temp 2 and Temp 4, respectively.
    - The pasteurizing temperature, T_{Past}, is defined as (Temp 2+ Temp 4)/2.
    - A temperature logger is placed in both the treatment tank and in the control tank prior to initiation of the treatment logging the temperatures in the tanks before and during treatment as well as during the retention time following the treatment. (Specifications in **Appendix 5.15)**

- Nitrogen flow:
  - Two types of flow sensors are applied
    - A Thorpe type glass flow meter
    - An electronic flow meter the output of which is logged in the Connect Base **(Appendix 5.10)**

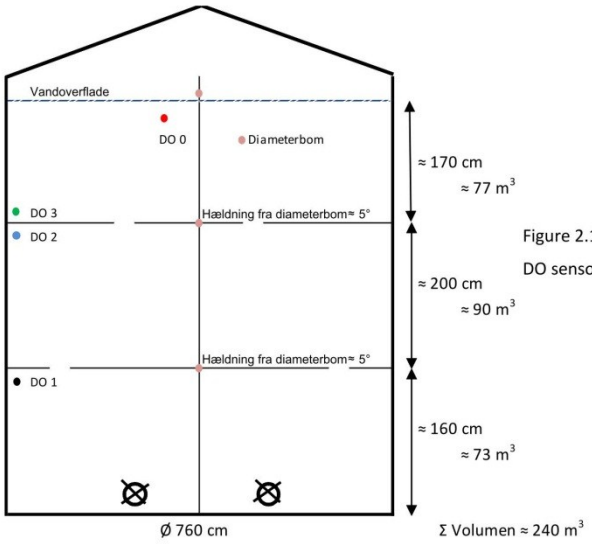

Figure 2.10.2/1

DO sensors in tank C2

2.10.3. Control and monitoring centre (CMC)

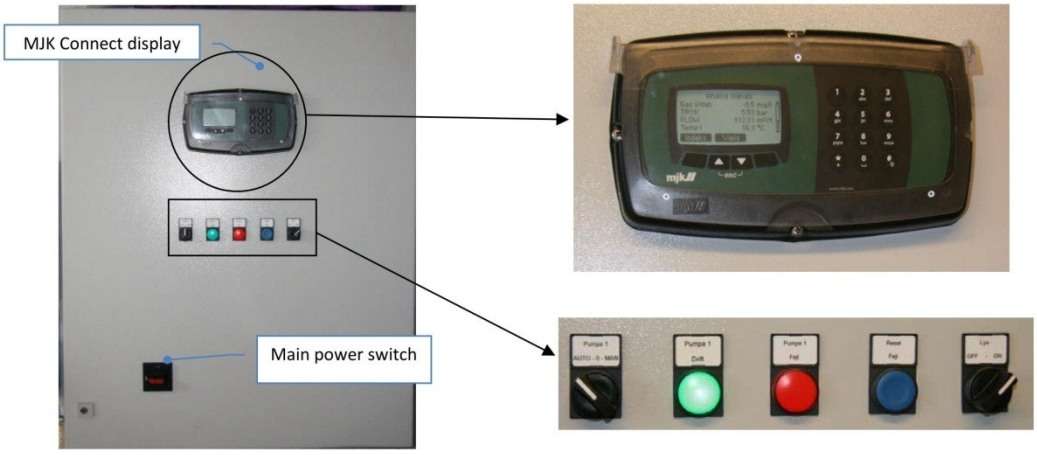

Figure 2.10.3/1-3 CMC Main panel

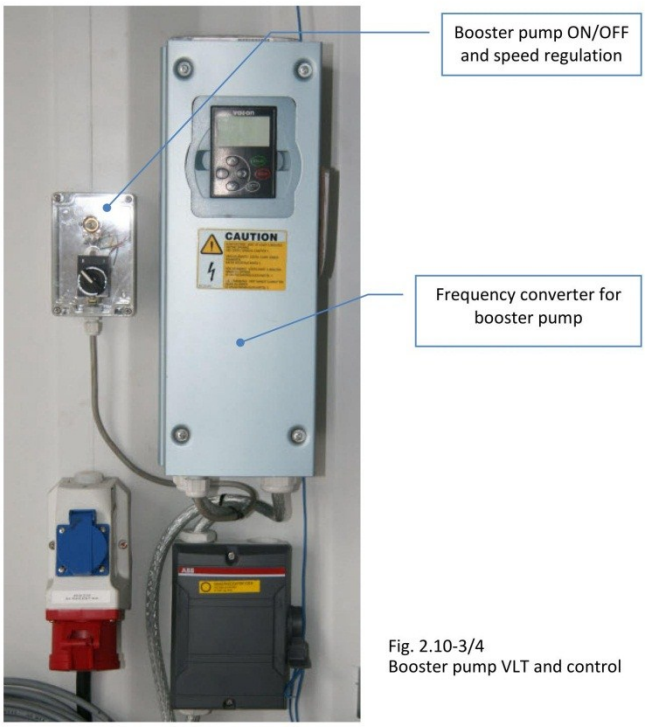

Fig. 2.10-3/4
Booster pump VLT and control

2.10.4. IGSS SCREEN

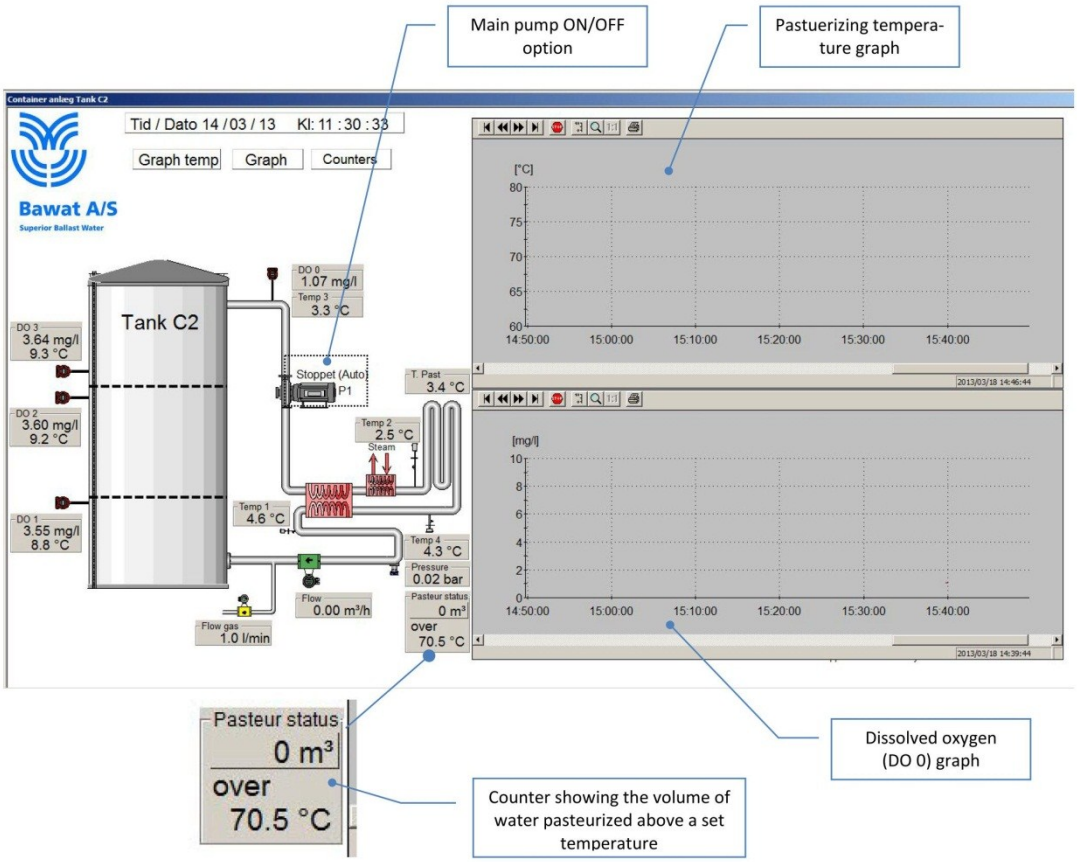

Figure 2.10.4/1: IGSS screen picture. Graphs not shown as system not in operation

2.11. PROCESS PARAMETERS

2.11.1. Main process parameters

The three main process parameters in the BAWAT System are:

1) The content of dissolved oxygen in the treated water = $\mathbf{DO_{treated}}$.

> The dexoygenation follows Henry's Law: "At a constant temperature, the amount of a given gas that dissolves in a given type and volume of liquid is directly proportional to the partial pressure of that gas in equilibrium with that liquid."
> Through the surface of the micro bubbles created by the injection of nitrogen under pressure into the water the nitrogen in the bubbles is exchanged with the oxygen dissolved in the water and thus reducing the dissolved oxygen content of the water. The level to which the dissolved oxygen can be dissolved is dependent on the oxygen content of the nitrogen gas injected.

2) The level of Pasteurization Units (PU) applied in the pasteurization process = $\mathbf{PU_{applied}}$.

> The destructive effect on micro-organisms of pasteurization is determined by the retention time and the temperature applied. It is calculated in terms of pasteurization units (PU) and is a measure for the microbiological effect of the heat treatment.
> It is calculated as follows:
> **PU = 'Retention time at temperature' ∗ 1.393**$^{(\text{Temperature} - 60\ °C)}$

3) The $\boldsymbol{\rho_{min}}$**-factor.**

> For a given pump rate the ρ-factor tells how many times a water volume equal to the water volume in the ballast water tank has passed through the pump.
> ρ_{min} is defined as the minimum number of times the ballast tank volume must pumped through the pump to ensure that a minimum of 99.9% of the water elements has passed the pump and consequently also the pasteurizing unit.

Re 1. Deoxygenation level

In the land-based test the dissolved oxygen content in the test water will be reduced to 2.0 mg/L or less.

Further, in the land-based tests the oxygen level in the nitrogen flow will be kept at 2 %.

Re.2. Pasteurization

In the land-based test a pasteurization temperature of 72 °C and a retention time of not less than 1 min will be applied.

Re 3. The Recirculation Factor.

Since an important part of the annihilation process in the BAWAT System takes place outside the ballast tank during the treatment process, namely the pasteurization, it is important to ensure that essentially all part of the ballast water (99.9%) passes through the pasteurization unit.

If a "plug flow" could be established in the recirculation loop, the ballast water volume would need to be pumped through the pasteurizer one time only. However, due to the internal mixing of the water in the ballast water tank taking place during the process, more than one recirculation is required to ensure that all water volume elements are passing through the pasteurizer at least one time.

In general, a ballast tank is constructed as a number of parallel sections each consisting of a number compartments in series which in most tanks form an L-shaped volume stretching longitudinally. The ballast water during the BAWAT treatment, will be recirculated from the top of the tank and reintroduced at the bottom of the tank mixed with the nitrogen. The water then moves slowly up through the tank towards the top.

A mathematical model describing the water flow in typical ballast water tanks have been developed at Denmark's Technical University[2].The models show that the de-oxygenation of the water takes place very quickly in the lower compartment at the introduction of the nitrogen micro bubbles through the nozzles.

The de-oxygenated water then moves slowly from compartment to compartment and is agitated by the larger bubbles of nitrogen. These bubbles are rising through the tank primarily along the inside of the tank structure, generating a mixing of the water in each compartment facilitating that all water elements are moved around and mixed into the main flow passing upwards towards the top. The speed of the rising bubbles relative to the slow moving water is in the order of 4-500 times faster.

The mathematical models indicate that in a typical L-shaped ballast water tank a recirculation factor (ρ_{min}) of between 2.0 and 5.5 should ensure that at least 99.99% of the water has passes through the pasteurizer.

A series of pasteurizing tests with biological sampling in the 1:10 tank at DTU, BAWAT A/S have shown that a ρ_{min} factor of between 2.0 and 2.5 results in satisfactory reduction of zooplancton, phytoplancton and bacteria meeting the D2 criteria. (Please see **Appendix 5.10**)

In several tests it has further been shown, that a deoxygenation to below 2.0 mg/L will reduce the zooplankton content to well below the D2 criteria and there are strong indications that deoxygenation to this level results in a substantial reduction of the phytoplankton concentration as well. The remaining phytoplankton and the bacteria are killed by pasteurization.

Before deciding finally on which ρ_{min} factor will be used in the land-based tests in Hundested, a number of tests will be performed in the 250 m^3 tanks, partly with de-oxygenation only, and partly in a pilot test also involving analysis of the full spectre of zooplankton phytoplankton and bacteria.

The theoretical models show the required number of recirculations in the Hundested set-up to be 3.8. However, considering the fact that the C2-tank in Hundested, although modified, is not an ideal ballast water tank, it was decided to add a safety-margin to the theoretical number of recirculations and perform the tests with **5 recirculations** of the tank volume through the pasteurizer unit.[3]

2.11.2. Water temperature in treated tank

As mentioned above the BAWAT system treatment process involves a recirculation of the water in the treatment tank through a pasteurizing unit. The ΔT (temperature increase) over the pasteurizing unit is 4 – 5 °C. This will increase the temperature in the treated tank by approximately the ΔT times the number of water recirculations during the treatment. The actual temperature increase will depend on the cooling conditions (temperature, wind, etc.) at the time of treatment. However, the temperature in the control tank will only change very slightly again depending on the actual temperature and wind condition at the time of the treatment.

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[2] Jakob K. Huusom and John Villadsen, Department of Chemical and Biochemical Engineering, DTU: Treatment of Ballast Tank Water in different scales – modelling of the ballast tank, and experimental validation of the model. (Included as **Appendix 5.13**)

[3] Please note that tests #1 through were performed with 4 recirculations.

The differences in after-treatment water temperatures between the treatment tank and the control tank can be considered an experimental artifact, as the temperature increase in a ship's BWT after treatment are expected to be very slight due to the efficient heat exchange through the ship's sides.

In order to mitigate the consequences of this artifact an-line cooling heat exchanger has been installed in accordance with Figure 2.1/3.

3. STANDARD OPERATING PROCEDURES

The Standard Operating Procedures implemented in the Land-based Test Series follow the principles of the SOPs implemented in the 1:10 tank test outlined in BAWAT Document 2012.007 entitled "1:10 Test Tank Description & Standard Operating Procedures" (**Appendix 5.12**), however, duly modified to reflect the installed equipment and interfaces to the DHI installations and the DHI sampling procedures to be followed.

For convenience the main routines are included below.

3.1. FILLING AND EMPYING OF TANKS

The tanks are filled and emptied according to the SOPs implemented by DHI and by DHI personnel.

3.2. SYSTEM START-UP

To start-up the system the following steps are required:

1) The on-site diesel driven electric generator is turned on according to the SOPs implemented by DHI and by DHI personnel.
2) Main power and system on-off switches are turned to ON. **Figure 2.10.3/1**.
3) The laptop is connected to the CMC and the IGSS (Interactive Graphical SCADA System) program is opened on laptop. Figure 2.4.10/1 shows the screen picture.
4) The steam generator is turned on and adjusted to deliver the necessary steam volume in accordance with the Operational Manual supplied by Clayton, Inc. See **Appendix 5.2**.
5) The requested pasteurization temperature is entered into the keypad on the steam pressure regulation unit in accordance with the Operational Manual supplied by the manufacturer. See **Appendix5.2** and **Figure 2.7.2/2**.
6) When the required steam pressure is established the main steam valve is opened. The valve is located above the control panel in the steam generator container. **Figure 2.7.2/3-4**.
7) Pumps are switched on and regulated to the required flow on the CMC control box and the booster pump VLT. See **Figure 2.10.3/1-4.** Main pump can also be switched on via IGSS program **– figure 2.10.4/1.**
8) The main water flow valve is opened. See **figure 2.5.1/1**.
9) The nitrogen generator is turned on in accordance with the Operational Manual supplied by Gazcon A/S. See **Figures 2.8.2/1-3**.
10) The nitrogen injection valve is opened and nitrogen flow established by manual adjustment of the gas valve. See **Figure 2.8.3/5**.
11) The flow of compressed air into the nitrogen flow is manually adjusted to the required oxygen content measured on the oxygen meter installed in line.

3.3. SYSTEM SHUT-DOWN

To shut-down the system the following steps are required:

1) The steam generator is switched off in accordance with the Operational Manual supplied by Clayton, Inc. See **Appendix 5.2**
2) Main water flow valve is closed and the pumps are switched off. See **figures 2.5.1/1; 2.10.3/1-4; 2.10.4/1.**
3) Nitrogen injection valve is closed and nitrogen generator is switched off in accordance with the Operational Manual supplied by Clayton, Inc. See **Figures 2.8.3/5;2.8.2/1-3.**
4) **If cooling of the treated water is required (See section 2.11.2) procedure 3.4 below is applied.**
5) Main power and system on-off switches are turned to OFF. **Figure 2.10.3/1.**
6) IGSS program is closed.
7) Data log file is copied to hard drive and USB stick.
8) Laptop is disconnected.

3.4. MEASUREMENTS

3.4.1. WATER FLOW

Water flow data are recorded in the data logging system and can continuously be read on the IGSS co sole and on the MJK Connect display (Fig. 1.3.7/3).

3.4.2. PRESSURE

System water data are recorded in the data logging system and can continuously be read on the IGSS console and on the MJK Connect display (Fig. 1.3.7/3).

3.4.3. TEMPERATURES

Temperatures are recorded in the data logging system and can continuously be read on the IGSS console and on the MJK Connect display (Fig. 1.3.7/3).

3.4.4. DISSOLVED OXYGEN

Dissolved oxygen content in the water are recorded in the data logging system and can continuously be read on the IGSS console and on the MJK Connect display (Fig. 1.3.7/3).

3.4.5. GAS FLOW

The N_2 flow is are recorded in the data logging system and can continuously be read on the IGSS console and on the MJK Connect display (Fig. 1.3.7/3).

3.4.6. BIOLOGICAL SAMPLING AND MEASUREMENTS

Biological samples are collected according to relevant DHI SOPs.

3.5. DATA RECORDING AND PROCESSING

Main process data are automatically recorded in the MJK Datalogging system:

1) Data points

   {Absolute time; Dissolved Oxygen at DO 0 [mg/L]; Dissolved Oxygen at DO 1 [mg/L]; Dissolved Oxygen at DO 2 [mg/L]; Dissolved Oxygen at DO 3 [mg/L]; Water Flow [m^3/h]; Pressure [bar]; Gas Flow [NL/min]; Temperature #1 [°C]; Temperature #2 [°C]; Temperature #3 [°C]; Temperature #4 [°C]}

   are collected every 30 seconds.

2) Selected, recorded data is continuously presented on screen by the IGSS software package.
3) Volume of water [m^3] above a set temperature [°C] is continuously presented on the screen and logged.
4) Oxygen content in nitrogen flow is manually recorded approx. every 15 min. during treatment.
5) Logged temperatures in treatment tank and control tank are saved to main data file after retention period (120 h).
6) The data are transferred into a Microsoft Excel spreadsheet for data processing.
7) The 'Raw data' and the subsequent Excel data processing files are stored (i) on the attached laptop, (ii) on a USB data storage stick, (iii) on a separate laptop and (iv) on a Drop-Box data storage facility.

Data are processed in Microsoft Excel and presented in graphical form. Figure 3.5 shows an example from the preliminary tests in the D2 test tank.

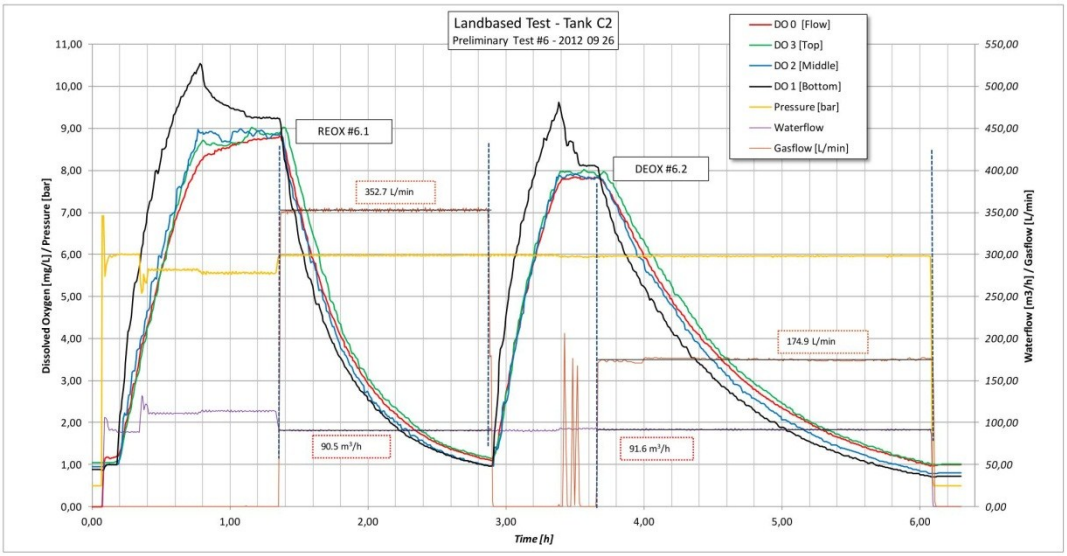


Figure 3.5: Example of graphic data presentation

4. EMERGENCY PROCEDURES

4.1. SHIPBOARD INSTALLATION

In shipboard BAWAT System installations existing equipment will part of the installations, e.g. the ballast pump and the nitrogen generator. For these the ship's emergency procedures will apply.

The proprietary BAWAT components to be installed will be equipped with emergency stops where appropriate and emergency procedures will be established.

It should be observed that ballast water tanks after treatment with the BAWAT System and after de-ballasting might contain a higher level of nitrogen than the content in 'normal' atmospheric air. Therefore in the procedures for entering a ballast water tank, special attention should be paid to ensure that after the normal and customary aeration procedure, the oxygen content is acceptable for entering.

As a side remark it should be kept in mind, that nitrogen in itself is slightly lighter than air. Therefore it will not pose the same problem as CO_2 , which might accumulate in the bottom of the tank, because its specific gravity is 50% higher than it is for air.

4.2. LAND-BASED TEST INSTALLATION

In the land-based test installation the following emergency procedures will apply:

4.2.1. STEAM GENERATOR

The steam generator is equipped with an emergency stop switch located as shown in figure 4.2.1/1.

In case of any malfunction of the steam generator, rupture of a steam pipe or connection in the steam generator container, in the 20' container with the pasteurizer or outside any of the containers the emergency switch must be activated and personnel evacuated from the vicinity of the system until the steam pressure has subsided.

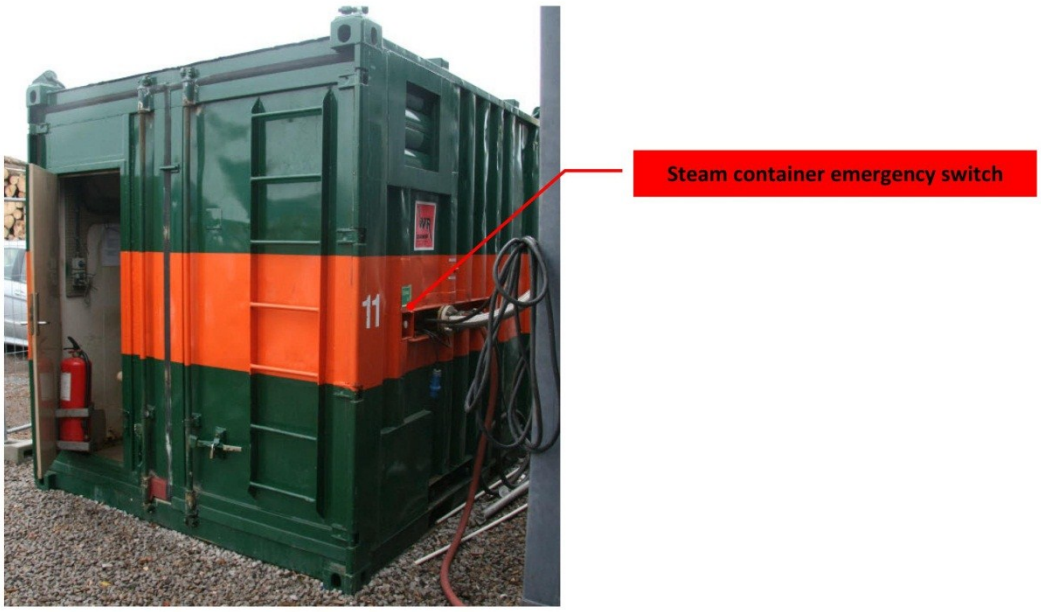


Figure 4.2.1/1: Location of steam generator emergency switch.

4.2.2. 20' CONTAINER

In case of escape of high pressure steam caused by a steam pipe rupture please refer to section 4.2.1 above.

The 20' container houses the nitrogen generator. In case of a generator malfunction there is a risk of increased nitrogen content in the air inside the container. Therefore, during operation of the generator at least one of the container doors must be fully open. Further, the feed-through openings of the various pipes through the container walls are constantly kept open to allow ventilation.

The compressor is equipped with an emergency switch located as shown in figure 4.2.2/1.

In case of malfunction of the nitrogen generator the emergency switch must be activated.

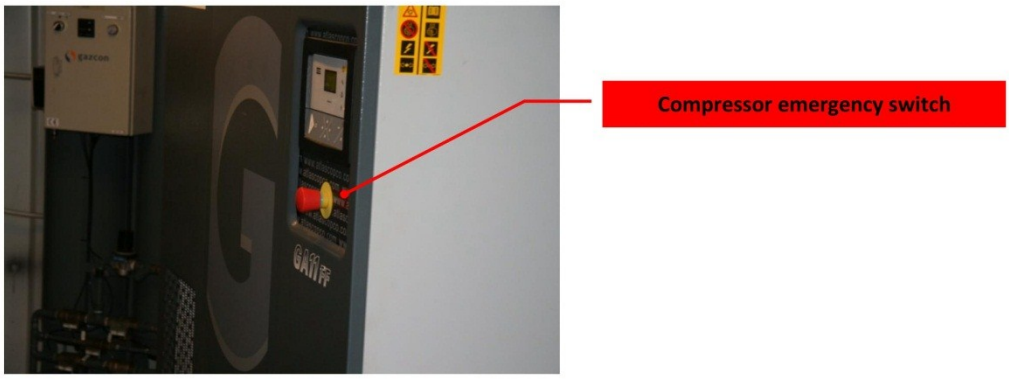


Figure 4.2.2/1: Location of compressor emergency switch.

4.2.3. 10' CONTAINER

The 10' container houses the BAWAT Control and Monitoring Centre (CMC) and the main recirculation pump.

The main fuse box with Residual Current Circuit Breakers is located outside on the back wall of the container – figure 4.2.3/1. In case of a malfunction in the pumps or the CMC that requires immediate power-down the power can be cut in the shown fuse box or on by turning the power switch to OFF on the front of the CMC unit inside the container - figure 4.2.3/2.

Figure 4.2.3/1: Main fuse box with Residual Current Circuit Breakers is located outside on the back wall of the 10' container.

5. APPENDICES

Appendices are available in digital form on a DVD or for download.

5.1. ISOMIX IM 25 ROTARY JET MIXER SPECIFICATIONS
5.2. STEAM GENERATOR SYSTEM
5.3. PASTEURIZER UNIT
5.4. IRON PUMPS CENTRIFUGAL PUMP
5.5. NITROGEN GENERATOR
5.6. DISSOLVED OXYGEN MEASUREMENT
5.7. PRESSURE MEASUREMENT
5.8. WATER FLOW MEASUREMENT
5.9. DATALOGGER AND SOFTWARE
5.10. NITROGEN FLOW INSTRUMENTATI
5.11. BIOLOGICAL TESTS (DHI)
5.12. BAWAT DOCUMENT 2012.007 ENTITLED "1:10 TEST TANK DESCRIPTION & STANDARD OPERATING PROCEDURES"
5.13. JAKOB K. HUUSOM AND JOHN VILLADSEN, DEPARTMENT OF CHEMICAL AND BIO-CHEMICAL ENGINEERING, DTU: TREATMENT OF BALLAST TANK WATER IN DIFFERENT SCALES – MODELLING OF THE BALLAST TANK, AND EXPERIMENTAL VALIDATION OF THE MODEL.
5.14. OXYGEN SENSOR
5.15. TEMPERATURE LOGGER

APPENDIX C

Overview of DHI SOPs

SUBJECT/SUBSUBJECT	DHI SOP NO.
ANALYTICAL METHOD DETERMINATION OF VIABLE ORGANISMS ≥50 µm	30/1700
ANALYTICAL METHOD DETERMINATION OF VIABLE ORGANISMS ≥10 µm AND < 50 µm	30/1701
ANALYTICAL METHOD DETERMINATION OF PRIMARY PRODUCTION OF MICROALGAE	30/1702
ANALYTICAL METHOD DETERMINATION OF VIABLE ALGAE BY RE-GROWTH ASSAY	30/1704
MICROBIOLOGICAL TESTS DETERMINATION OF TOTAL NUMBER OF BACTERIA BY EPIFLUORESCENCE MICROSCOPY	30/1705
MICROBIOLOGICAL TESTS DETERMINATION OF HETEROTROPHIC PLATE COUNT	30/1706
MICROBIOLOGICAL TESTS DETERMINATION OF *VIBRIO CHOLERAE* IN WATER	30/1707
MICROBIOLOGICAL TESTS DETERMINATION OF TOTAL COLIFORM, E.COLI AND ENTEROCOCCI	30/1708
MEASUREMENT METHOD TRO MEASUREMENT IN WATER	30/1732
HARVESTING, CULTURING AND ADDITION OF ORGANISMS	30/1734
COLLECTION OF SEAWATER	30/1735
COLLECTION OF FRESH WATER	30/1736
CRITERIA FOR TEST WATER ADDITION OF DOC, POC, MM AND BRINE	30/1737
SAMPLING PREPARATION, SUBSAMPLING AND TRANSPORTATION OF SAMPLES	30/1738
DATABASE SAMPLES, LABELS AND DATA SHEETS	30/1750
OPERATION OF THE DHI MTEF	30/1762
CLEANING RETENTION TANKS; PIPINGS AND OTHER EQUIPMENT AT TEST SITE	30/1763
MEASUREMENT METHOD ON-LINE MONITORING OF PRESSURE, TEMPERATURE, FLOW RATES AND QUALITY PARAMETERS AT TEST SITE	30/1764
MEASUREMENT METHOD FLUORESCENCE	30/1765
MEASUREMENT METHOD TURBIDITY	30/1766
DHI MTEF HEALTH AND SAFETY	30/1767
MEASUREMENT METHOD DETERMINATION OF TSS	30/1768
MEASUREMENT METHOD DETERMINATION OF DOC AND POC	30/1769
MEASUREMENT METHOD DETERMINATION OF TRANSMITTANCE	30/1770

APPENDIX 2

Data logging from the biological efficacy testing with the BAWAT BWMS

Table A2.1 Biological efficacy test cycle data logging

Subject	Results
Client treatment system	BAWAT
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	Heat exchanger (72°C) Deoxygenation Recirculation: 4 times After treatment cooling
Salinity (PSU)	32
Retention tank No.	C2
Test cycle No.	M-1
Use of cultured/harvested organisms	Addition of backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2013.03.20 09:35
Date and time ballast stop	2013.03.20 10:36
Flow rate to control and retention tank during ballast (average)	436 m^3/h
Power consumption during treatment*	13.216 kW/m^3
Treated volume	246 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.03.25 10:03
Date and time de-ballast stop	2013.03.25 10:49
Flow rate during discharge (average)	294 m^3/h

* Information on manufacturer-specified parameters and power consumption data provided by the client

Table A2.2 Onsite measurements (standard deviations in parenthesis)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Inlet (T0)	94 (±1.1)	7.7 (±0.03)	32 (±0.05)	3.4 (±0.06)	38 (±1.2)
Treated discharge (T5)	5.6 (±1.8)	7.1 (±0.02)	32 (±0.01)	6.7 (±0.41)	21 (±5.0)
Control discharge (T5)	72 (±0.85)	7.4 (±0.01)	32 (±0.01)	1.8 (±0.33)	6.5 (±4.0)

PSU Practical salinity units
NTU Nephelometric turbidity units

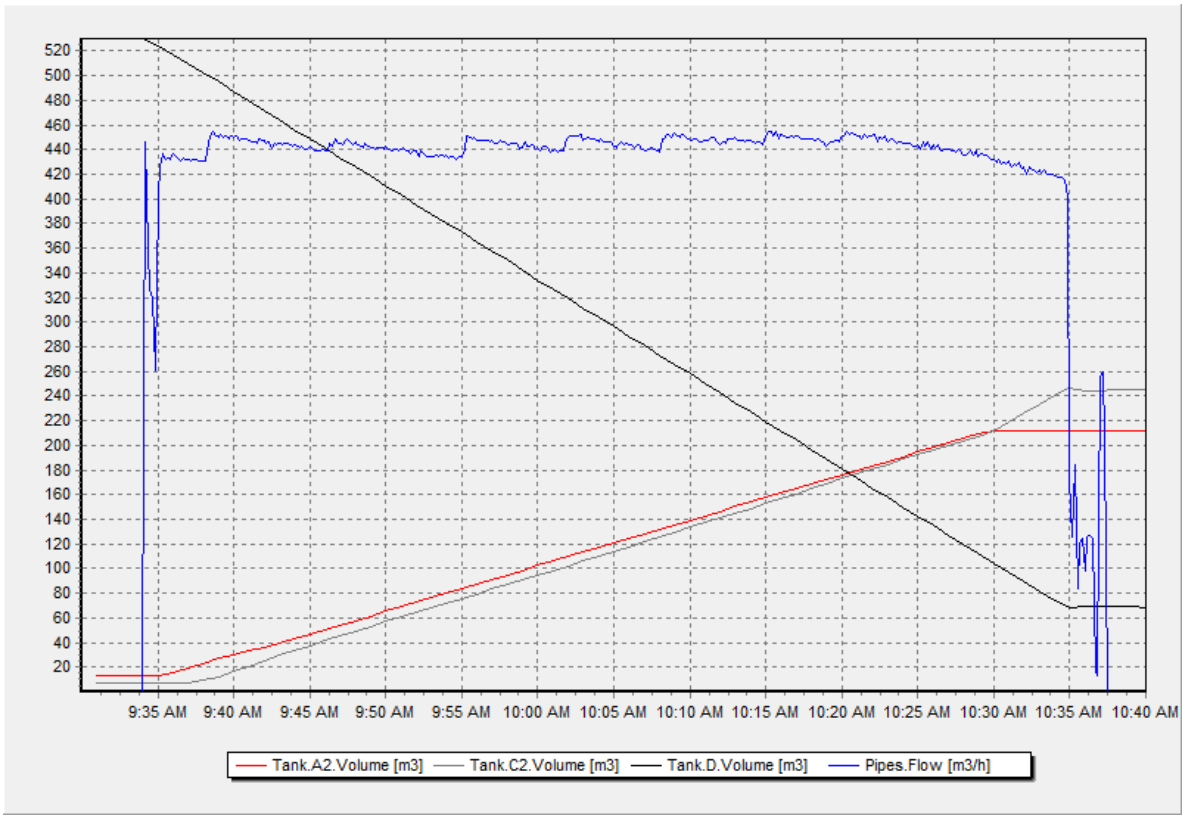


Figure A2.1 Test cycle M-1 data plot. Ballast operation.

Figure A2.2 Test cycle M-1 data plot. De-ballast operation.

Table A2.3 Biological efficacy test cycle data logging

Subject	Results
Client treatment system	BAWAT
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	Heat exchanger (72°C) Deoxygenation Recirculation: 5 times After treatment cooling
Salinity (PSU)	34
Retention tank No.	C2
Test cycle No.	M-2
Use of cultured/harvested organisms	Addition of backwash water from onsite 10-µm low pressure filter, cultivated Artemia and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2013.05.08 08:55
Date and time ballast stop	2013.05.08 09:48
Flow rate to control and retention tank during ballast (average)	500 m^3/h
Power consumption during treatment*	13.123 kW/m^3
Treated volume	250 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.05.14 08:44
Date and time de-ballast stop	2013.05.14 09:27
Flow rate during discharge (average)	313 m^3/h

* Information on manufacturer-specified parameters and power consumption data provided by the client

Table A2.4 Onsite measurements (standard deviations in parenthesis)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Inlet (T0)	106 (±0.38)	7.7 (±0.02)	34 (±0.02)	13 (±0.01)	25 (±1.5)
Treated discharge (T6)	4.3 (±1.2)	7.4 (±0.03)	35 (±0.01)	15 (±0.14)	16 (±1.4)
Control discharge (T6)	75 (±1.8)	7.8 (±0.04)	35 (±0.01)	13 (±0.13)	2.7 (±1.3)

PSU Practical salinity units
NTU Nephelometric turbidity units

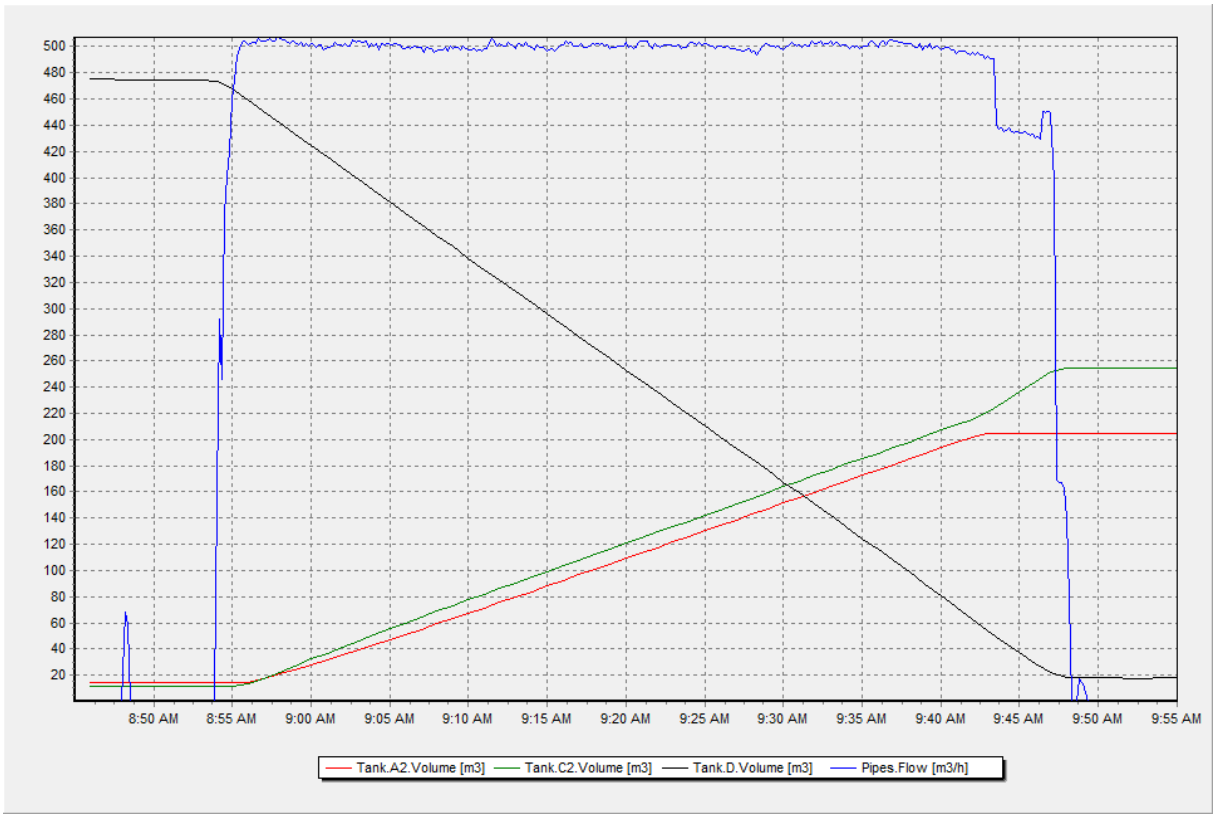


Figure A2.3 Test cycle M-2 data plot. Ballast operation.

Figure A2.4 Test cycle M-2 data plot. De-ballast operation.

Table A2.5 Biological efficacy test cycle data logging

Subject	Results
Client treatment system	BAWAT
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	Heat exchanger (72°C) Deoxygenation Recirculation: 5 times In-line cooling of treated water
Salinity (PSU)	34
Retention tank No.	C2
Test cycle No.	M-3
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated Artemia and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2013.05.28 09:06
Date and time ballast stop	2013.05.28 10:01
Flow rate to control and retention tank during ballast (average)	478 m^3/h
Power consumption during treatment*	15.972 kW/m^3
Treated volume	239 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.06.03 08:24
Date and time de-ballast stop	2013.06.03 09:10
Flow rate during discharge (average)	282 m^3/h

* Information on manufacturer-specified parameters and power consumption data provided by the client

Table A2.6 Onsite measurements (standard deviations in parenthesis)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Inlet (T0)	101 (±0.11)	8.0 (±0.02)	34 (±0.04)	15 (±0.03)	33 (±0.87)
Treated discharge (T6)	7.8 (±0.56)	7.5 (±0.01)	34 (±0.01)	21 (±0.19)	21 (±8.9)
Control discharge (T6)	41 (±4.1)	7.4 (±0.04)	34 (±0.02)	17 (±0.40)	4.6 (±2.1)

PSU Practical salinity units
NTU Nephelometric turbidity units

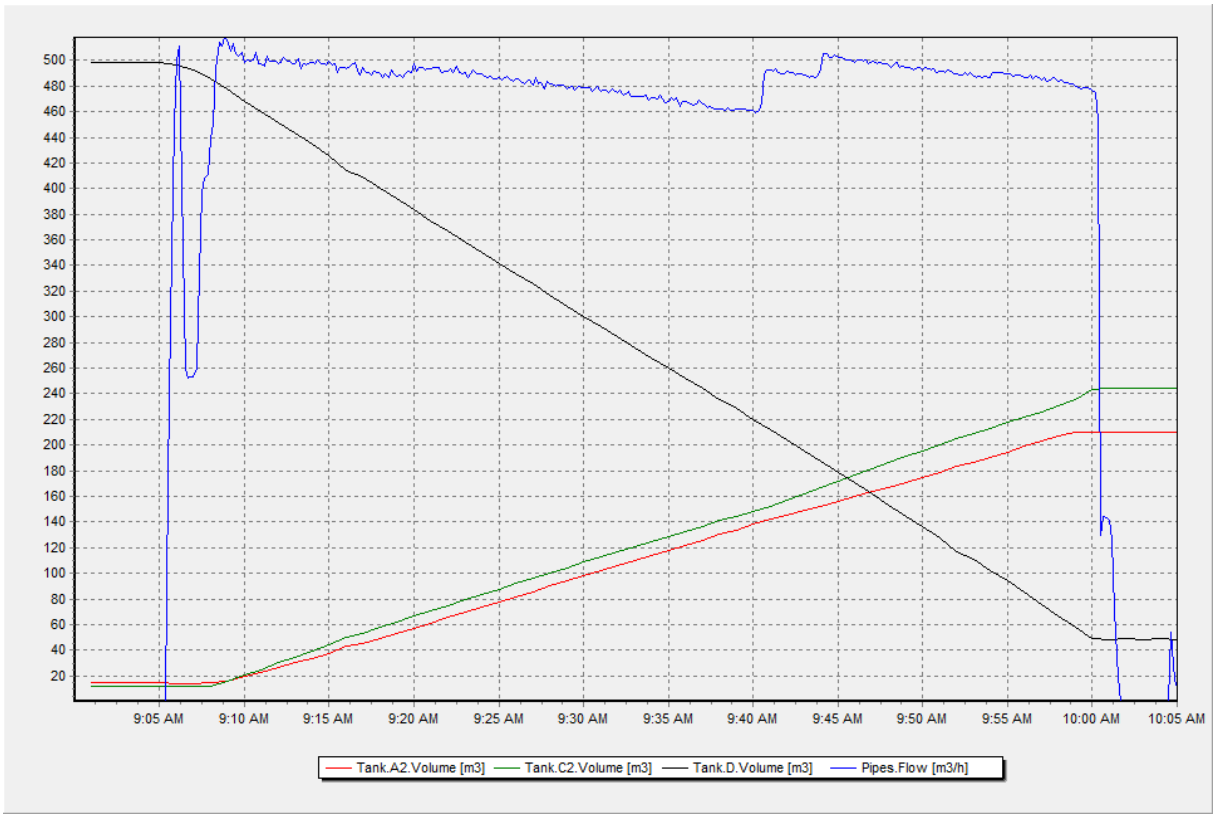


Figure A2.5 Test cycle M-3 data plot. Ballast operation.

Figure A2.6 Test cycle M-3 data plot. De-ballast operation.

Table A2.7 Biological efficacy test cycle data logging

Subject	Results
Client treatment system	BAWAT
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	Heat exchanger (72°C) Deoxygenation Recirculation: 5 times In-line cooling of treated water
Salinity (PSU)	34
Retention tank No.	C2
Test cycle No.	M-4
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2013.06.04 09:05
Date and time ballast stop	2013.06.04 09:59
Flow rate to control and retention tank during ballast (average)	499 m^3/h
Power consumption during treatment*	17.559 kWh/m^3
Treated volume	242 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.06.10 09:40
Date and time de-ballast stop	2013.06.10 10:26
Flow rate during discharge (average)	295 m^3/h

* Information on manufacturer-specified parameters and power consumption data provided by the client

Table A2.8 Onsite measurements (standard deviations in parenthesis)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Inlet (T0)	101 (±0.13)	8.0 (±0.02)	34 (±0.03)	16 (±0.02)	24 (±1.4)
Treated discharge (T6)	10 (±2.7)	7.6 (±0.01)	34 (±0.03)	23 (±0.30)	37 (±11)
Control discharge (T6)	59 (±6.8)	7.5 (±0.04)	34 (±0.12)	18 (±0.42)	56 (±14)

PSU Practical salinity units
NTU Nephelometric turbidity units

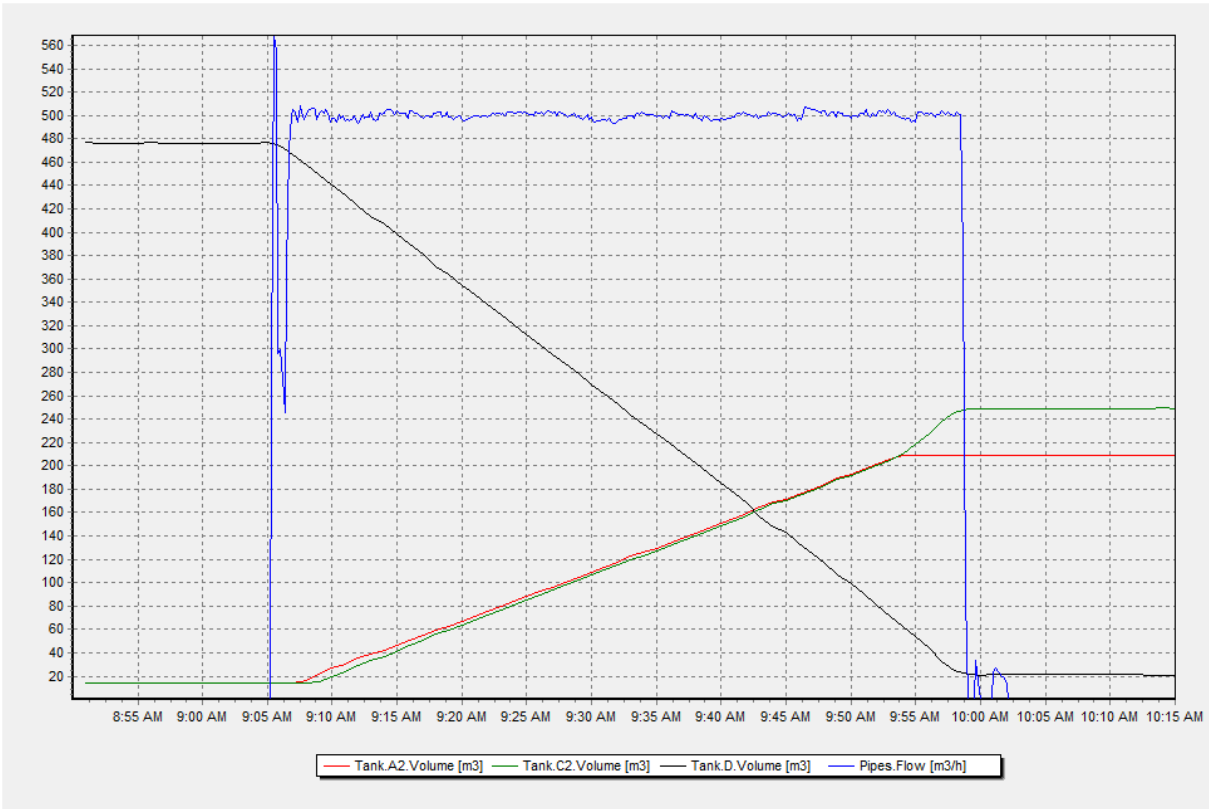


Figure A2.7 Test cycle M-4 data plot. Ballast operation.

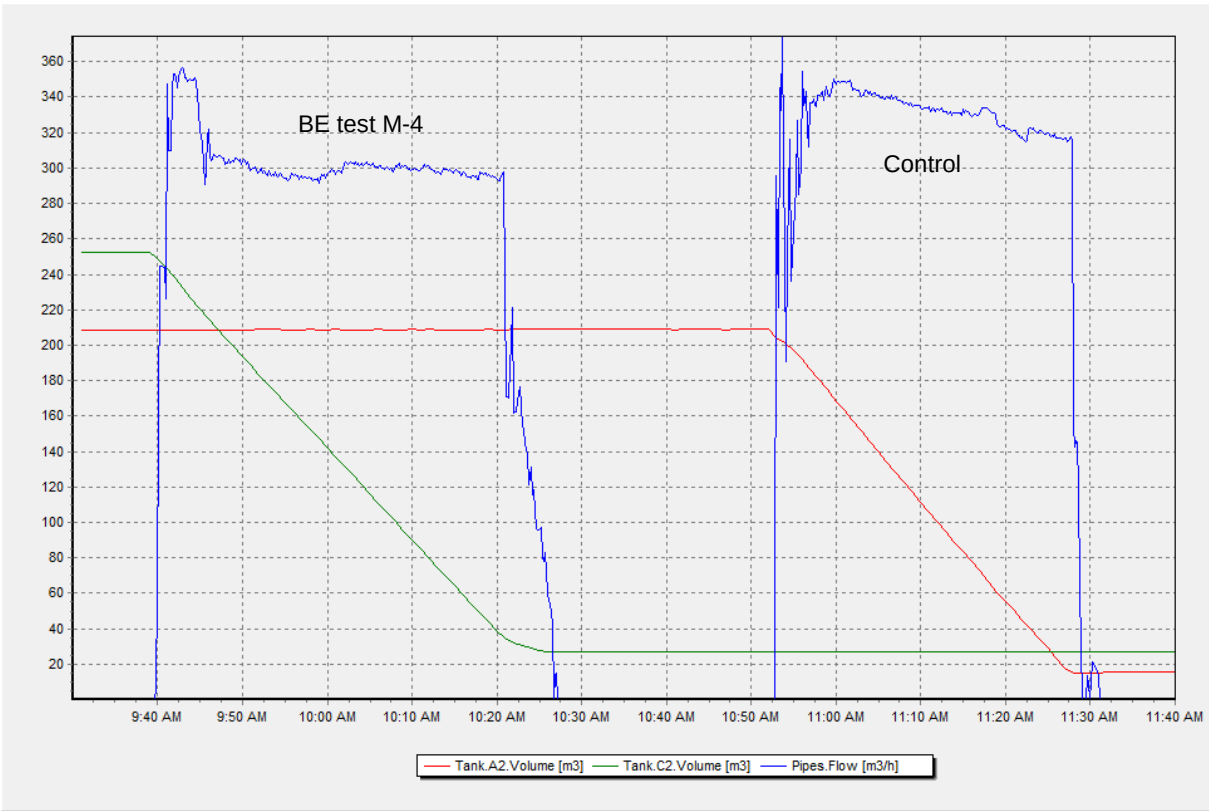


Figure A2.8 Test cycle M-4 data plot. De-ballast operation.

Table A2.9 Biological efficacy test cycle data logging

Subject	Results
Client treatment system	BAWAT
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	Heat exchanger (72°C) Deoxygenation Recirculation: 5 times In-line cooling of treated water
Salinity (PSU)	34
Retention tank No.	C2
Test cycle No.	M-5
Use of cultured/harvested organisms	Addition of backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2013.06.18 08:59
Date and time ballast stop	2013.06.18 09:51
Flow rate to control and retention tank during ballast (average)	522 m^3/h
Power consumption during treatment*	18.438 kW/m^3
Treated volume	243 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.06.24 09:25
Date and time de-ballast stop	2013.06.24 09:59
Flow rate during discharge (average)	343 m^3/h

* Information on manufacturer-specified parameters and power consumption data provided by the client

Table A2.10 Onsite measurements (standard deviations in parenthesis)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Inlet (T0)	97 (±0.12)	8.0 (±0.02)	34 (±0.02)	16 (±0.03)	27 (±2.2)
Treated discharge (T6)	4.6 (±1.3)	7.0 (±0.05)	35 (±0.01)	22 (±0.14)	24 (±4.6)
Control discharge (T6)	27 (±9.3)	7.0 (±0.08)	35 (±0.01)	18 (±0.23)	2.4 (±2.3)

PSU Practical salinity units
NTU Nephelometric turbidity units

Figure A2.9 Test cycle M-5 data plot. Ballast operation.

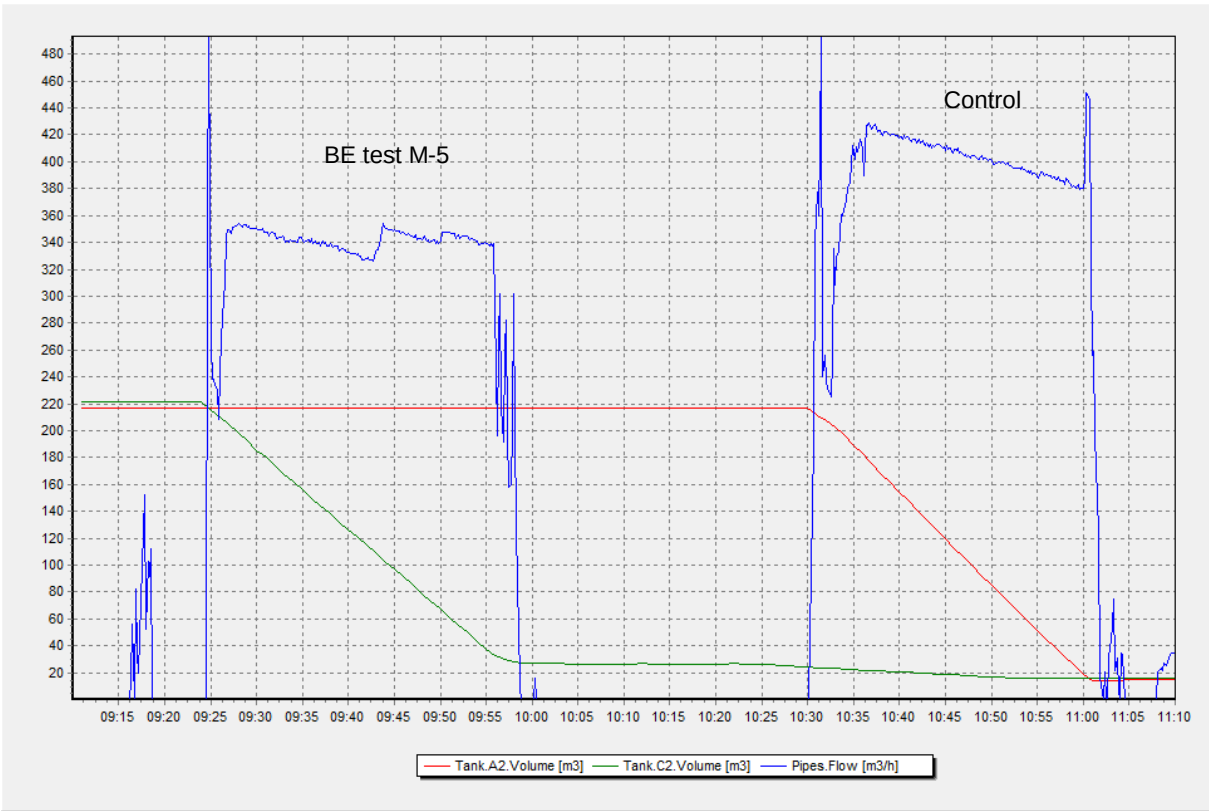


Figure A2.10 Test cycle M-5 data plot. De-ballast operation.

Table A2.11 Biological efficacy test cycle data logging

Subject	Results
Client treatment system	BAWAT
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	Heat exchanger (72°C) Deoxygenation Recirculation: 5 times In-line cooling of treated water
Salinity (PSU)	37
Retention tank No.	C2
Test cycle No.	M-6
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2013.06.25 09:05
Date and time ballast stop	2013.06.25 09:59
Flow rate to control and retention tank during ballast (average)	495 m^3/h
Power consumption during treatment*	17.167 kW/m^3
Treated volume	241 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.07.01 09:13
Date and time de-ballast stop	2013.07.01 09:58
Flow rate during discharge (average)	300 m^3/h

* Information on manufacturer-specified parameters and power consumption data provided by the client

Table A2.12 Onsite measurements (standard deviations in parenthesis)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Inlet (T0)	99 (±0.20)	7.8 (±0.02)	37 (±0.01)	17 (±0.02)	27 (±1.7)
Treated discharge (T6)	4.5 (±1.1)	7.1 (±0.02)	37 (±0.01)	20 (±0.15)	26 (±0.76)
Control discharge (T6)	31 (±5.0)	7.0 (±0.07)	37 (±0.02)	17 (±0.18)	1.3 (±0.64)

PSU Practical salinity units
NTU Nephelometric turbidity units

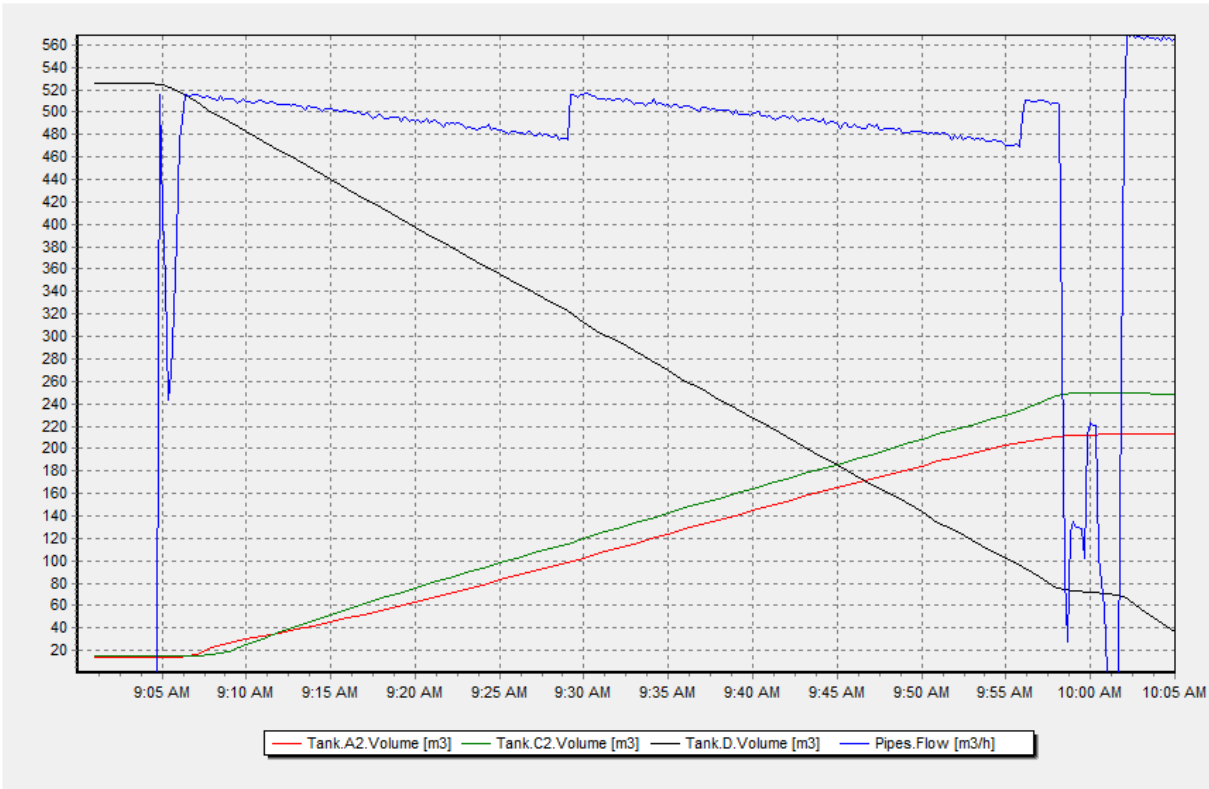


Figure A2.11 Test cycle M-6 data plot. Ballast operation.

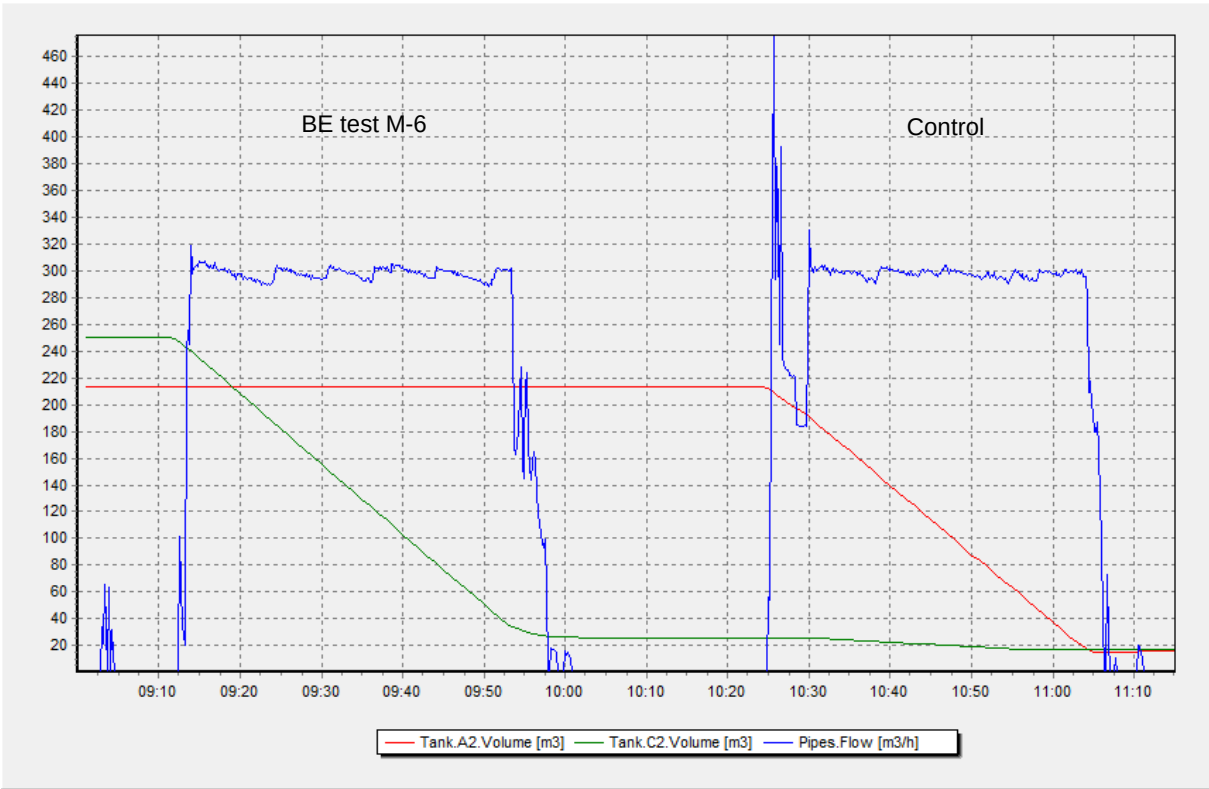


Figure A2.12 Test cycle M-6 data plot. De-ballast operation.

Table A2.13 Biological efficacy test cycle data logging

Subject	Results
Client treatment system	BAWAT
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	Heat exchanger (72°C) Deoxygenation Recirculation: 4 times After treatment cooling
Salinity (PSU)	19
Retention tank No.	C2
Test cycle No.	B-1
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2013.04.10 09:15
Date and time ballast stop	2013.04.10 10:10
Flow rate to control and retention tank during ballast (average)	495 m^3/h
Power consumption during treatment*	12.156 kW/m^3
Treated volume	250 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.04.15 08:45
Date and time de-ballast stop	2013.04.15 09:28
Flow rate during discharge (average)	312 m^3/h

* Information on manufacturer-specified parameters and power consumption data provided by the client

Table A2.14 Onsite measurements (standard deviations in parenthesis)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Inlet (T0)	102 (±0.46)	7.8 (±0.01)	19 (±0.09)	3.6 (±0.04)	32 (±0.46)
Treated discharge (T5)	5.0 (±0.94)	7.1 (±0.02)	19 (±0.00)	11 (±0.21)	19 (±1.7)
Control discharge (T5)	89 (±0.75)	7.6 (±0.00)	19 (±0.01)	5.4 (±0.38)	10 (±4.3)

PSU Practical salinity units
NTU Nephelometric turbidity units

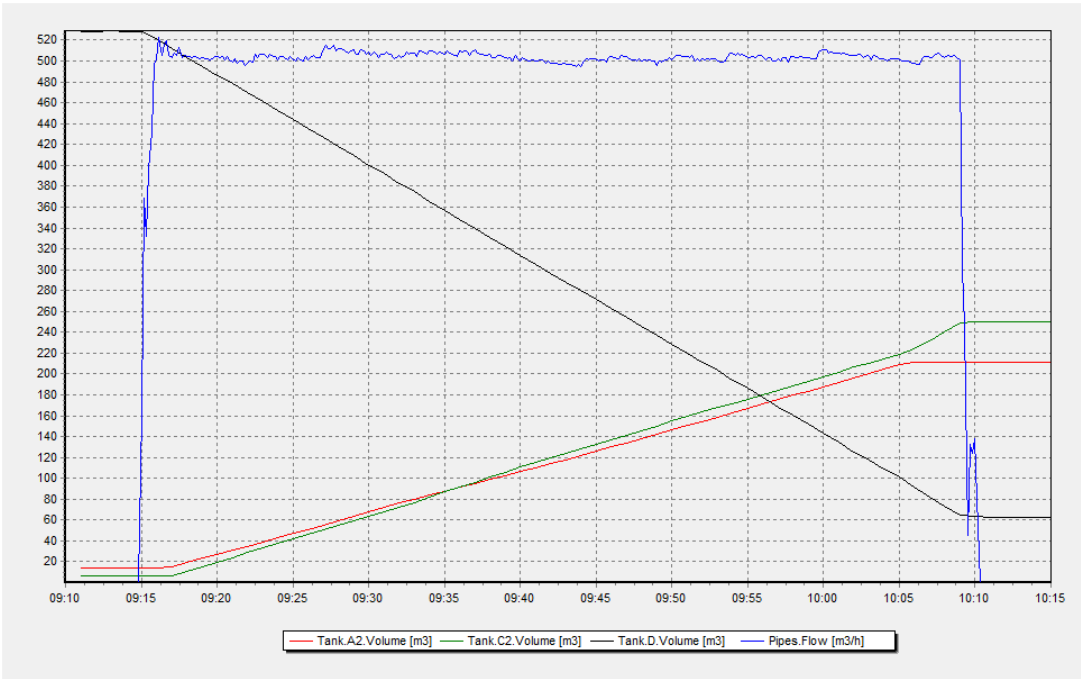


Figure A2.13 Test cycle B-1 data plot. Ballast operation.

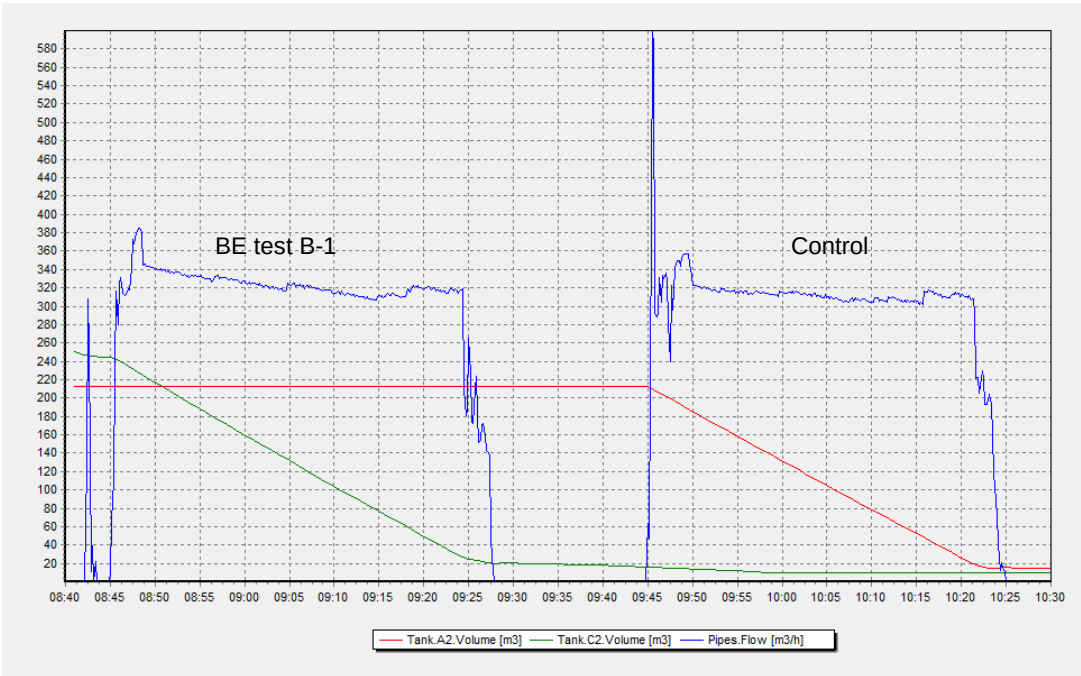


Figure A2.14 Test cycle B-1 data plot. De-ballast operation.

Table A2.15 Biological efficacy test cycle data logging

Subject	Results
Client treatment system	BAWAT
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	Heat exchanger (72°C) Deoxygenation Recirculation: 4 times After treatment cooling
Salinity (PSU)	21
Retention tank No.	C2
Test cycle No.	B-2
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2013.04.16 08:58
Date and time ballast stop	2013.04.16 09:57
Flow rate to control and retention tank during ballast (average)	454 m^3/h
Power consumption during treatment*	15.206 kW/m^3
Treated volume	245 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.04.22 08:45
Date and time de-ballast stop	2013.04.22 09:27
Flow rate during discharge (average)	308 m^3/h

* Information on manufacturer-specified parameters and power consumption data provided by the client

Table A2.16 Onsite measurements (standard deviations in parenthesis)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Inlet (T0)	106 (±0.74)	7.7 (±0.02)	21 (±0.01)	6.0 (±0.02)	18 (±2.1)
Treated discharge (T6)	5.7 (±1.5)	6.8 (±0.03)	21 (±0.01)	13 (±0.32)	11 (±1.2)
Control discharge (T6)	87 (±0.26)	7.5 (±0.02)	21 (±0.01)	9.2 (±0.39)	3.5 (±1.0)

PSU Practical salinity units
NTU Nephelometric turbidity units

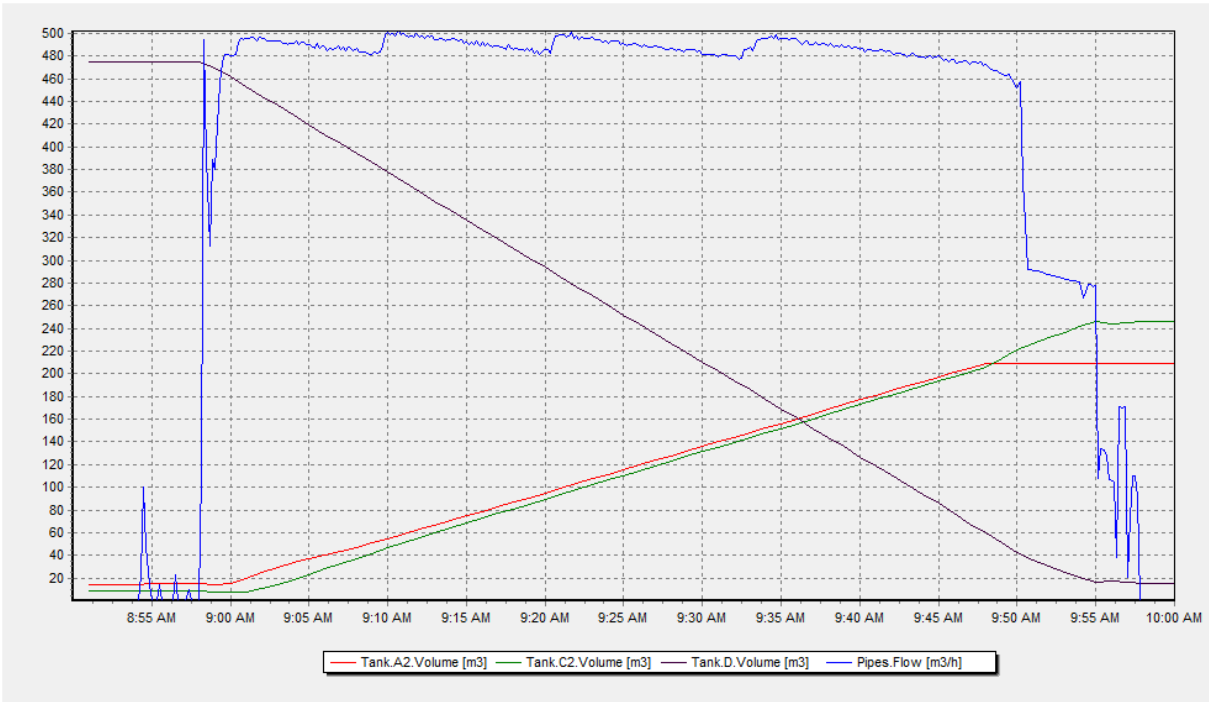


Figure A2.15 Test cycle B-2 data plot. Ballast operation.

Figure A2.16 Test cycle B-2 data plot. De-ballast operation.

Table A2.17 Biological efficacy test cycle data logging

Subject	Results
Client treatment system	BAWAT
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	Heat exchanger (72°C) Deoxygenation Recirculation: 4 times After treatment cooling
Salinity (PSU)	19
Retention tank No.	C2
Test cycle No.	B-3
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2013.04.23 08:48
Date and time ballast stop	2013.04.23 09:43
Flow rate to control and retention tank during ballast (average)	473 m^3/h
Power consumption during treatment*	15.216 kW/m^3
Treated volume	235 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.04.29 08:55
Date and time de-ballast stop	2013.04.29 09:40
Flow rate during discharge (average)	289 m^3/h

* Information on manufacturer-specified parameters and power consumption data provided by the client

Table A2.18 Onsite measurements (standard deviations in parenthesis)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Inlet (T0)	100 (±0.12)	7.7 (±0.00)	19 (±0.00)	7.8 (±0.01)	31 (±1.7)
Treated discharge (T6)	4.0 (±0.62)	7.0 (±0.03)	19 (±0.01)	12 (±0.30)	13 (±0.29)
Control discharge (T6)	76 (±0.33)	7.4 (±0.02)	19 (±0.00)	10 (±0.28)	2.9 (±1.6)

PSU Practical salinity units
NTU Nephelometric turbidity units

Figure A2.17 Test cycle B-3 data plot. Ballast operation.

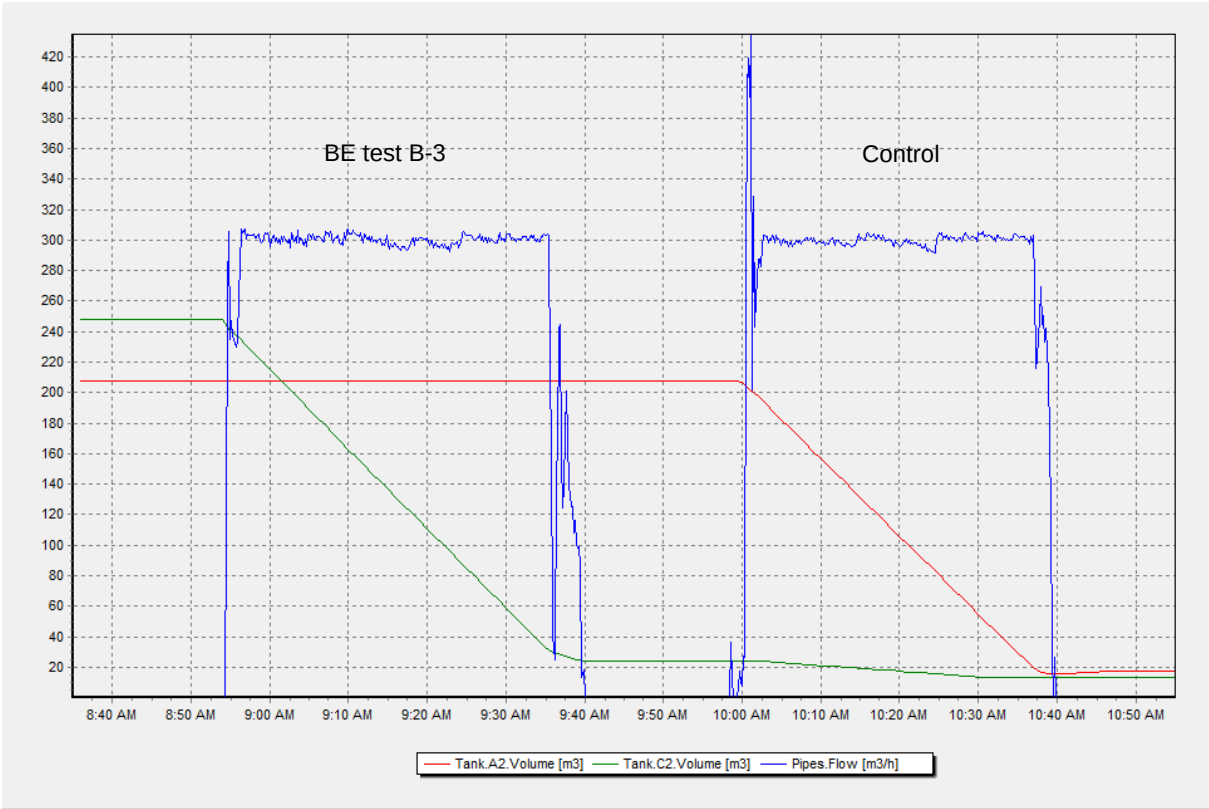


Figure A2.18 Test cycle B-3 data plot. De-ballast operation.

Table A2.19 Biological efficacy test cycle data logging

Subject	Results
Client treatment system	BAWAT
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	Heat exchanger (72°C) Deoxygenation Recirculation: 5 times After treatment cooling
Salinity (PSU)	19
Retention tank No.	C2
Test cycle No.	B-4
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2013.04.30 08:57
Date and time ballast stop	2013.04.30 09:51
Flow rate to control and retention tank during ballast (average)	500 m^3/h
Power consumption during treatment*	13.673 kW/m^3
Treated volume	246 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.05.06 08:57
Date and time de-ballast stop	2013.05.06 09:42
Flow rate during discharge (average)	295 m^3/h

* Information on manufacturer-specified parameters and power consumption data provided by the client

Table A2.20 Onsite measurements (standard deviations in parenthesis)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Inlet (T0)	102 (±0.30)	7.8 (±0.02)	19 (±0.00)	8.7 (±0.02)	35 (±0.75)
Treated discharge (T6)	12 (±0.67)	7.2 (±0.02)	19 (±0.01)	16 (±0.52)	25 (±4.6)
Control discharge (T6)	72 (±0.43)	7.5 (±0.02)	19 (±0.01)	12 (±0.57)	1.5 (±0.48)

PSU Practical salinity units
NTU Nephelometric turbidity units

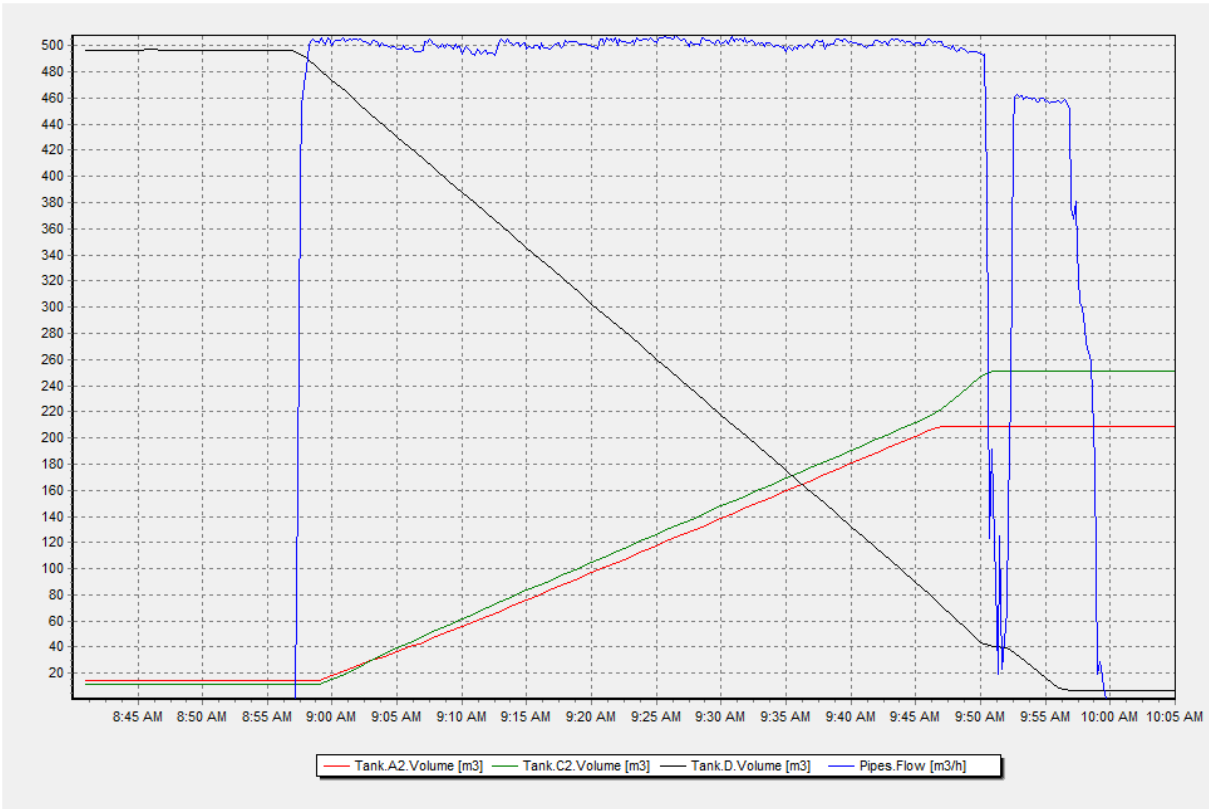


Figure A2.19 Test cycle B-4 data plot. Ballast operation.

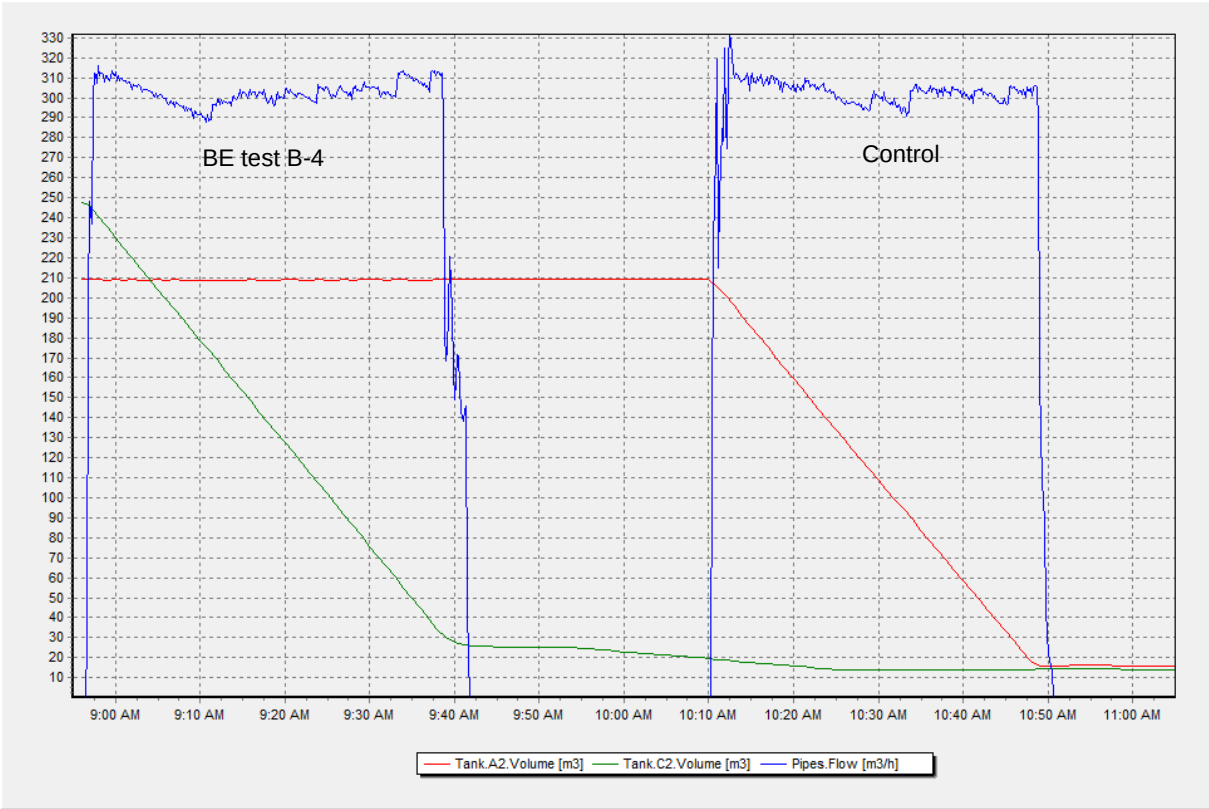


Figure A2.20 Test cycle B-4 data plot. De-ballast operation.

Table A2.21 Biological efficacy test cycle data logging

Subject	Results
Client treatment system	BAWAT
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	Heat exchanger (72°C) Deoxygenation Recirculation: 5 times In-line cooling of treated water
Salinity (PSU)	18
Retention tank No.	C2
Test cycle No.	B-5
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2013.08.06 09:01
Date and time ballast stop	2013.08.06 10:00
Flow rate to control and retention tank during ballast (average)	451 m^3/h
Power consumption during treatment*	10.786 kW/m^3
Treated volume	238 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.08.12 08:42
Date and time de-ballast stop	2013.08.12 09:24
Flow rate during discharge (average)	311 m^3/h

* Information on manufacturer-specified parameters and power consumption data provided by the client

Table A2.22 Onsite measurements (standard deviations in parenthesis)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Inlet (T0)	98 (±0.06)	8.0 (±0.02)	18 (±0.00)	21 (±0.02)	39 (±1.6)
Treated discharge (T6)	4.4 (±1.3)	7.1 (±0.05)	18 (±0.01)	24 (±0.24)	22 (±1.9)
Control discharge (T6)	44 (±3.1)	7.5 (±0.10)	18 (±0.01)	21 (±0.16)	1.1 (±2.5)

PSU Practical salinity units
NTU Nephelometric turbidity units

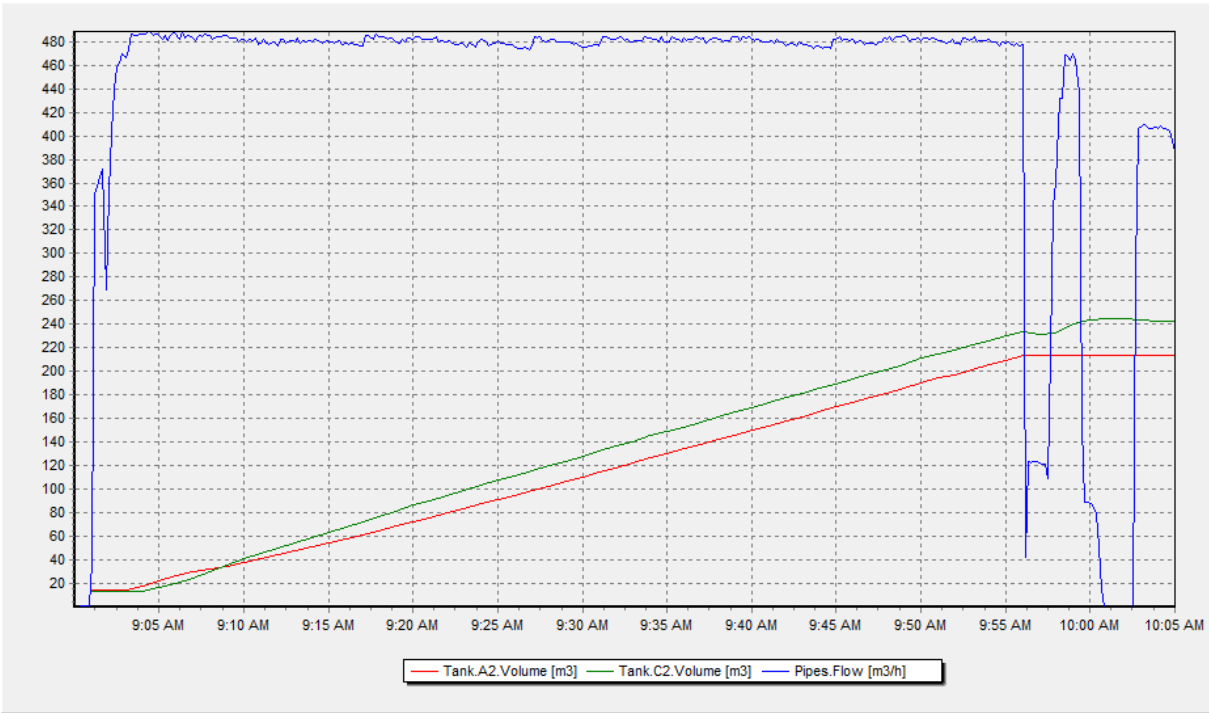


Figure A2.21 Test cycle B-5 data plot. Ballast operation.

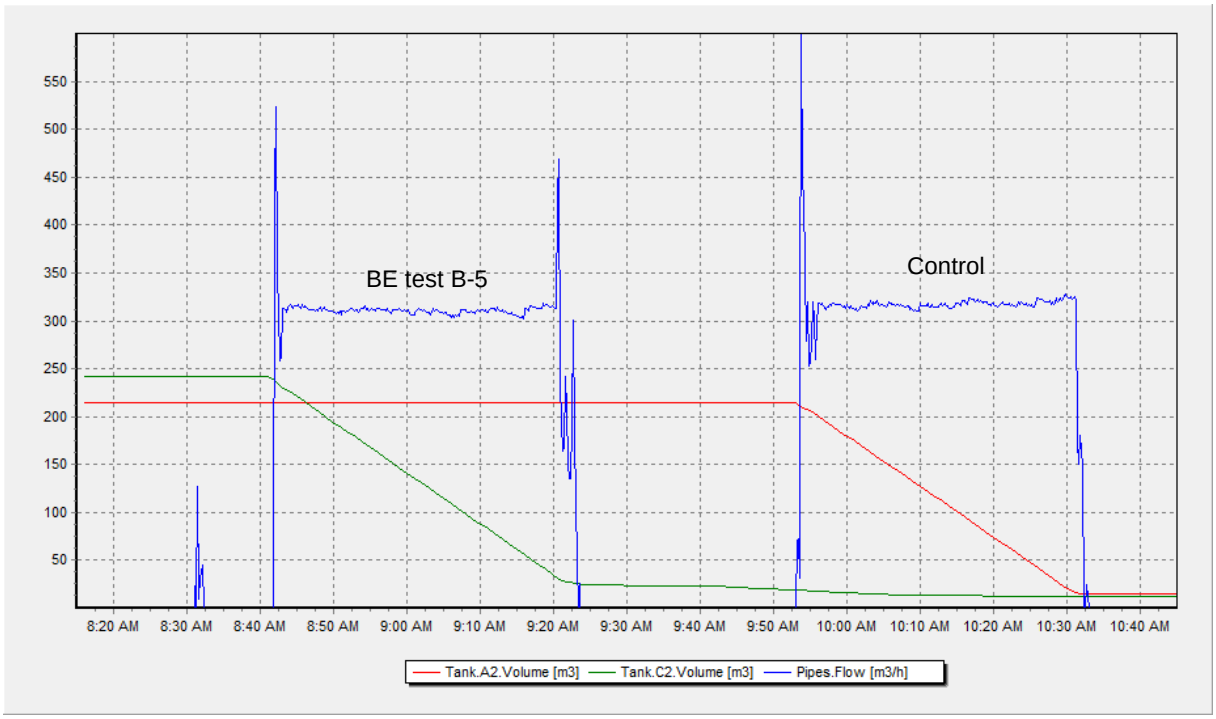


Figure A2.22 Test cycle B-5 data plot. De-ballast operation.

Table A2.23 Biological efficacy test cycle data logging

Subject	Results
Client treatment system	BAWAT
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	Heat exchanger (72°C) Deoxygenation Recirculation: 5 times In-line cooling of treated water
Salinity (PSU)	18
Retention tank No.	C2
Test cycle No.	B-6
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2014.03.18 09:13
Date and time ballast stop	2014.03.18 10:06
Flow rate to control and retention tank during ballast (average)	501 m^3/h
Power consumption during treatment*	19.304 kW/m^3
Treated volume	242 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2014.03.24 09:10
Date and time de-ballast stop	2014.03.24 09:56
Flow rate during discharge (average)	293 m^3/h

* Information on manufacturer-specified parameters and power consumption data provided by the client

Table A2.24 Onsite measurements (standard deviations in parenthesis)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Inlet (T0)	98 (±0.06)	7.9 (±0.02)	21 (±0.01)	6.6 (±0.01)	33 (±0.93)
Treated discharge (T6)	-	-	-	-	-
Control discharge (T6)	-	-	-	-	-

PSU Practical salinity units
NTU Nephelometric turbidity units

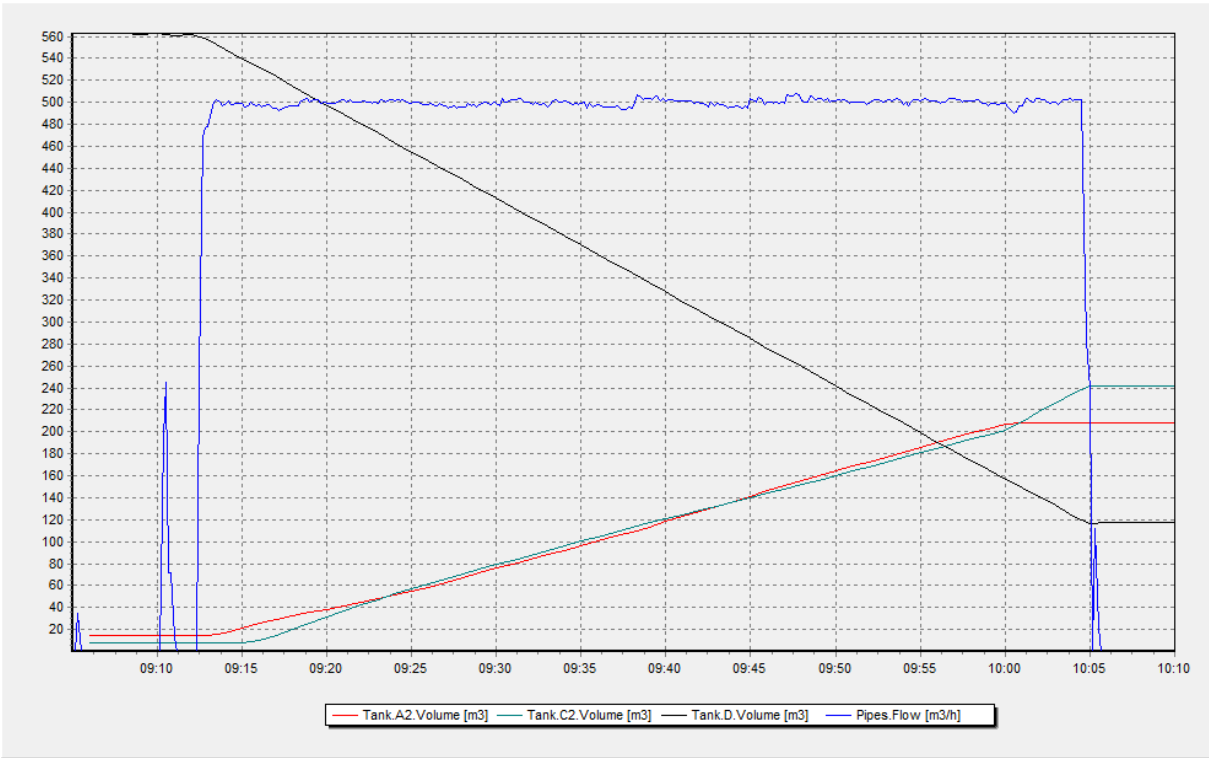


Figure A2.23 Test cycle B-6 data plot. Ballast operation.

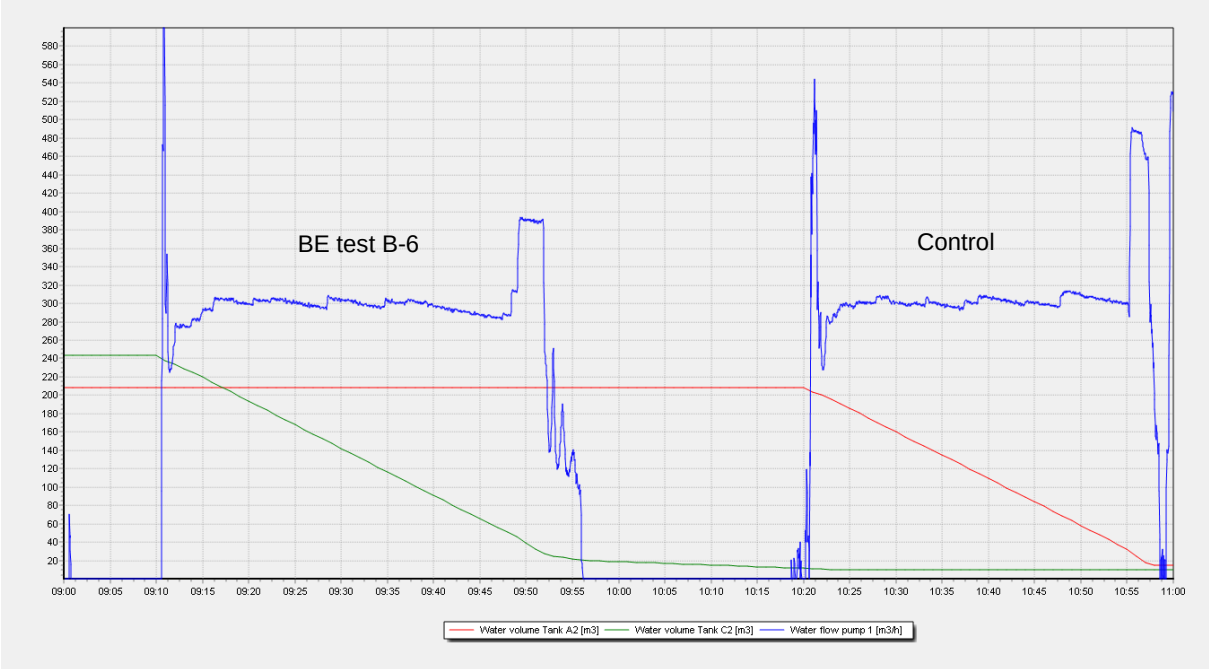


Figure A2.24 Test cycle B-6 data plot. De-ballast operation.

Table A2.25 Biological efficacy test cycle data logging

Subject	Results
Client treatment system	BAWAT
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	Heat exchanger (72°C) Deoxygenation Recirculation: 5 times In-line cooling of treated water
Salinity (PSU)	18
Retention tank No.	C2
Test cycle No.	B-7
Use of cultured/harvested organisms	Addition backwash water from onsite 10-µm low pressure filter, cultivated *Artemia* and cultivated algae
System cleaned before ballast	Yes
Date and time ballast start	2014.03.27 09:12
Date and time ballast stop	2014.03.27 10:05
Flow rate to control and retention tank during ballast (average)	502 m^3/h
Power consumption during treatment*	19.752 kW/m^3
Treated volume	242 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2014.04.02 09:08
Date and time de-ballast stop	2014.04.02 09:54
Flow rate during discharge (average)	294 m^3/h

* Information on manufacturer-specified parameters and power consumption data provided by the client

Table A2.26 Onsite measurements (standard deviations in parenthesis)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Inlet (T0)	93 (±0.95)	7.9 (±0.00)	21 (±1.5)	5.8 (±0.01)	36 (±3.0)
Treated discharge (T6)	5.1 (±0.94)	7.1 (±0.05)	21 (±1.8)	14 (±0.29)	11 (±1.4)
Control discharge (T6)	66 (±5.7)	7.4 (±0.02)	21 (±0.02)	7.4 (±0.33)	3.6 (±0.77)

PSU Practical salinity units
NTU Nephelometric turbidity units

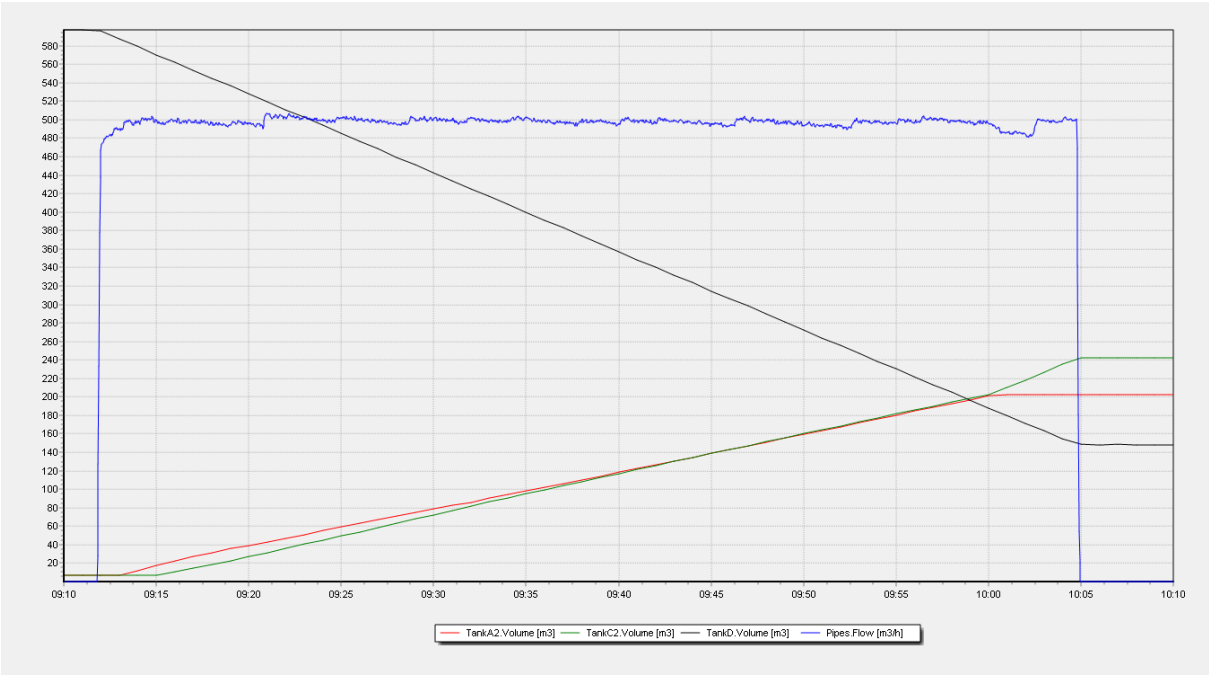


Figure A2.25 Test cycle B-7 data plot. Ballast operation.

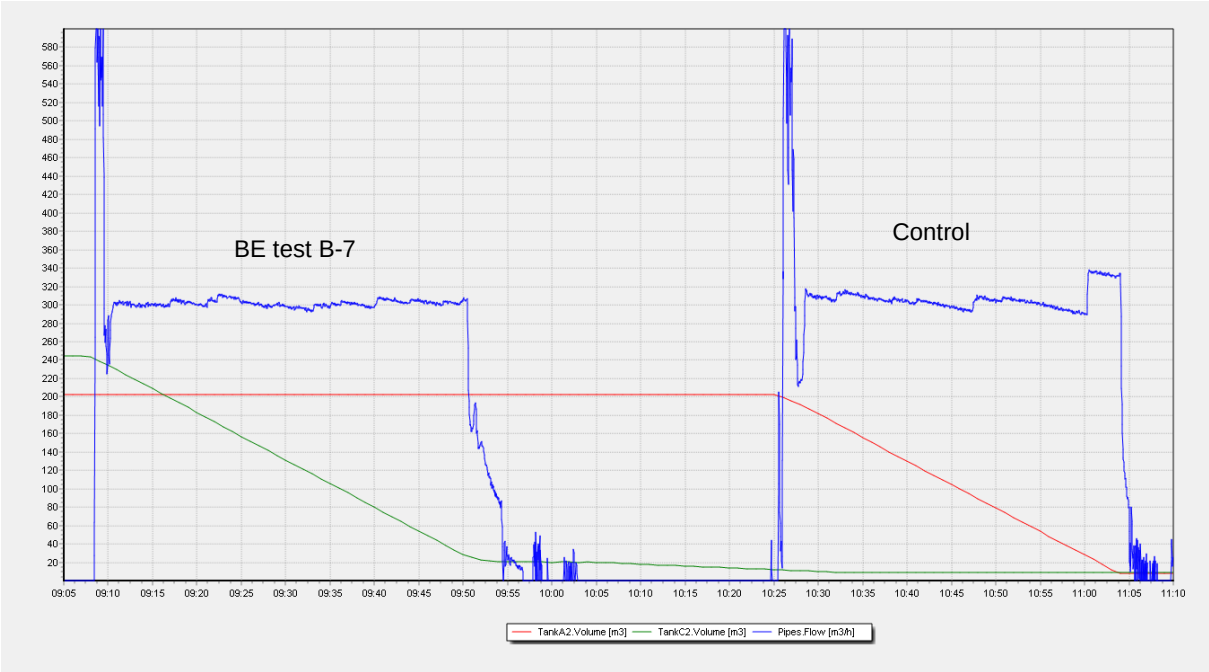


Figure A2.26 Test cycle B-7 data plot. De-ballast operation.

Table A2.27 Biological efficacy test cycle data logging

Subject	Results
Client treatment system	BAWAT
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	Heat exchanger (72°C) Deoxygenation Recirculation: 5 times In-line cooling of treated water
Salinity (PSU)	0.37
Retention tank No.	C2
Test cycle No.	F-1
Use of cultured/harvested organisms	No
System cleaned before ballast	Yes
Date and time ballast start	2013.08.13 08:37
Date and time ballast stop	2013.08.13 09:35
Flow rate to control and retention tank during ballast (average)	443 m^3/h
Power consumption during treatment*	12.270 kW/m^3
Treated volume	234 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.08.19 09:24
Date and time de-ballast stop	2013.08.19 10:06
Flow rate during discharge (average)	303 m^3/h

* Information on manufacturer-specified parameters and power consumption data provided by the client

Table A2.28 Onsite measurements (standard deviations in parenthesis)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Inlet (T0)	103 (±0.44)	8.2 (±0.00)	0.37 (±0.00)	17 (±0.01)	41 (±1.1)
Treated discharge (T6)	4.1 (±0.39)	7.6 (±0.00)	0.63 (±0.00)	22 (±0.13)	19 (±1.3)
Control discharge (T6)	81 (±2.1)	8.0 (±0.01)	0.37 (±0.00)	19 (±0.28)	5.5 (±0.90)

PSU Practical salinity units
NTU Nephelometric turbidity units

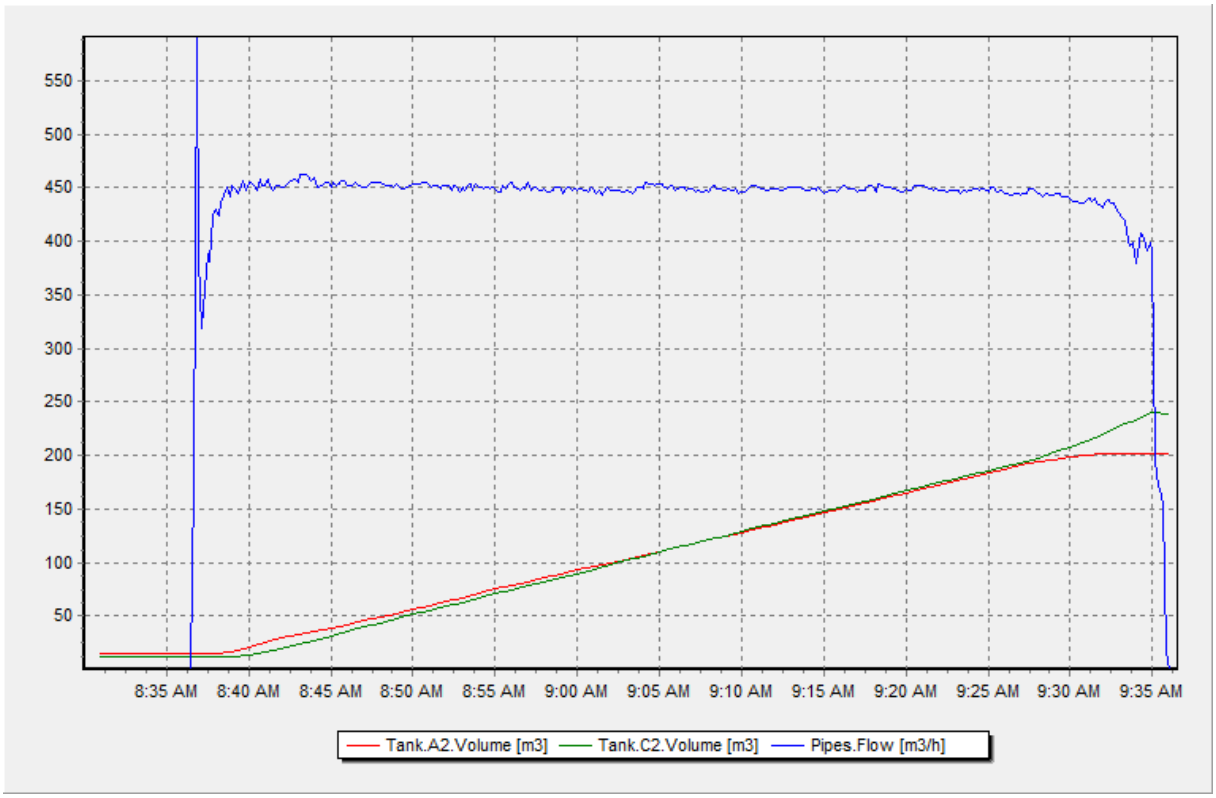


Figure A2.27 Test cycle F-1 data plot. Ballast operation.

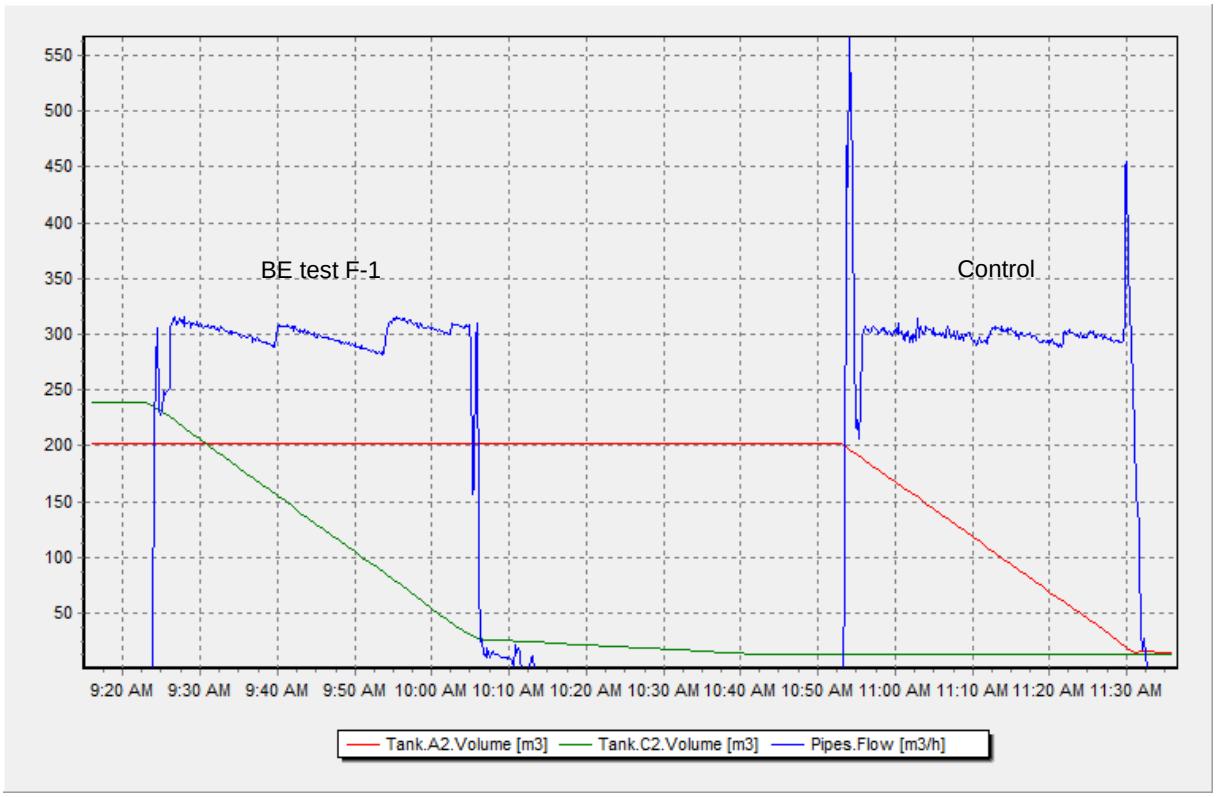


Figure A2.28 Test cycle F-1 data plot. De-ballast operation.

Table A2.29 Biological efficacy test cycle data logging

Subject	Results
Client treatment system	BAWAT
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	Heat exchanger (72°C) Deoxygenation Recirculation: 5 times In-line cooling of treated water
Salinity (PSU)	0.39
Retention tank No.	C2
Test cycle No.	F-2
Use of cultured/harvested organisms	No
System cleaned before ballast	Yes
Date and time ballast start	2013.08.20 08:23
Date and time ballast stop	2013.08.20 09:19
Flow rate to control and retention tank during ballast (average)	466 m^3/h
Power consumption during treatment*	12.959 kW/m^3
Treated volume	235 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.08.26 08:59
Date and time de-ballast stop	2013.08.26 09:45
Flow rate during discharge (average)	283 m^3/h

* Information on manufacturer-specified parameters and power consumption data provided by the client

Table A2.30 Onsite measurements (standard deviations in parenthesis)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Inlet (T0)	103 (±0.17)	8.2 (±0.00)	0.39 (±0.00)	18 (±0.01)	39 (±1.4)
Treated discharge (T6)	4.7 (±0.73)	7.5 (±0.01)	0.38 (±0.00)	24 (±0.22)	11 (±1.4)
Control discharge (T6)	88 (±3.0)	7.9 (±0.01)	0.38 (±0.00)	20 (±0.45)	4.1 (±1.5)

PSU Practical salinity units
NTU Nephelometric turbidity units

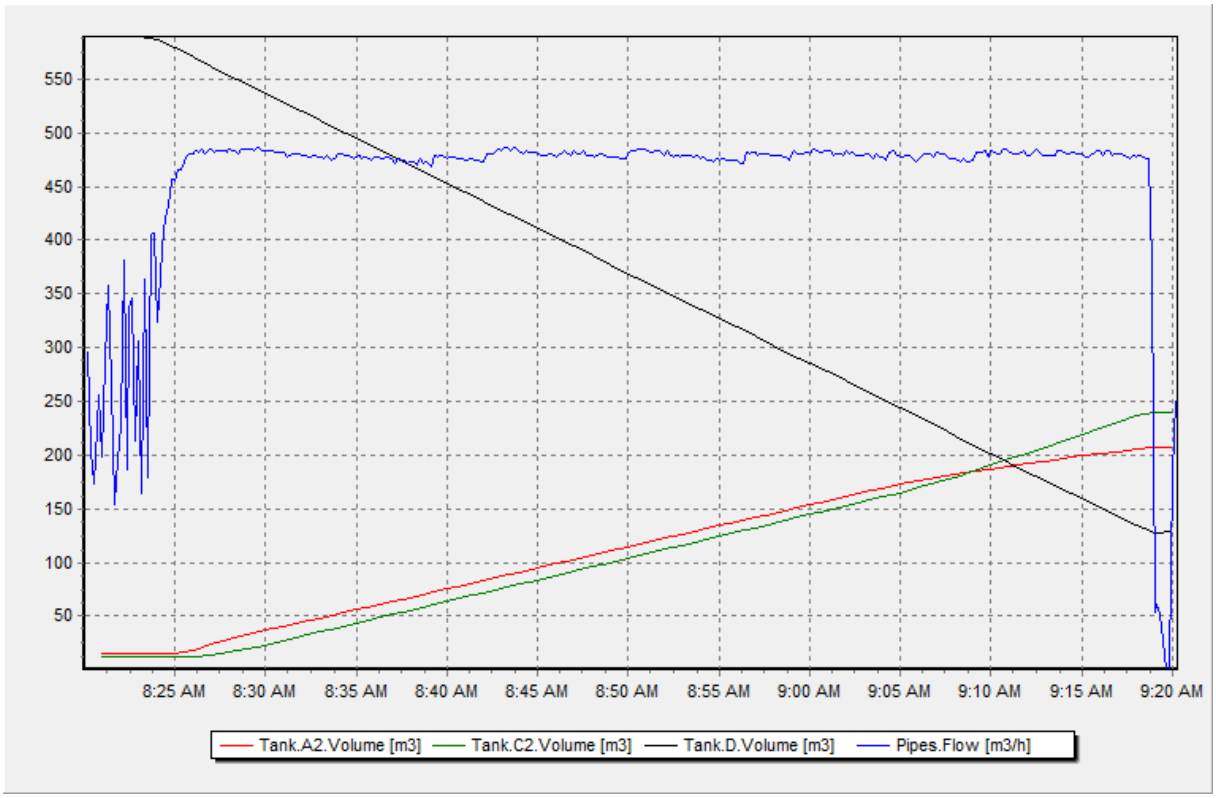


Figure A2.29 Test cycle F-2 data plot. Ballast operation.

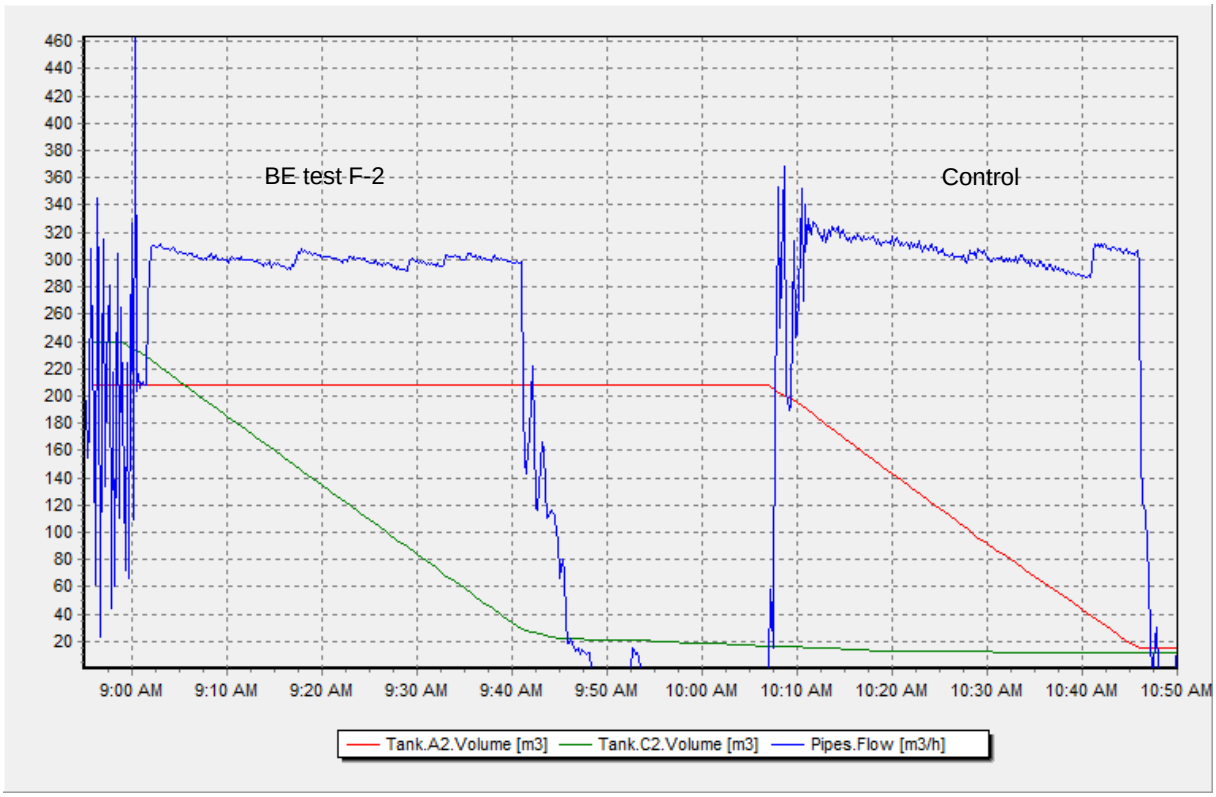


Figure A2.30 Test cycle F-2 data plot. De-ballast operation.

Table A2.31 Biological efficacy test cycle data logging

Subject	Results
Client treatment system	BAWAT
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	Heat exchanger (72°C) Deoxygenation Recirculation: 5 times In-line cooling of treated water
Salinity (PSU)	0.36
Retention tank No.	C2
Test cycle No.	F-3
Use of cultured/harvested organisms	-
System cleaned before ballast	Yes
Date and time ballast start	2013.09.03 08:24
Date and time ballast stop	2013.09.03 09:19
Flow rate during ballast (average)	464 m^3/h
Power consumption during treatment*	13.130 kW/m^3
Treated volume	235 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.09.09 08:57
Date and time de-ballast stop	2013.09.09 09:38
Flow rate during discharge (average)	308 m^3/h

* Information on manufacturer-specified parameters and power consumption data provided by the client

Table A2.32 Onsite measurements (standard deviations in parenthesis)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Inlet (T0)	101 (±0.10)	8.3 (±0.00)	0.36 (±0.00)	16 (±0.01)	43 (±1.6)
Treated discharge (T6)	4.5 (±0.42)	7.5 (±0.00)	0.36 (±0.00)	23 (±0.13)	13 (±2.2)
Control discharge (T6)	80 (±0.87)	8.0 (±0.01)	0.37 (±0.00)	18 (±0.32)	7.2 (±0.76)

PSU Practical salinity units
NTU Nephelometric turbidity units

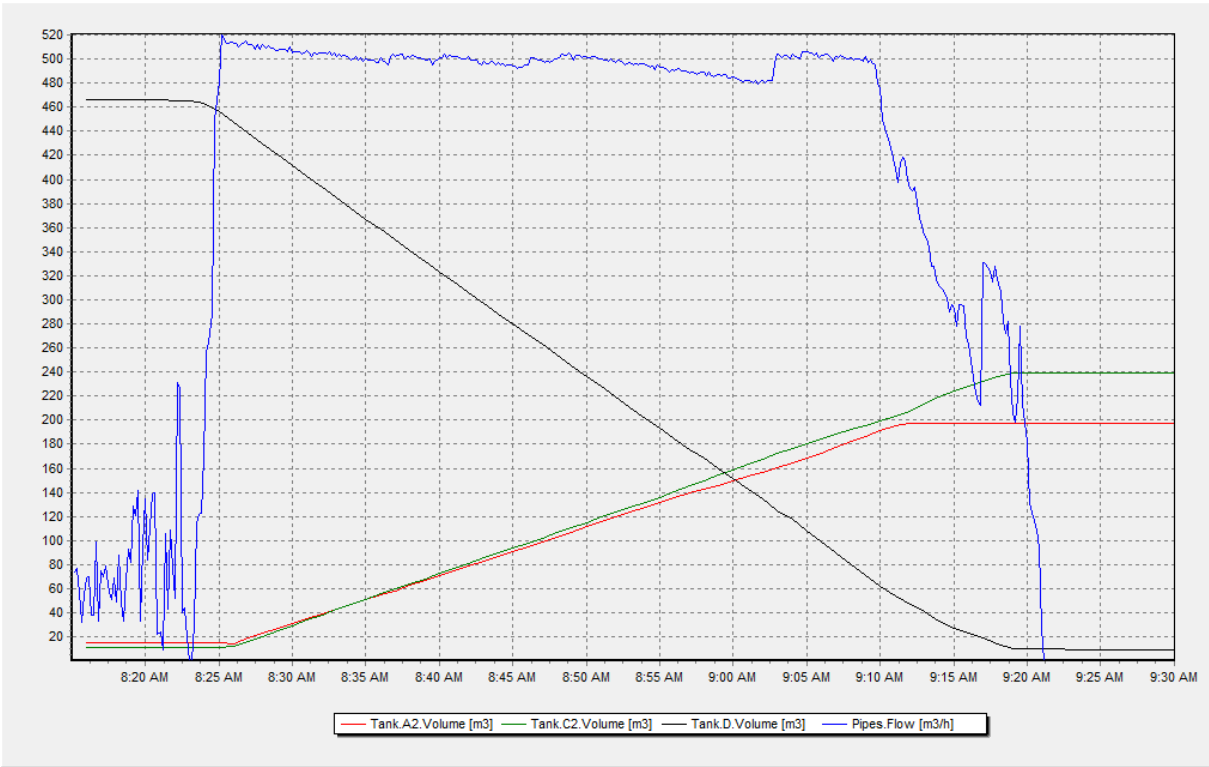


Figure A2.31 Test cycle F-3 data plot. Ballast operation.

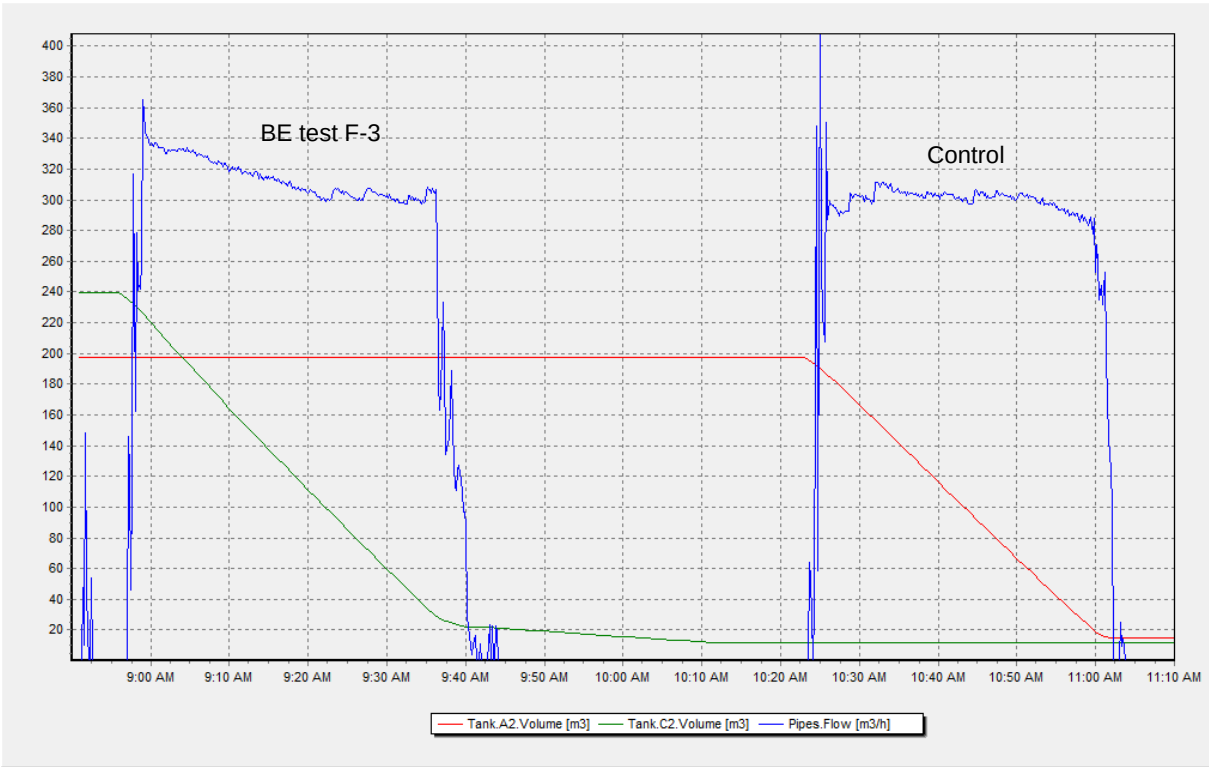


Figure A2.32 Test cycle F-3 data plot. De-ballast operation.

Table A2.33 Biological efficacy test cycle data logging

Subject	Results
Client treatment system	BAWAT
Client specified parameters (e.g. number of treatment reactors/units, filter model, filter mesh size, etc.)*	Heat exchanger (72°C) Deoxygenation Recirculation: 5 times In-line cooling of treated water
Salinity (PSU)	0.33
Retention tank No.	C2
Test cycle No.	F-4
Use of cultured/harvested organisms	-
System cleaned before ballast	Yes
Date and time ballast start	2013.11.12 09:17
Date and time ballast stop	2013.11.12 10:15
Flow rate during ballast (average)	447 m^3/h
Power consumption during treatment*	20.135 kW/m^3
Treated volume	232 m^3
System cleaned before de-ballast	Yes
Date and time de-ballast start	2013.11.18 09:19
Date and time de-ballast stop	2013.11.18 10:02
Flow rate during discharge (average)	289 m^3/h

* Information on manufacturer-specified parameters and power consumption data provided by the client

Table A2.34 Onsite measurements (standard deviations in parenthesis)

Water type	Dissolved oxygen (%)	pH	Salinity (PSU)	Temperature (°C)	Turbidity (NTU)
Inlet (T0)	97 (±0.31)	8.1 (±0.01)	0.33 (±0.01)	0.66 (±0.01)	8.0 (±0.01)
Treated discharge (T6)	4.5 (±0.90)	7.5 (±0.00)	0.64 (±0.00)	12 (±0.07)	13 (±1.9)
Control discharge (T6)	88 (±0.48)	8.0 (±0.01)	0.34 (±0.00)	8.1 (±0.06)	14 (±0.71)

PSU Practical salinity units
NTU Nephelometric turbidity units

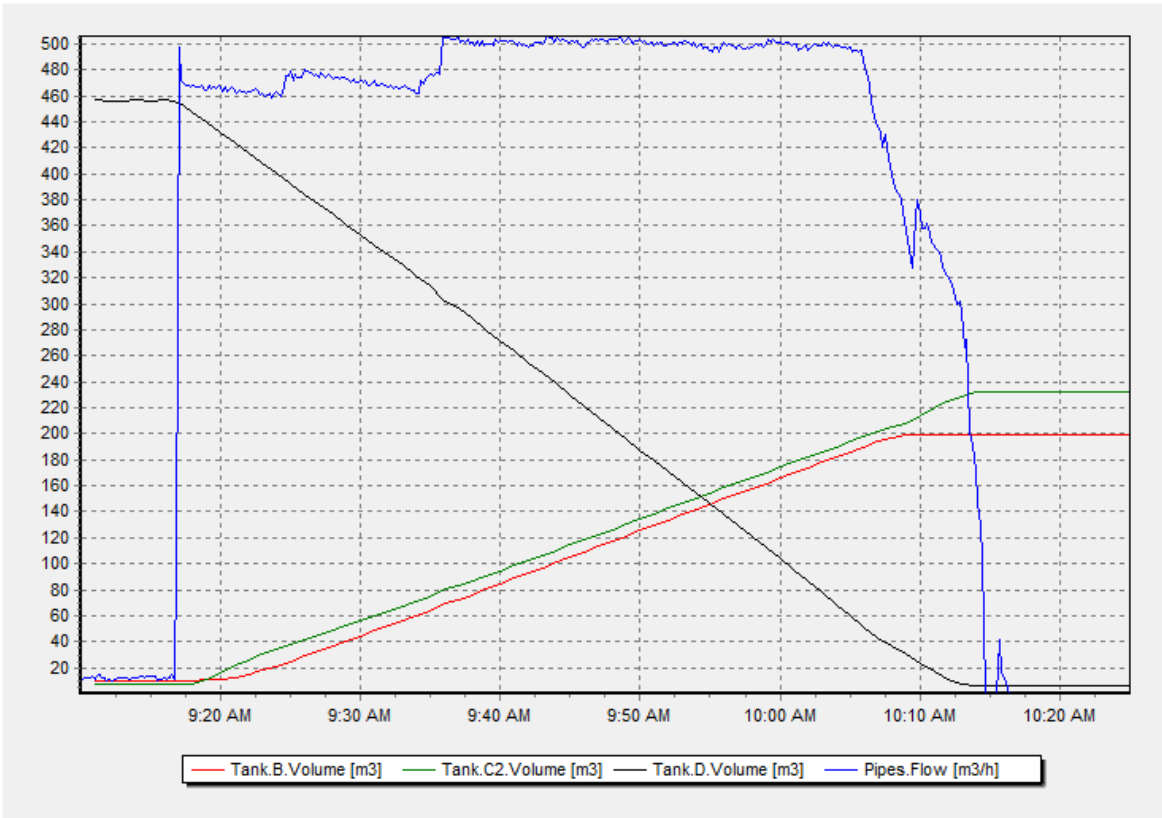


Figure A2.33 Test cycle F-4 data plot. Ballast operation.

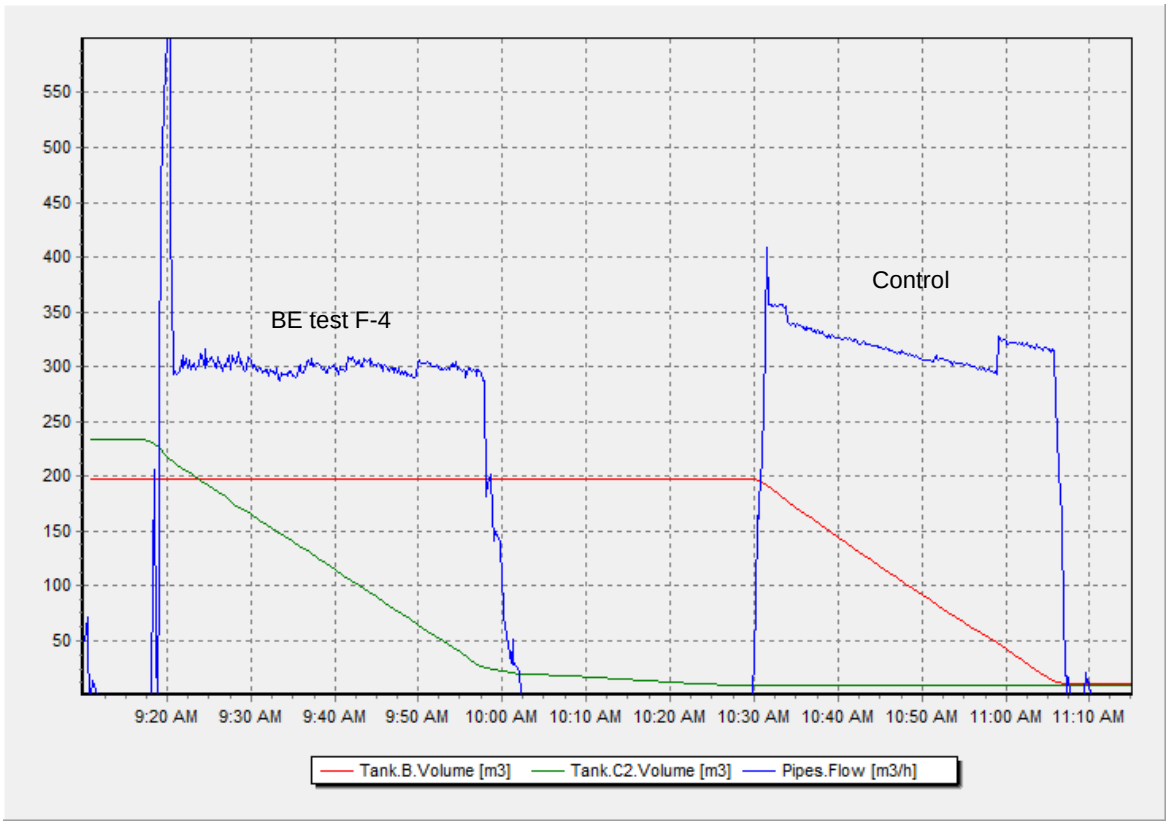


Figure A2.34 Test cycle F-4 data plot. De-ballast operation.

APPENDIX 3

Data logging from the operation of the BAWAT BWMS

SUMMARY OF LAND BASED TESTS

24 MARCH 2013 – 27 MARCH 2014

Test set-up

Energy Consumption

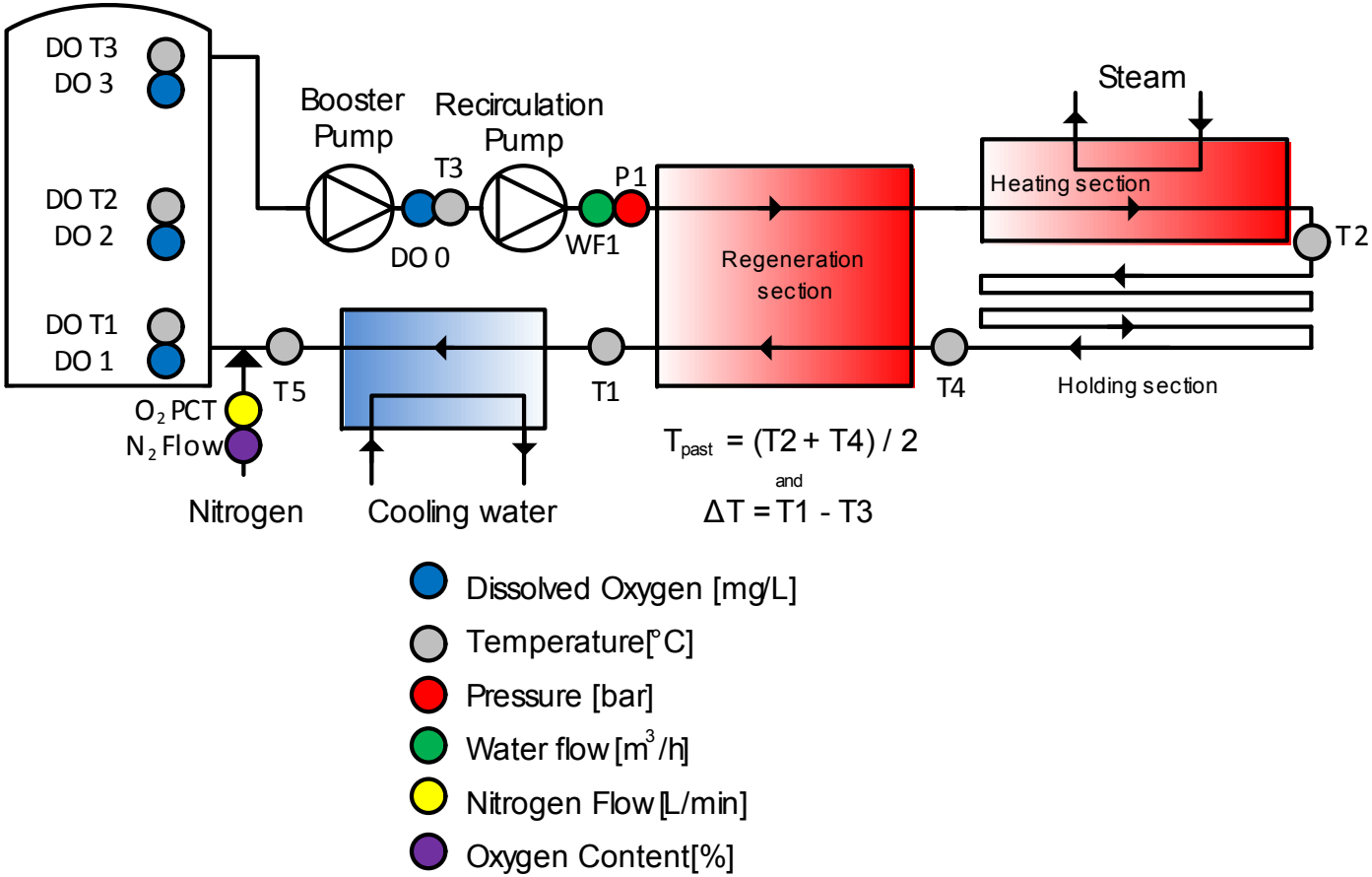
Summary datatables

Deoxygenation and pasteurizing graphs

Discussion of Failed Tests

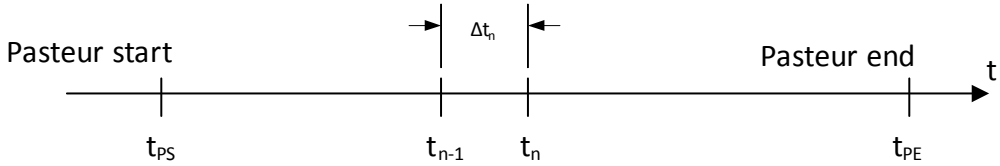
04 September 2014/OLC

Test set-up Land Based Tests



Estimate of energy consumption.

The pasteurization process starts at $t = t_{PS}$ and ends at $t = t_{PE}$.



The process parameters are sampled and logged every 30 seconds. In the time interval ΔT_n during the pasteurization the following are recorded or can be calculated:

V_n = Water volume passing the pasteurizer in ΔT_n.

ΔT_n = Average ΔT over the pasteurizer ($T_1 - T_3$) in ΔT_n.

Further, the following factors are known:

The heat capacity or water: $c = 4.185\ kJ * kg^{-1} * °C^{-1}$.

The density of water[1]: $d = 1020\ kg * ton^{-1}$.

The energy applied, E{n}, in Δt_n can be calculated as

$$E\{n\} = c * d * V_n * \Delta T_n$$

and the total energy, E [kJ], applied during the pasteurization as

$$E = \sum_{n=(PS+1)}^{n=PE} E\{n\}$$

V_{tank} being the actual water volume to be treated the energy consumption per m^3, V_{m3}, [kJ/m^3], treated is

$$V_{m3} = E / V_{tank}$$

11 June 2014/OLC

[1] Heat capacity and density dependencies on water salinity and temperature are ignored in the estimate.

Summary of Land Based Tests
20 March 2013 - 27 March 2014

Bawat

Test	Date	Water	Recir-cula-tions	Comments	Energy consumption/m^3 [kJ/m^3] (1)	Pasteur time [h]	Average water flow during pasteurization [m^3/h]	Holding time [s] (2)	Pasteurizing temperature [°C]	Water temperature in tank [°C] (3)			Average N_2 flow during pasteurization [L/min]		Average O_2 level in N_2 during pasteurization [%]	Dissolved oxygen in flow end-of-treatment [mg/L] (4)	
										Before treatment	After treatment and cooling	ΔT	[L/min]	[% of water flow]		Average	STD
B-1	10-04-2013	Brackish	4	30 min. power loss / ATC / Leaking by-pass valve	114.270	9,4	124,3	72,4	72,3	3,4	16,5	13,1	148,1	7,1%	2,1	0,60	0,24
B-2	16-04-2013	Brackish	4	ATC	118.300	7,8	126,0	71,4	72,6	6,1	16,9	10,8	150,3	7,2%	2,0	0,50	0,23
B-3	23-04-2013	Brackish	4	ATC, WET test samples / Leaking by-pass valve	118.076	7,8	125,7	71,6	72,6	7,7	16,5	8,8	148,0	7,1%	2,0	0,70	0,13
B-4	30-04-2013	Brackish	5	ATC	131.674	9,6	127,0	70,9	72,6	8,7	17,6	8,9	150,1	7,1%	2,0	0,60	0,11
B-5	06-08-2013	Brackish	5	In-line cooling, WET test samples	109.797	10,2	118,8	75,8	71,7	21,5	34,2	12,7	151,7	7,7%	2,0	1,00	0,32
B-6	18-03-2014	Brackish	5	In-line cooling	193.035	10,0	119,8	75,1	73,5	6,8	19,3	12,5	160,1	8,0%	2,0	1,20	0,32
B-7	27-03-2014	Brackish	5	In-line cooling	204.429	10,4	119,0	75,6	73,2	5,9	20,1	14,2	158,2	8,0%	2,1	1,00	0,40
M-1	20-03-2013	High salinity	4	After-treatment cooling (ATC)	111.943	8,5	123,1	73,1	72,3	3,3	15,5	12,2	153,6	7,5%	-	0,50	0,25
M-2	08-05-2013	High salinity	5	ATC	126.904	9,7	125,9	71,5	72,3	12,7	18,4	5,7	154,4	7,4%	2,0	0,50	0,12
M-3	28-05-2013	High salinity	5	In-line cooling / Leaking by-pass valve	163.397	10,2	117,7	76,5	72,3	15,1	26,5	11,4	150,2	7,7%	2,0	1,00	0,23
M-4	04-06-2013	High salinity	5	In-line cooling	176.997	10,1	117,9	76,3	72,3	16,0	27,1	11,1	149,3	7,6%	2,0	0,80	0,17
M-5	18-06-2013	High salinity	5	In-line cooling	189.542	10,3	117,5	76,6	72,2	20,6	28,5	7,9	151,7	7,7%	2,1	0,70	0,21
M-6	25-06-2013	High salinity	5	In-line cooling	179.910	10,5	117,1	76,9	71,8	17,5	28,6	11,1	151,8	7,8%	2,1	0,60	0,23
F-1	13-08-2013	Fresh	5	In-line cooling	121.723	9,9	119,1	75,6	71,9	17,2	30,5	13,3	152,5	7,7%	2,0	1,10	0,17
F-2	20-08-2013	Fresh	5	In-line cooling	130.628	10,1	119,1	75,6	71,9	17,8	32,1	14,3	150,5	7,6%	2,0	1,10	0,20
F-3	03-09-2013	Fresh	5	In-line cooling / Tarpaulin failure	133.003	10,1	119,1	75,6	72,1	16,5	30,2	13,7	151,0	7,6%	2,0	1,30	0,17
F-4	12-11-2013	Fresh	5	In-line cooling / Tarpaulin failure	218.664	10,9	110,1	81,7	73,1	8,0	20,3	12,3	149,9	8,2%	2,1	1,40	0,12
Averages LBT				4 recirculations	115.647	8,4	118,3	76,3	72,4			11,2	151,8	7,6%	2,0	0,86	0,21
				5 recirculations	159.977	10,1						11,5					
SBT#1	**Shipboard tests' data for comparison**			Alongside tests	131.448	17,2	106,4	84,6	72,3	37,4	54,5	17,1	150,0	8,5%	2,0	0,40	0,29
SBT#2					126.370	16,9	106,9	84,2	72,3	38,0	52,9	14,9	183,3	10,3%	2,0	0,70	0,26
SBT#3				In-voyage test	183.876	17,6	104,8	85,9	72,6	30,8	43,4	12,6	131,7	7,5%	2,0	0,90	0,37
Averages SBT					147.231	17,2	106,0	84,9	72,4			15,8	155,0	8,8%	2,0	0,67	0,31

Failures in tests B-1, B-3 and M-3 were caused by a leaking by-pass valve in the 'After Treatment Cooling' piping installed for test purposes only.

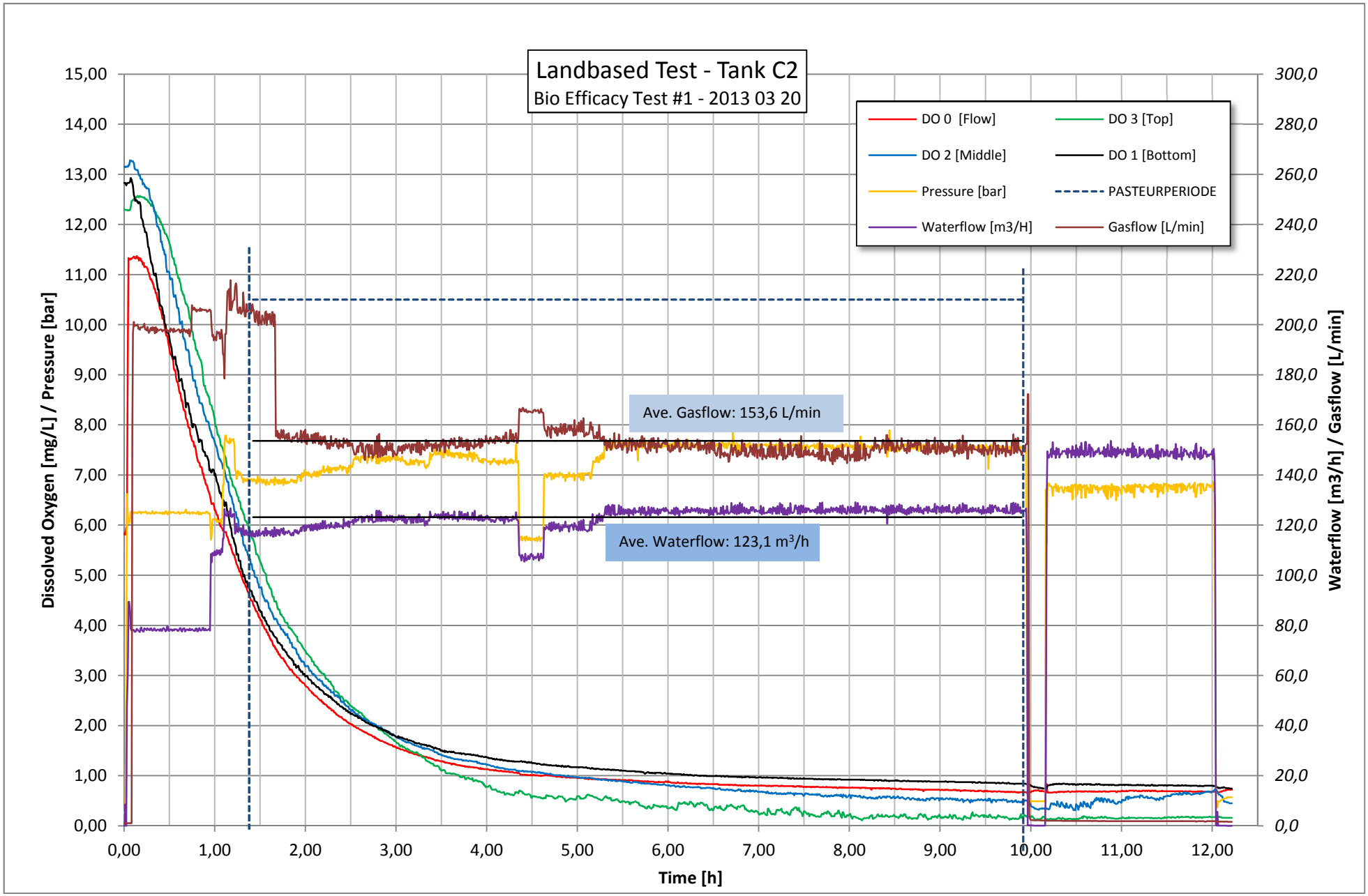
Failures in tests F-3 and F-4 were caused by defects in the scaffolding/tarpaulin structure in the test tank installed for test purposes only.

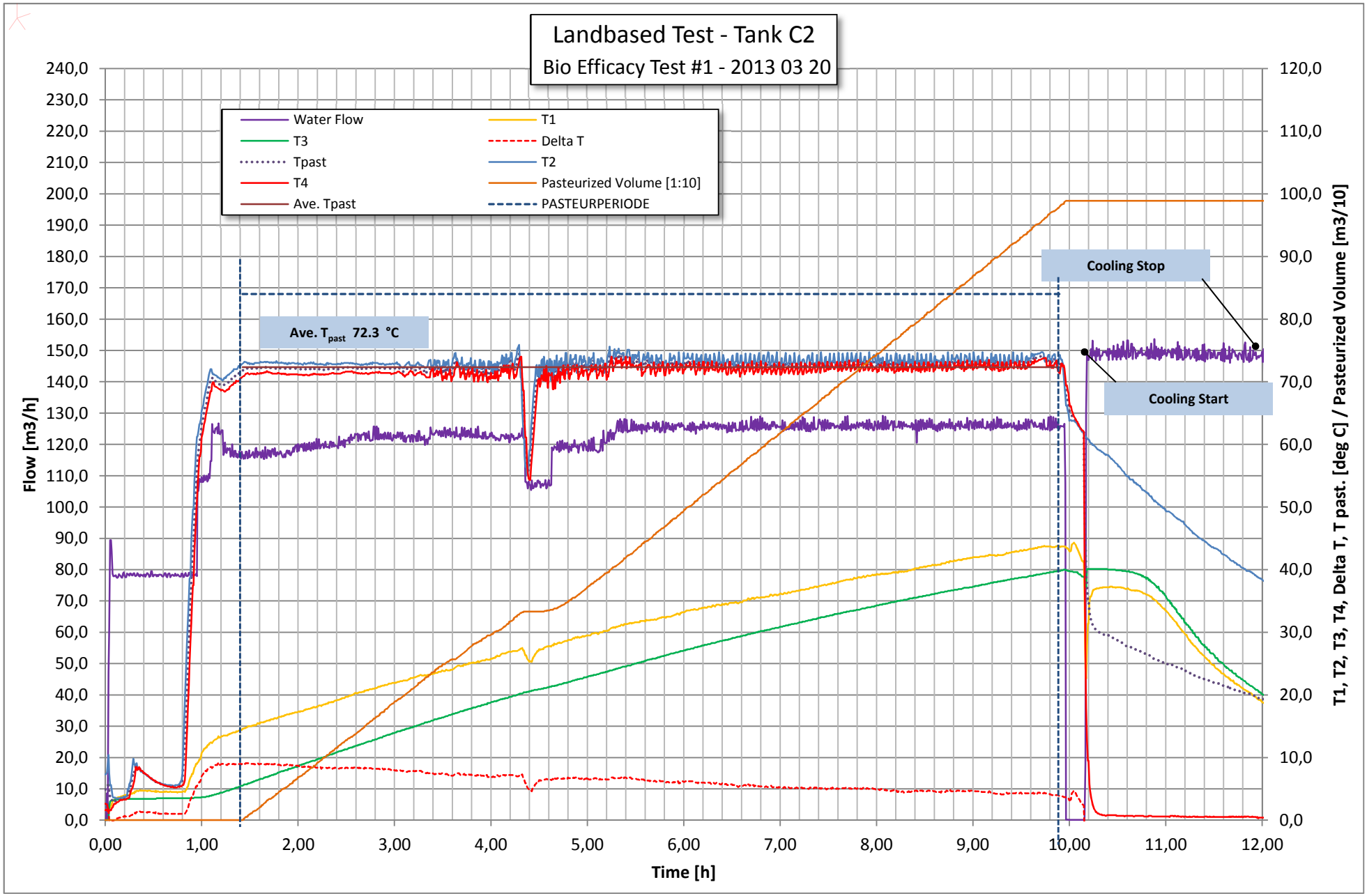
(1) Energy consumption calculated as outlined below

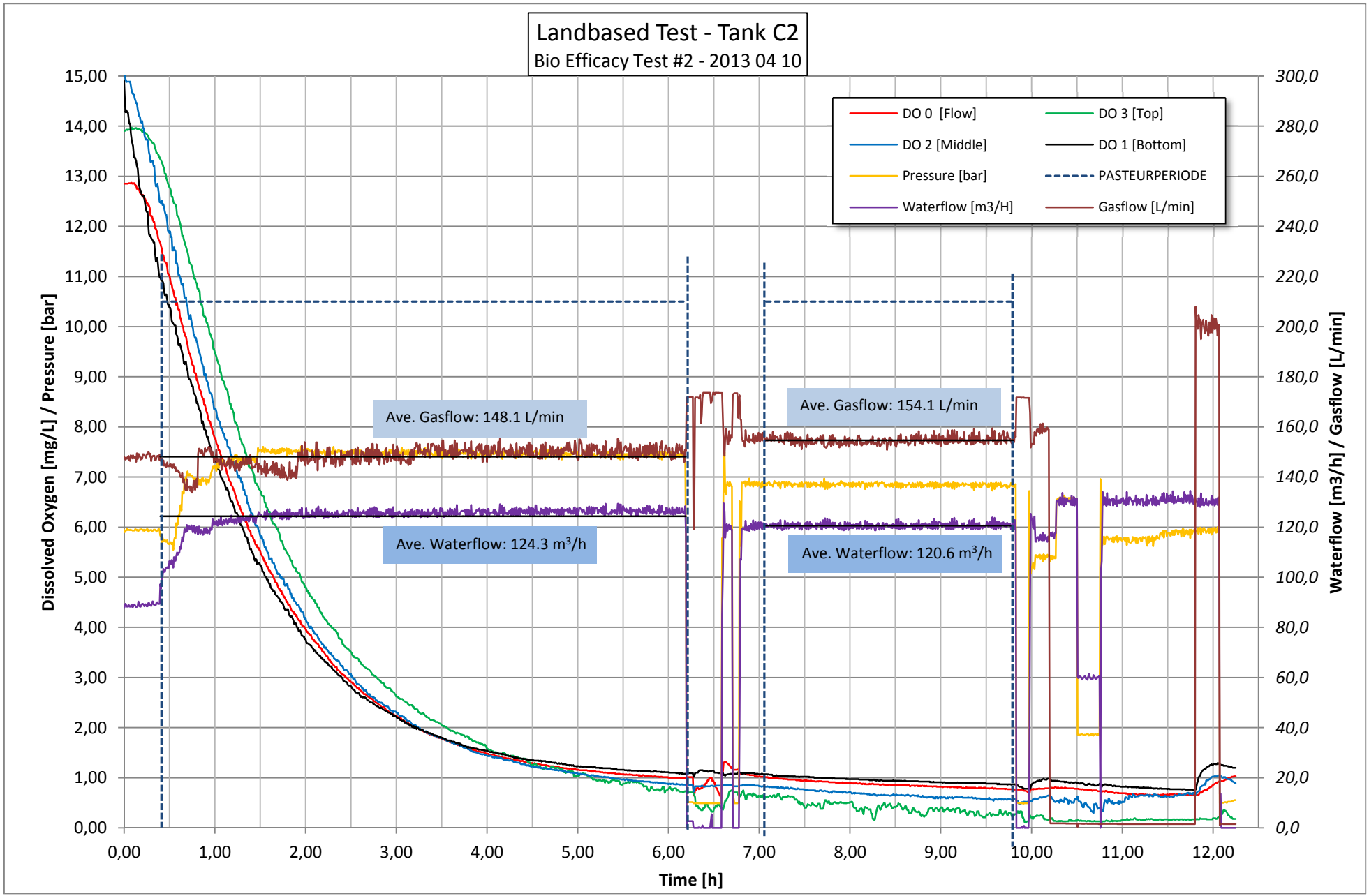
(2) Holding time [s] = Rentention tank volume (2.5 m^3)x3600 [s/h]/Water flow [m^3/h]

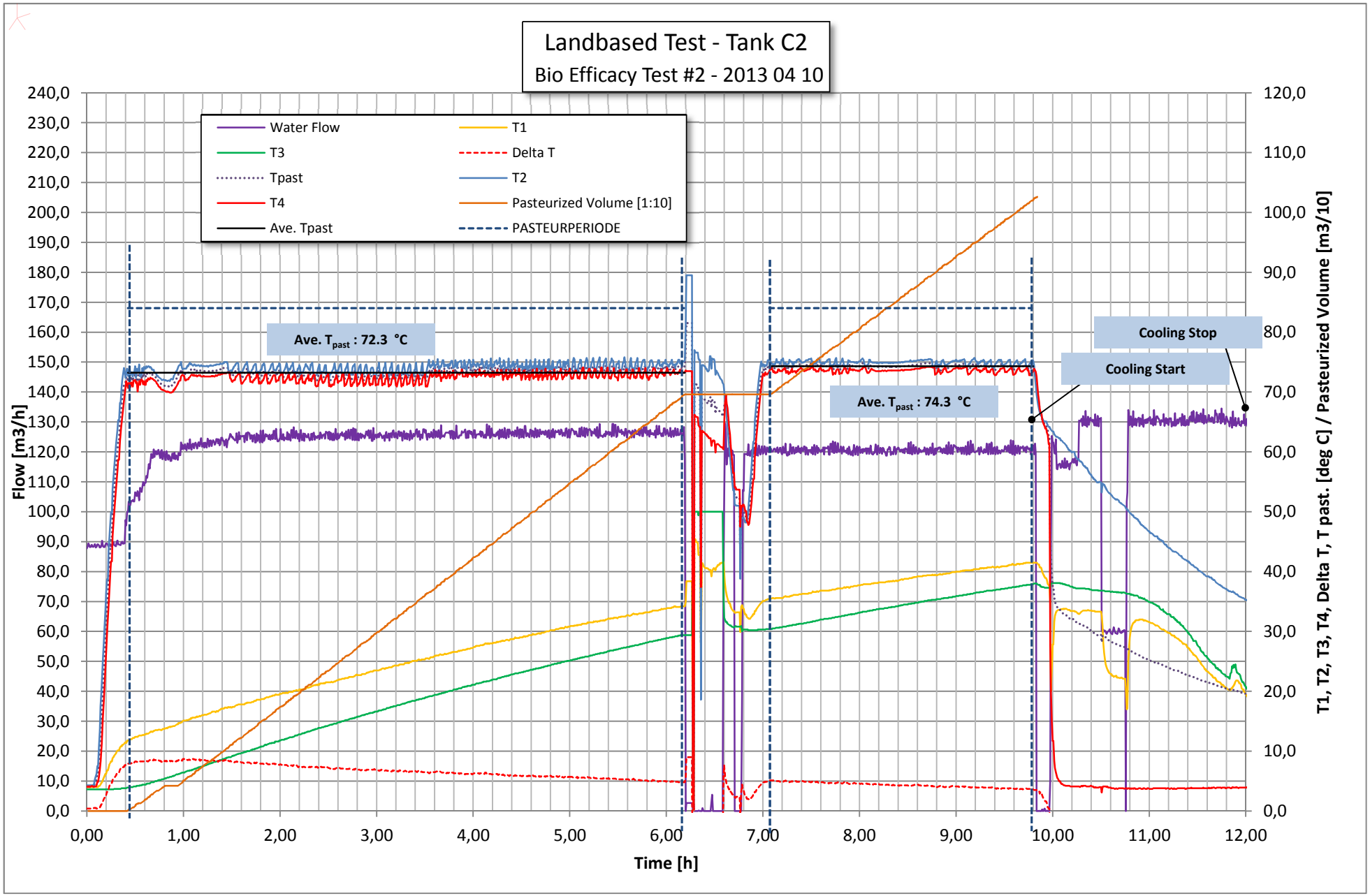
(3) Average of in-tank temperature sensors

(4) Average of all DO-sensors in tank and sensor i flow


Landbased Test - Tank C2
Bio Efficacy Test #1 - 2013 03 20
DO 0 [Flow]
DO 3 [Top]
DO 2 [Middle]
DO 1 [Bottom]
Pressure [bar]
PASTEURPERIODE
Waterflow [m3/H]
Gasflow [L/min]
Ave. Gasflow: 153,6 L/min
Ave. Waterflow: 123,1 m³/h
Dissolved Oxygen [mg/L] / Pressure [bar]
Waterflow [m3/h] / Gasflow [L/min]
Time [h]
15,00
14,00
13,00
12,00
11,00
10,00
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
300,0
280,0
260,0
240,0
220,0
200,0
180,0
160,0
140,0
120,0
100,0
80,0
60,0
40,0
20,0
0,0
0,00
1,00
2,00
3,00
4,00
5,00
6,00
7,00
8,00
9,00
10,00
11,00
12,00


Landbased Test - Tank C2
Bio Efficacy Test #1 - 2013 03 20
Water Flow
T1
T3
Delta T
Tpast
T2
T4
Pasteurized Volume [1:10]
Ave. Tpast
PASTEURPERIODE
Ave. Tpast 72.3 °C
Cooling Stop
Cooling Start
Flow [m3/h]
T1, T2, T3, T4, Delta T, T past. [deg C] / Pasteurized Volume [m3/10]
Time [h]
240,0
230,0
220,0
210,0
200,0
190,0
180,0
170,0
160,0
150,0
140,0
130,0
120,0
110,0
100,0
90,0
80,0
70,0
60,0
50,0
40,0
30,0
20,0
10,0
0,0
120,0
110,0
100,0
90,0
80,0
70,0
60,0
50,0
40,0
30,0
20,0
10,0
0,0
0,00
1,00
2,00
3,00
4,00
5,00
6,00
7,00
8,00
9,00
10,00
11,00
12,00


Landbased Test - Tank C2
Bio Efficacy Test #2 - 2013 04 10
DO 0 [Flow]
DO 3 [Top]
DO 2 [Middle]
DO 1 [Bottom]
Pressure [bar]
PASTEURPERIODE
Waterflow [m3/H]
Gasflow [L/min]
Ave. Gasflow: 148.1 L/min
Ave. Gasflow: 154.1 L/min
Ave. Waterflow: 124.3 m³/h
Ave. Waterflow: 120.6 m³/h
Dissolved Oxygen [mg/L] / Pressure [bar]
Waterflow [m3/h] / Gasflow [L/min]
Time [h]
15,00
14,00
13,00
12,00
11,00
10,00
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
300,0
280,0
260,0
240,0
220,0
200,0
180,0
160,0
140,0
120,0
100,0
80,0
60,0
40,0
20,0
0,0
0,00
1,00
2,00
3,00
4,00
5,00
6,00
7,00
8,00
9,00
10,00
11,00
12,00


Landbased Test - Tank C2
Bio Efficacy Test #2 - 2013 04 10
Water Flow
T1
T3
Delta T
Tpast
T2
T4
Pasteurized Volume [1:10]
Ave. Tpast
PASTEURPERIODE
Ave. Tpast : 72.3 °C
Ave. Tpast : 74.3 °C
Cooling Stop
Cooling Start
Flow [m3/h]
T1, T2, T3, T4, Delta T, T past. [deg C] / Pasteurized Volume [m3/10]
Time [h]
240,0
230,0
220,0
210,0
200,0
190,0
180,0
170,0
160,0
150,0
140,0
130,0
120,0
110,0
100,0
90,0
80,0
70,0
60,0
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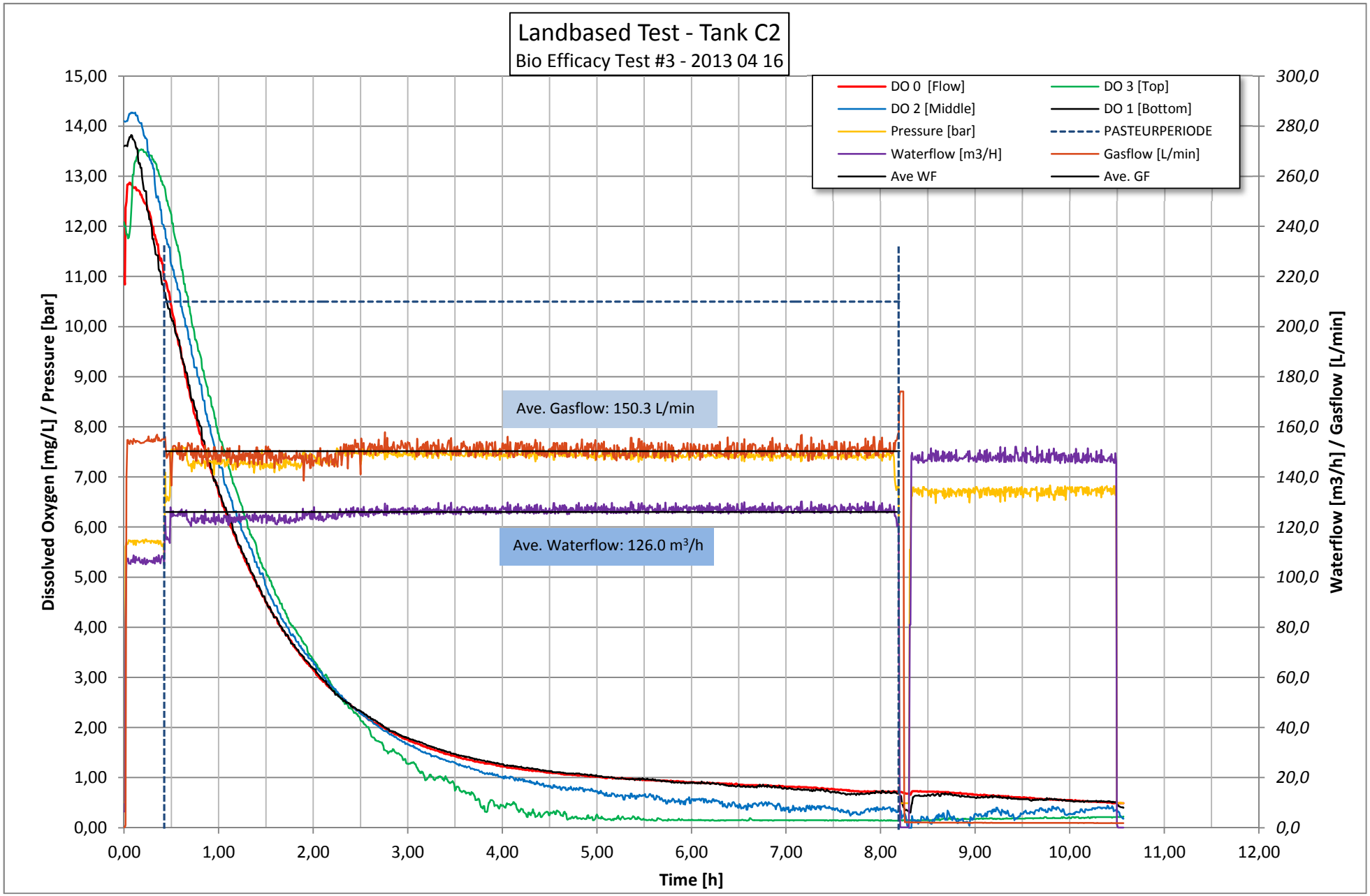
12,00


Landbased Test - Tank C2
Bio Efficacy Test #3 - 2013 04 16
DO 0 [Flow]
DO 3 [Top]
DO 2 [Middle]
DO 1 [Bottom]
Pressure [bar]
PASTEURPERIODE
Waterflow [m3/H]
Gasflow [L/min]
Ave WF
Ave. GF
Ave. Gasflow: 150.3 L/min
Ave. Waterflow: 126.0 m³/h
Dissolved Oxygen [mg/L] / Pressure [bar]
Waterflow [m3/h] / Gasflow [L/min]
Time [h]
15,00
14,00
13,00
12,00
11,00
10,00
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
300,0
280,0
260,0
240,0
220,0
200,0
180,0
160,0
140,0
120,0
100,0
80,0
60,0
40,0
20,0
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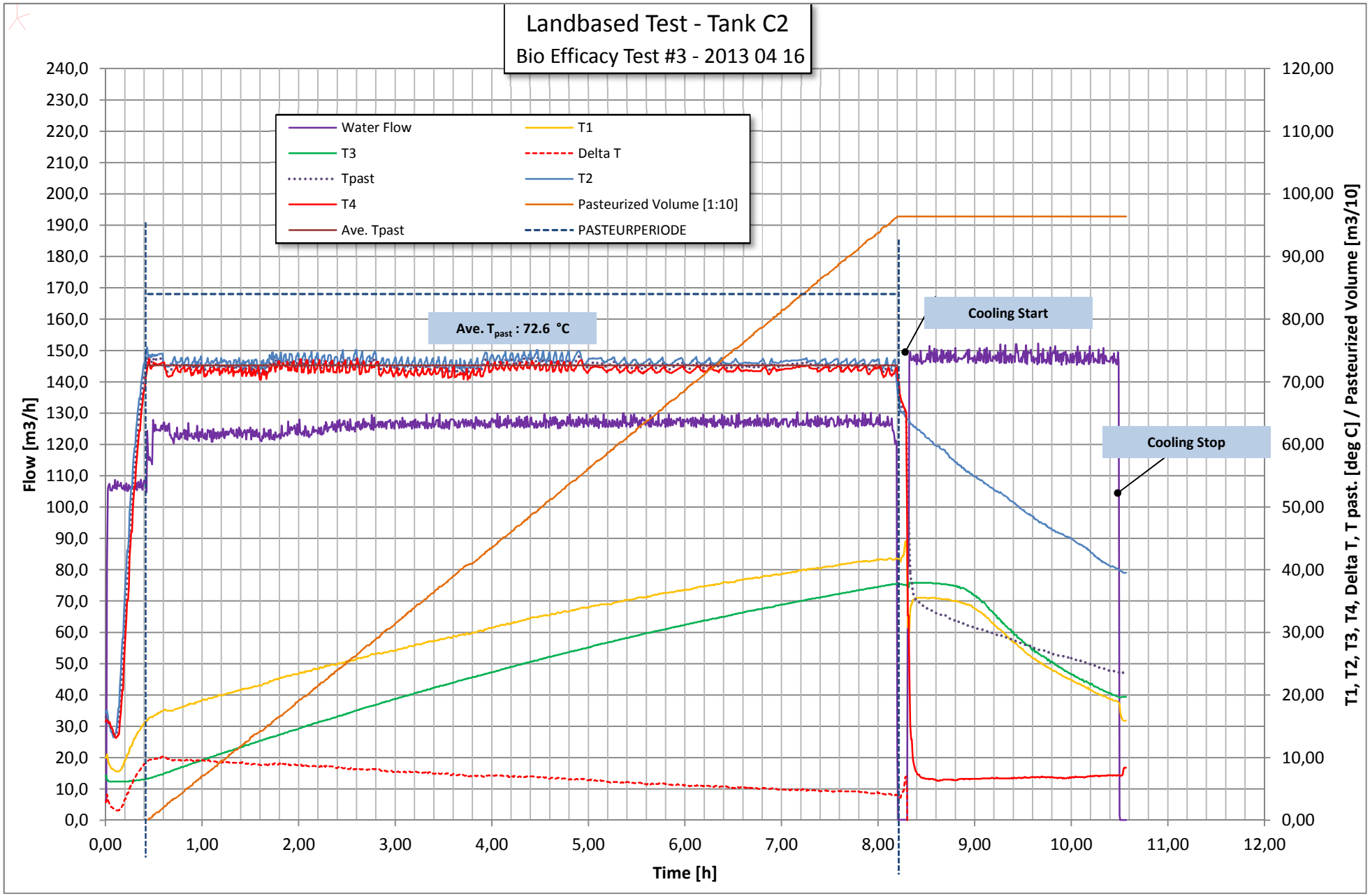
12,00


Landbased Test - Tank C2
Bio Efficacy Test #3 - 2013 04 16
Water Flow
T1
T3
Delta T
Tpast
T2
T4
Pasteurized Volume [1:10]
Ave. Tpast
PASTEURPERIODE
Ave. Tpast : 72.6 °C
Cooling Start
Cooling Stop
Flow [m3/h]
T1, T2, T3, T4, Delta T, T past. [deg C] / Pasteurized Volume [m3/10]
Time [h]
240,0
230,0
220,0
210,0
200,0
190,0
180,0
170,0
160,0
150,0
140,0
130,0
120,0
110,0
100,0
90,0
80,0
70,0
60,0
50,0
40,0
30,0
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10,0
0,0
120,00
110,00
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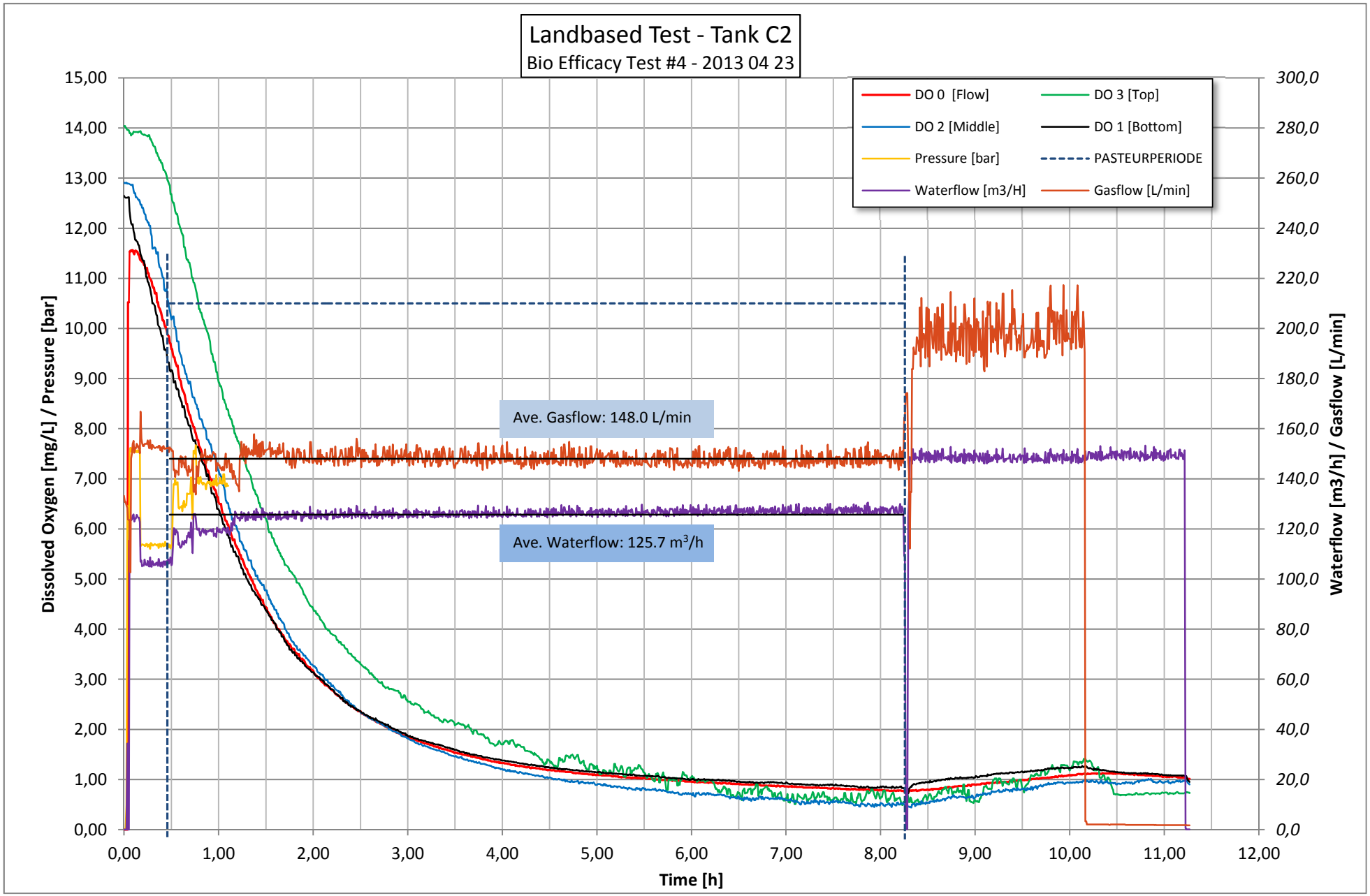
11,00
12,00


Landbased Test - Tank C2
Bio Efficacy Test #4 - 2013 04 23
DO 0 [Flow]
DO 3 [Top]
DO 2 [Middle]
DO 1 [Bottom]
Pressure [bar]
PASTEURPERIODE
Waterflow [m3/H]
Gasflow [L/min]
Ave. Gasflow: 148.0 L/min
Ave. Waterflow: 125.7 m³/h
Dissolved Oxygen [mg/L] / Pressure [bar]
Waterflow [m3/h] / Gasflow [L/min]
Time [h]
15,00
14,00
13,00
12,00
11,00
10,00
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
300,0
280,0
260,0
240,0
220,0
200,0
180,0
160,0
140,0
120,0
100,0
80,0
60,0
40,0
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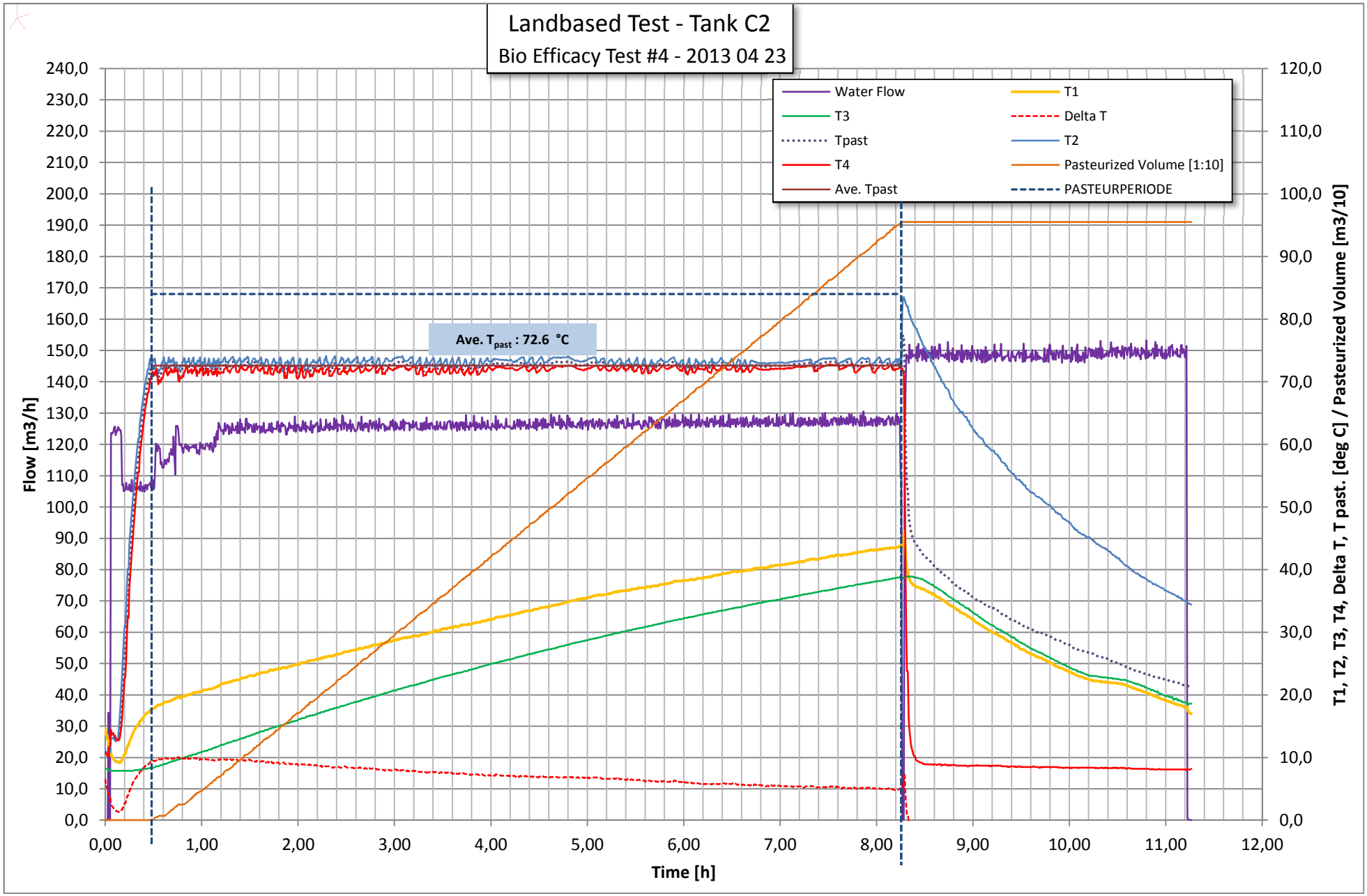
11,00
12,00


Landbased Test - Tank C2
Bio Efficacy Test #4 - 2013 04 23
Water Flow
T1
T3
Delta T
Tpast
T2
T4
Pasteurized Volume [1:10]
Ave. Tpast
PASTEURPERIODE
Ave. Tpast : 72.6 °C
Flow [m3/h]
T1, T2, T3, T4, Delta T, T past. [deg C] / Pasteurized Volume [m3/10]
Time [h]
240,0
230,0
220,0
210,0
200,0
190,0
180,0
170,0
160,0
150,0
140,0
130,0
120,0
110,0
100,0
90,0
80,0
70,0
60,0
50,0
40,0
30,0
20,0
10,0
0,0
120,0
110,0
100,0
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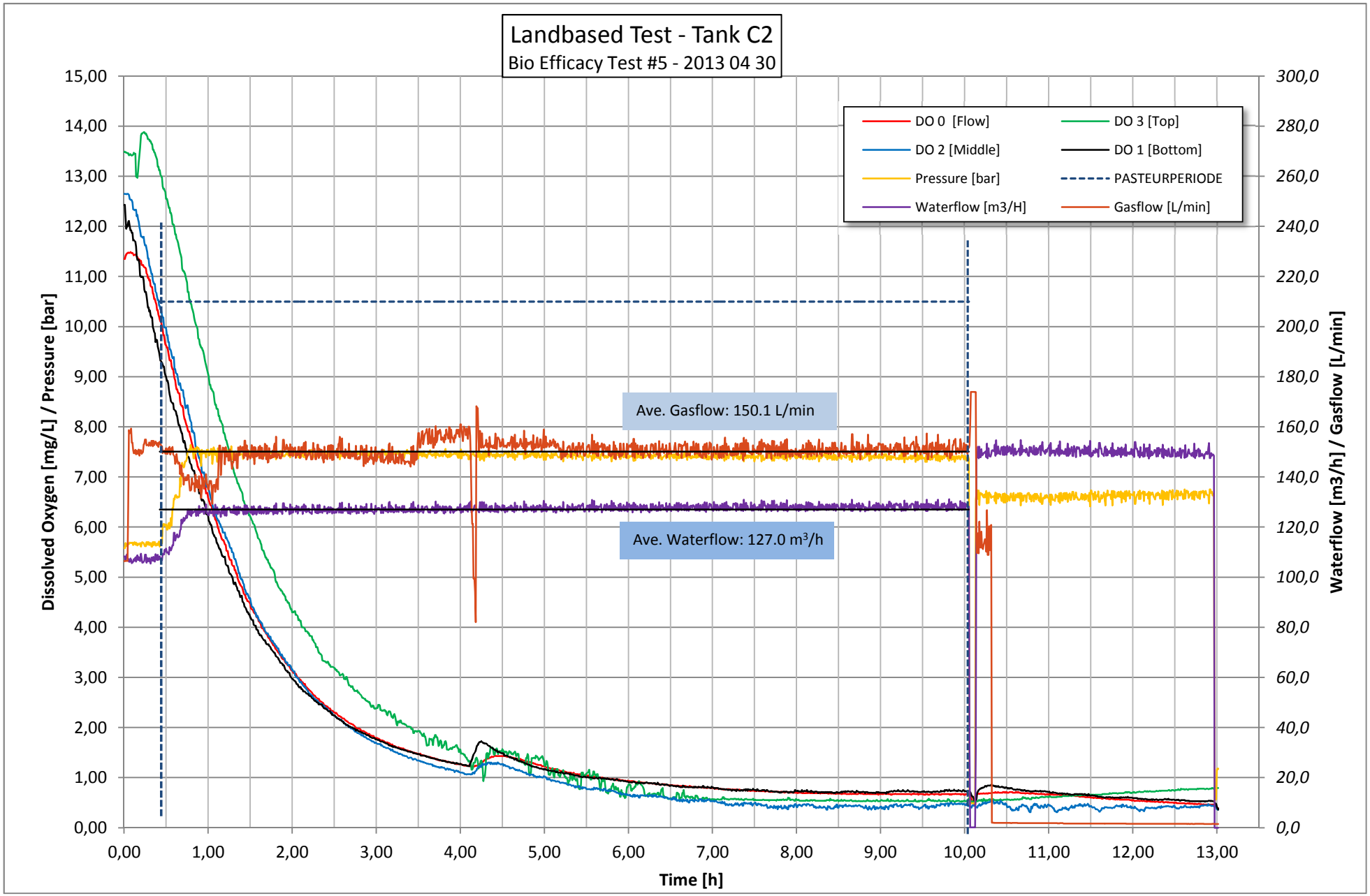
11,00
12,00


Landbased Test - Tank C2
Bio Efficacy Test #5 - 2013 04 30
DO 0 [Flow]
DO 3 [Top]
DO 2 [Middle]
DO 1 [Bottom]
Pressure [bar]
PASTEURPERIODE
Waterflow [m3/H]
Gasflow [L/min]
Ave. Gasflow: 150.1 L/min
Ave. Waterflow: 127.0 m³/h
Dissolved Oxygen [mg/L] / Pressure [bar]
Waterflow [m3/h] / Gasflow [L/min]
Time [h]
15,00
14,00
13,00
12,00
11,00
10,00
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
300,0
280,0
260,0
240,0
220,0
200,0
180,0
160,0
140,0
120,0
100,0
80,0
60,0
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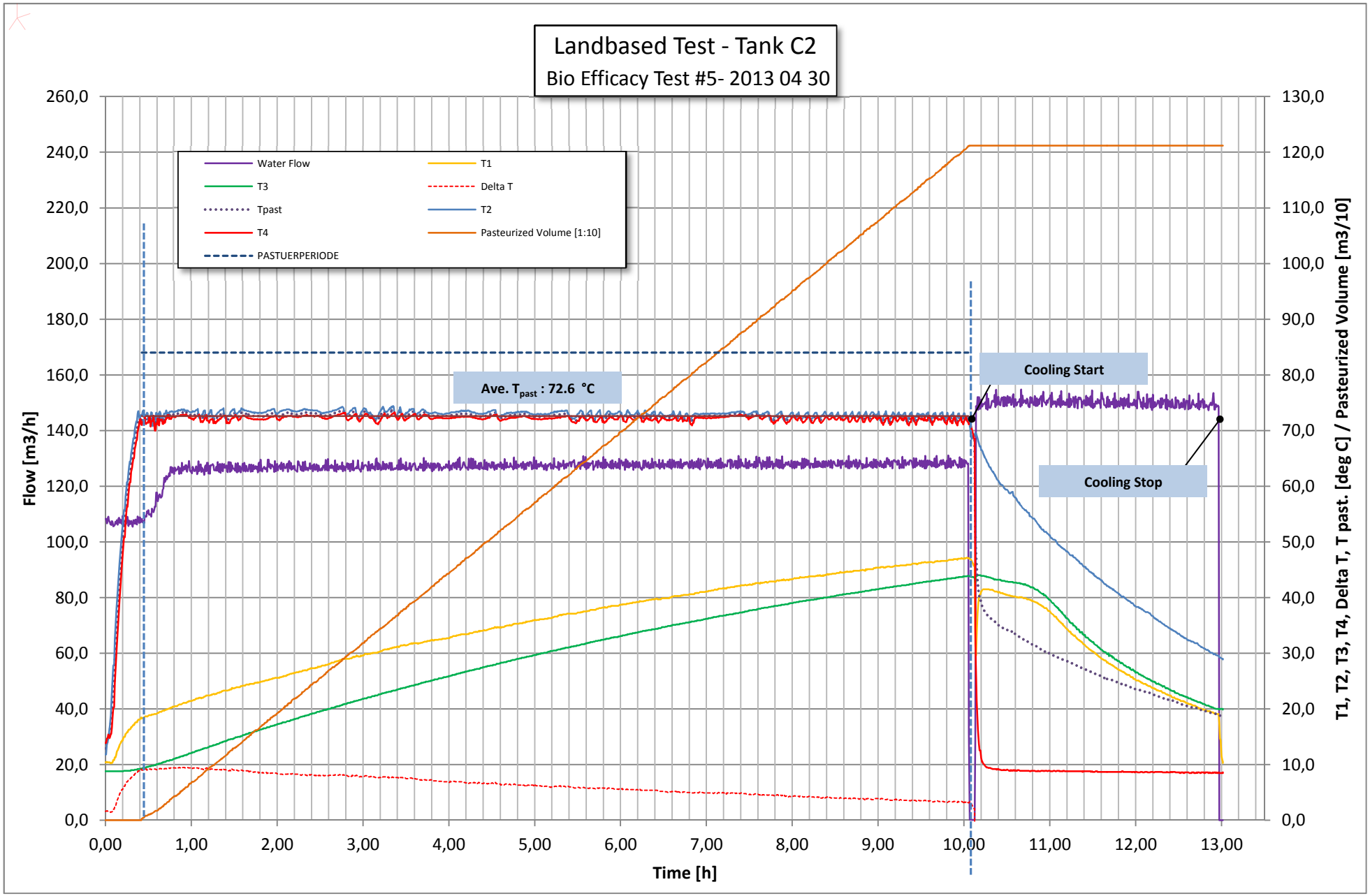
12,00
13,00


Landbased Test - Tank C2
Bio Efficacy Test #5- 2013 04 30
Water Flow
T1
T3
Delta T
Tpast
T2
T4
Pasteurized Volume [1:10]
PASTUERPERIODE
Ave. T_{past} : 72.6 °C
Cooling Start
Cooling Stop
Flow [m3/h]
T1, T2, T3, T4, Delta T, T past. [deg C] / Pasteurized Volume [m3/10]
Time [h]
260,0
240,0
220,0
200,0
180,0
160,0
140,0
120,0
100,0
80,0
60,0
40,0
20,0
0,0
130,0
120,0
110,0
100,0
90,0
80,0
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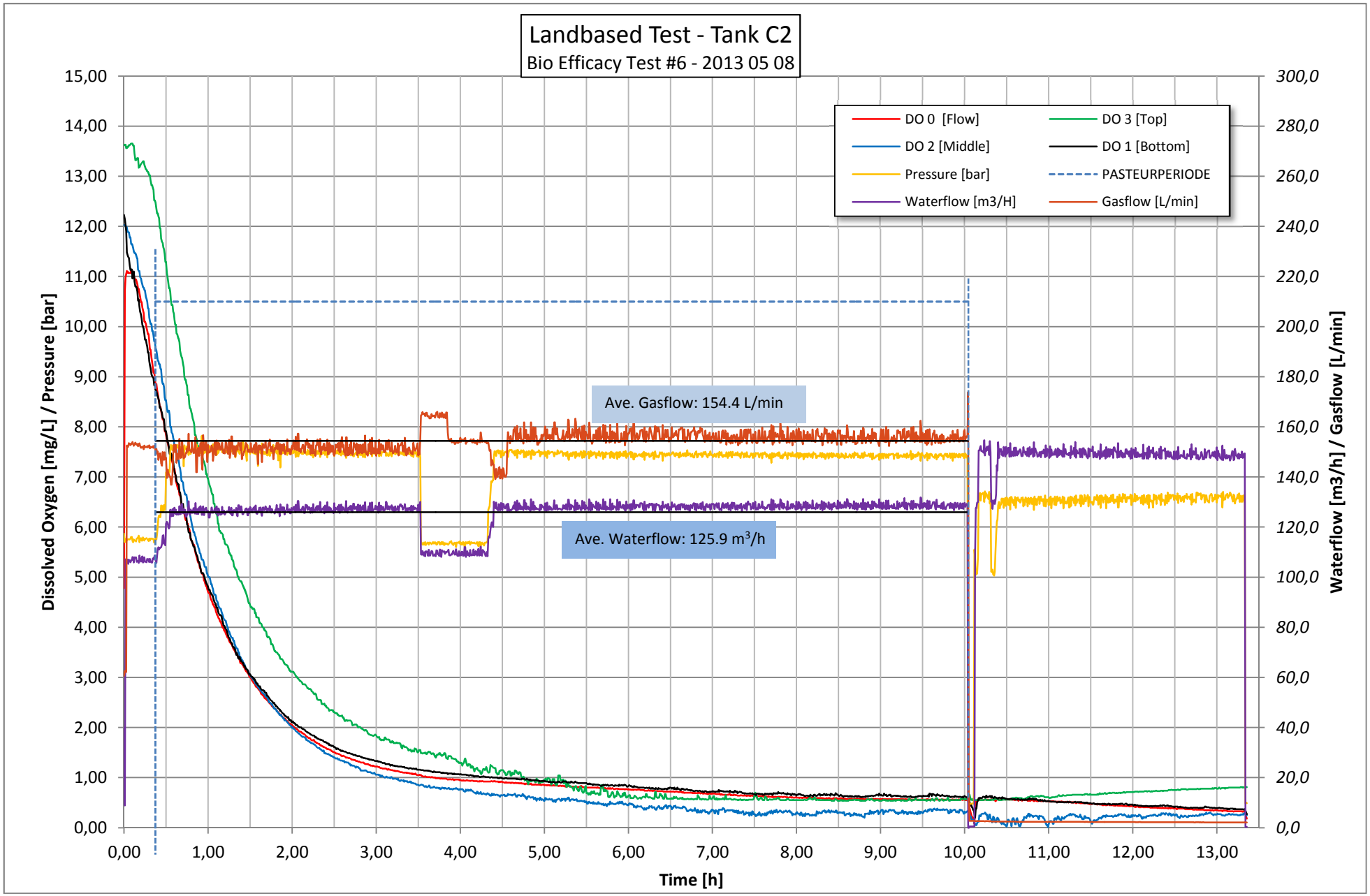
Landbased Test - Tank C2
Bio Efficacy Test #6 - 2013 05 08
DO 0 [Flow]
DO 3 [Top]
DO 2 [Middle]
DO 1 [Bottom]
Pressure [bar]
PASTEURPERIODE
Waterflow [m3/H]
Gasflow [L/min]
Ave. Gasflow: 154.4 L/min
Ave. Waterflow: 125.9 m³/h
Dissolved Oxygen [mg/L] / Pressure [bar]
Waterflow [m3/h] / Gasflow [L/min]
Time [h]
15,00
14,00
13,00
12,00
11,00
10,00
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
300,0
280,0
260,0
240,0
220,0
200,0
180,0
160,0
140,0
120,0
100,0
80,0
60,0
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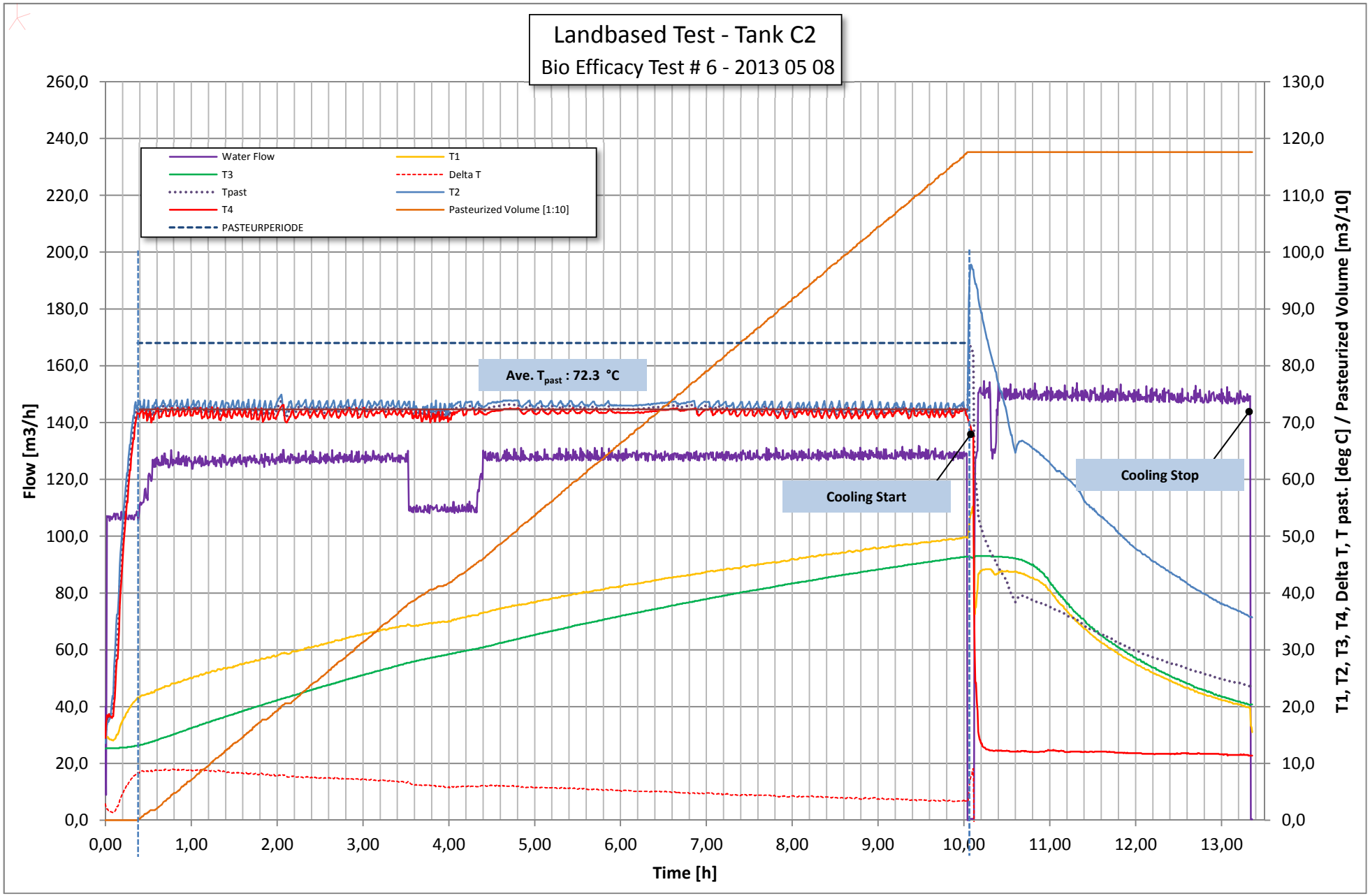
13,00


Landbased Test - Tank C2
Bio Efficacy Test # 6 - 2013 05 08
Water Flow
T1
T3
Delta T
Tpast
T2
T4
Pasteurized Volume [1:10]
PASTEURPERIODE
Ave. T_{past} : 72.3 °C
Cooling Start
Cooling Stop
Flow [m3/h]
T1, T2, T3, T4, Delta T, T past. [deg C] / Pasteurized Volume [m3/10]
Time [h]
260,0
240,0
220,0
200,0
180,0
160,0
140,0
120,0
100,0
80,0
60,0
40,0
20,0
0,0
130,0
120,0
110,0
100,0
90,0
80,0
70,0
60,0
50,0
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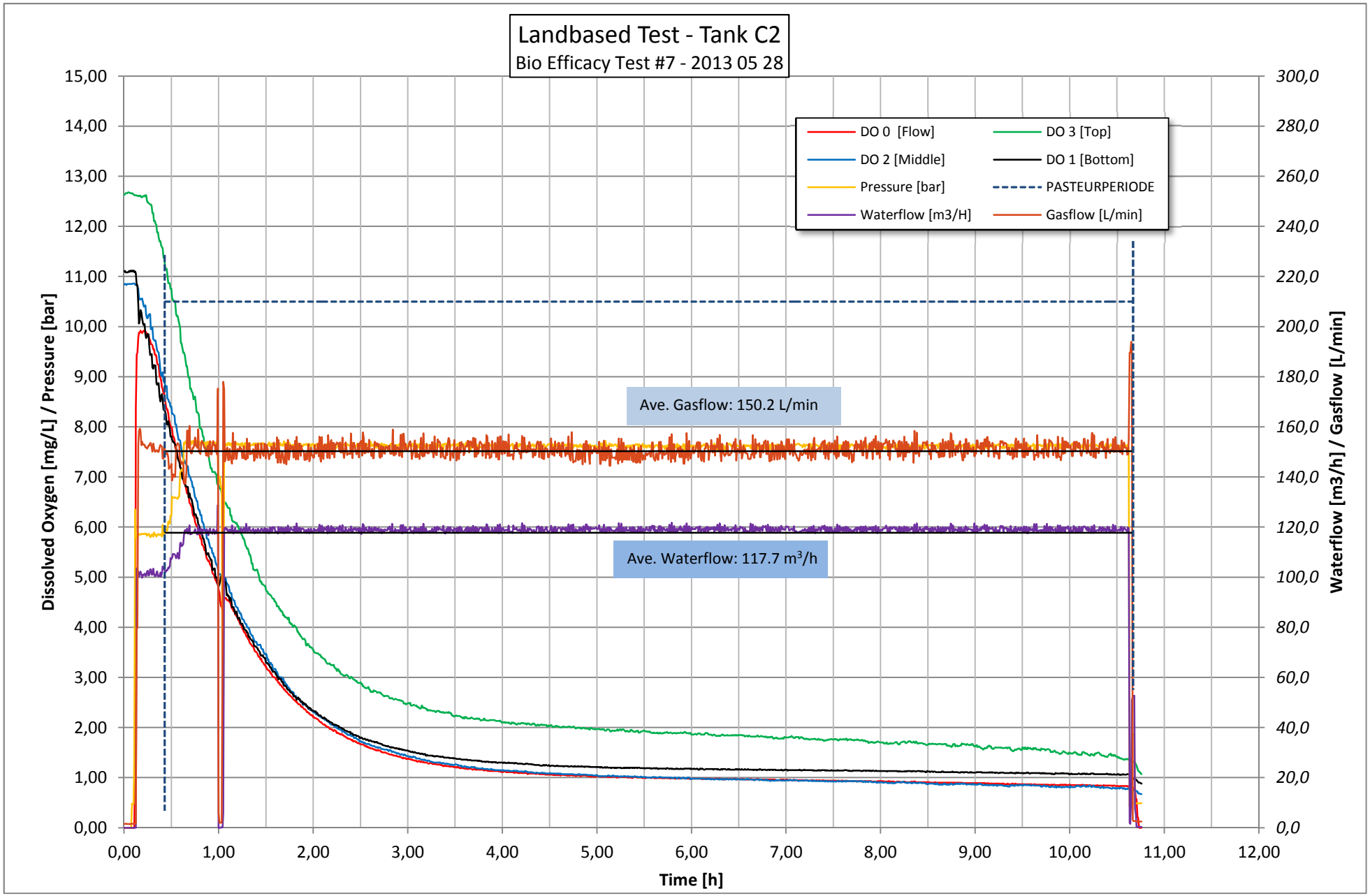
13,00


Landbased Test - Tank C2
Bio Efficacy Test #7 - 2013 05 28
DO 0 [Flow]
DO 3 [Top]
DO 2 [Middle]
DO 1 [Bottom]
Pressure [bar]
PASTEURPERIODE
Waterflow [m3/H]
Gasflow [L/min]
Ave. Gasflow: 150.2 L/min
Ave. Waterflow: 117.7 m³/h
Dissolved Oxygen [mg/L] / Pressure [bar]
Waterflow [m3/h] / Gasflow [L/min]
Time [h]
15,00
14,00
13,00
12,00
11,00
10,00
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
300,0
280,0
260,0
240,0
220,0
200,0
180,0
160,0
140,0
120,0
100,0
80,0
60,0
40,0
20,0
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8,00
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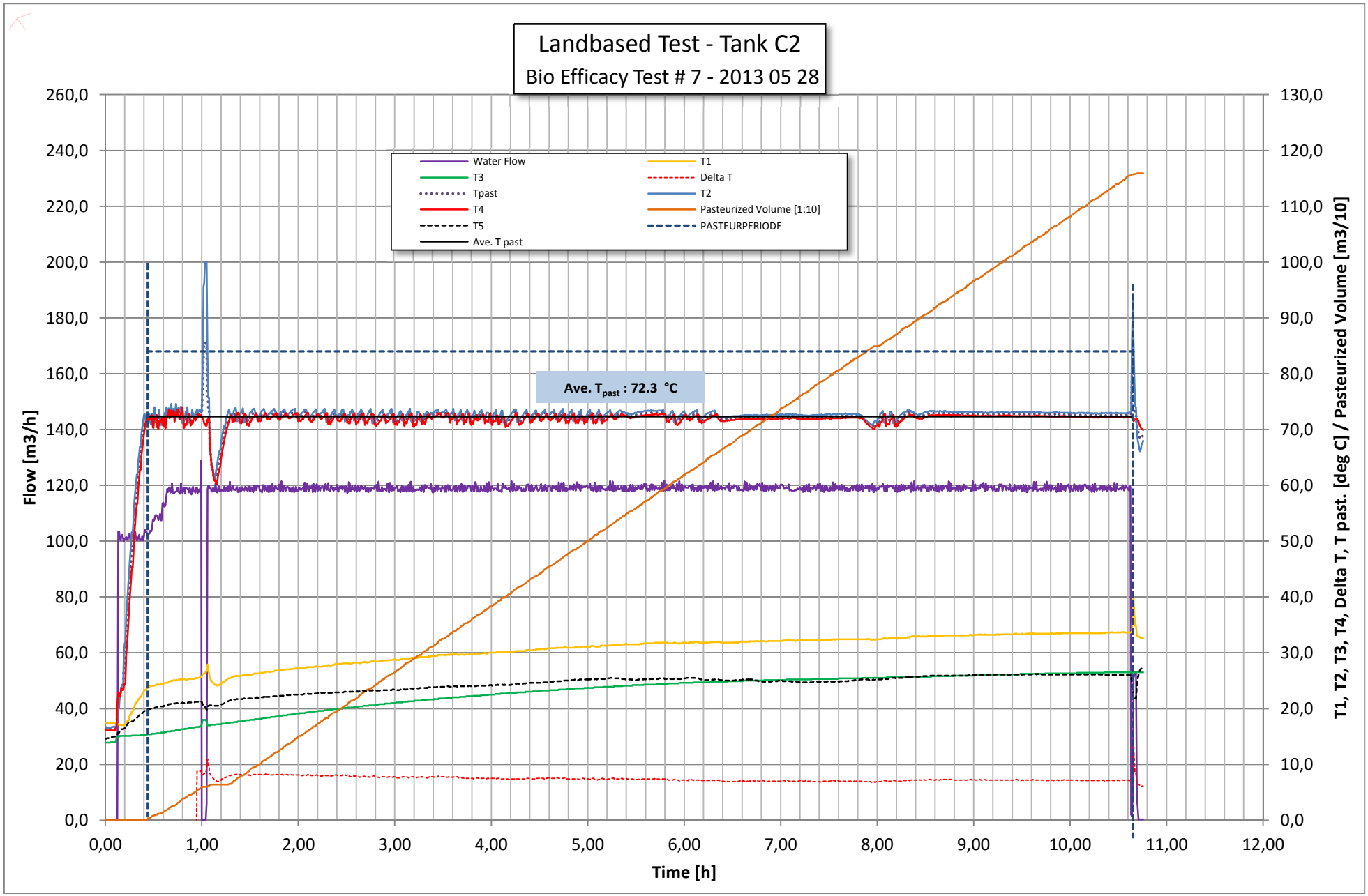
10,00
11,00
12,00


Landbased Test - Tank C2
Bio Efficacy Test # 7 - 2013 05 28
Water Flow
T1
T3
Delta T
Tpast
T2
T4
Pasteurized Volume [1:10]
T5
PASTEURPERIODE
Ave. T past
Ave. T_{past} : 72.3 °C
Flow [m3/h]
T1, T2, T3, T4, Delta T, T past. [deg C] / Pasteurized Volume [m3/10]
Time [h]
260,0
240,0
220,0
200,0
180,0
160,0
140,0
120,0
100,0
80,0
60,0
40,0
20,0
0,0
130,0
120,0
110,0
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90,0
80,0
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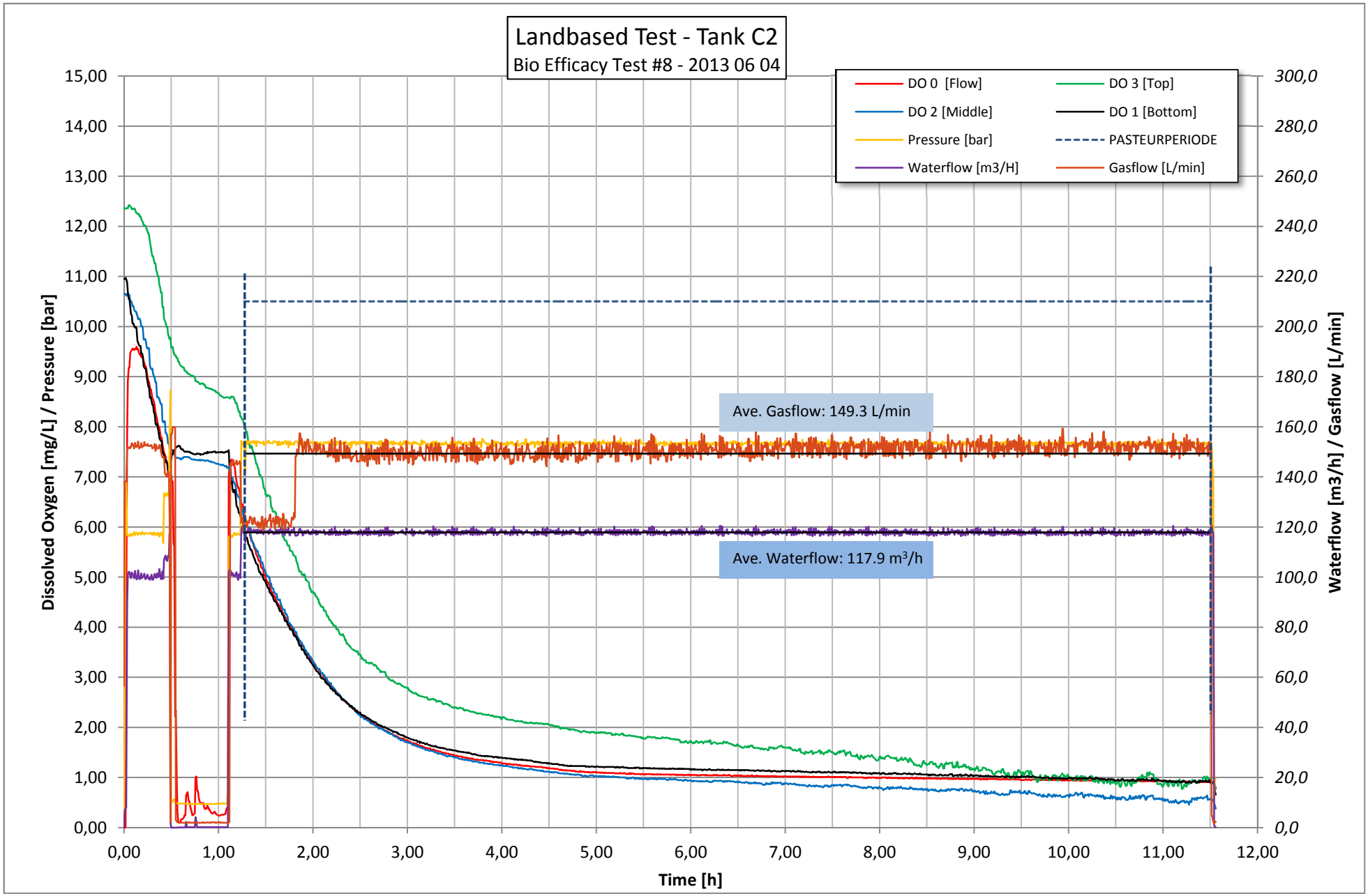
11,00
12,00


Landbased Test - Tank C2
Bio Efficacy Test #8 - 2013 06 04
DO 0 [Flow]
DO 3 [Top]
DO 2 [Middle]
DO 1 [Bottom]
Pressure [bar]
PASTEURPERIODE
Waterflow [m3/H]
Gasflow [L/min]
Ave. Gasflow: 149.3 L/min
Ave. Waterflow: 117.9 m³/h
Dissolved Oxygen [mg/L] / Pressure [bar]
Waterflow [m3/h] / Gasflow [L/min]
Time [h]
15,00
14,00
13,00
12,00
11,00
10,00
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
300,0
280,0
260,0
240,0
220,0
200,0
180,0
160,0
140,0
120,0
100,0
80,0
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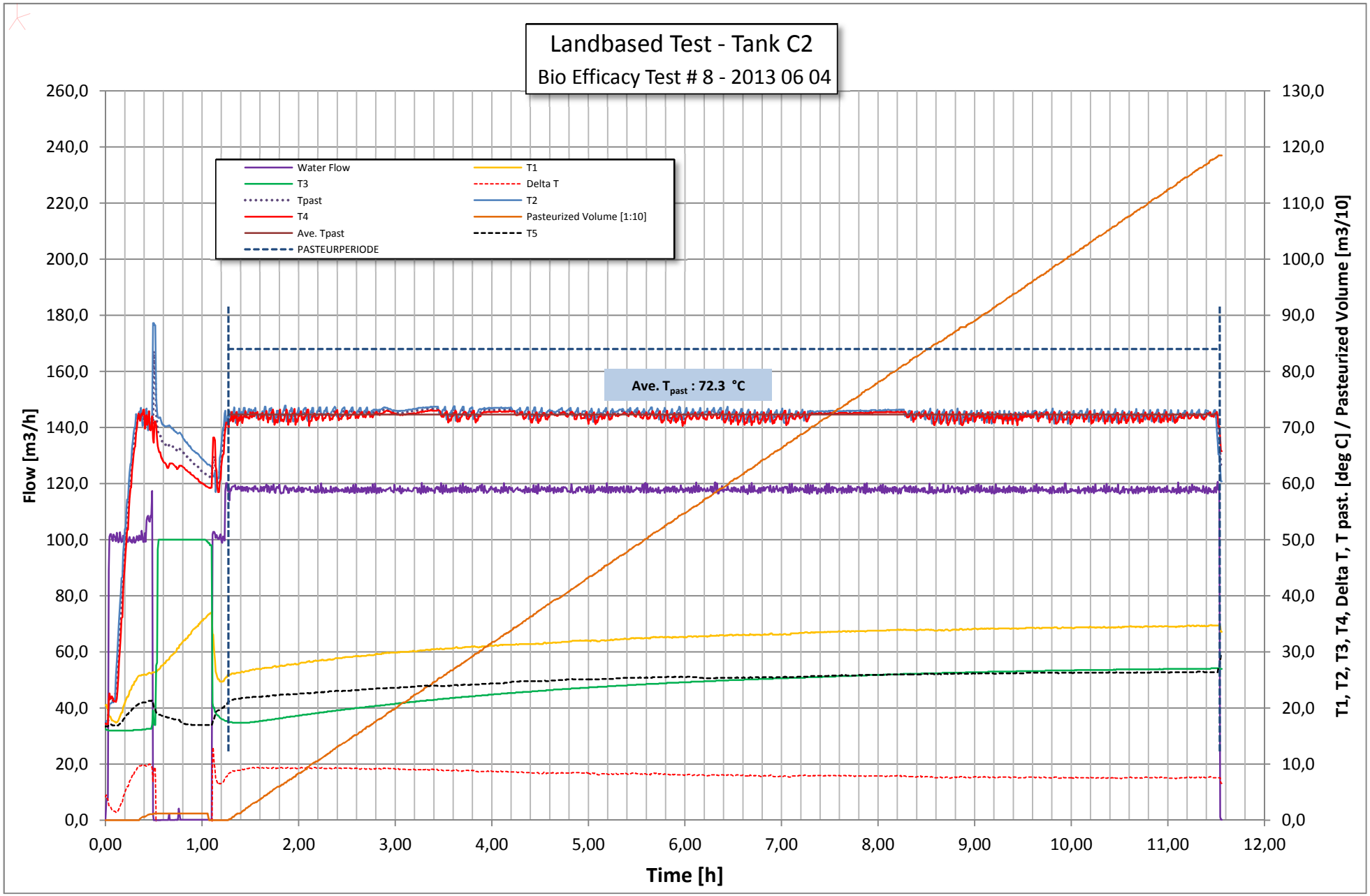
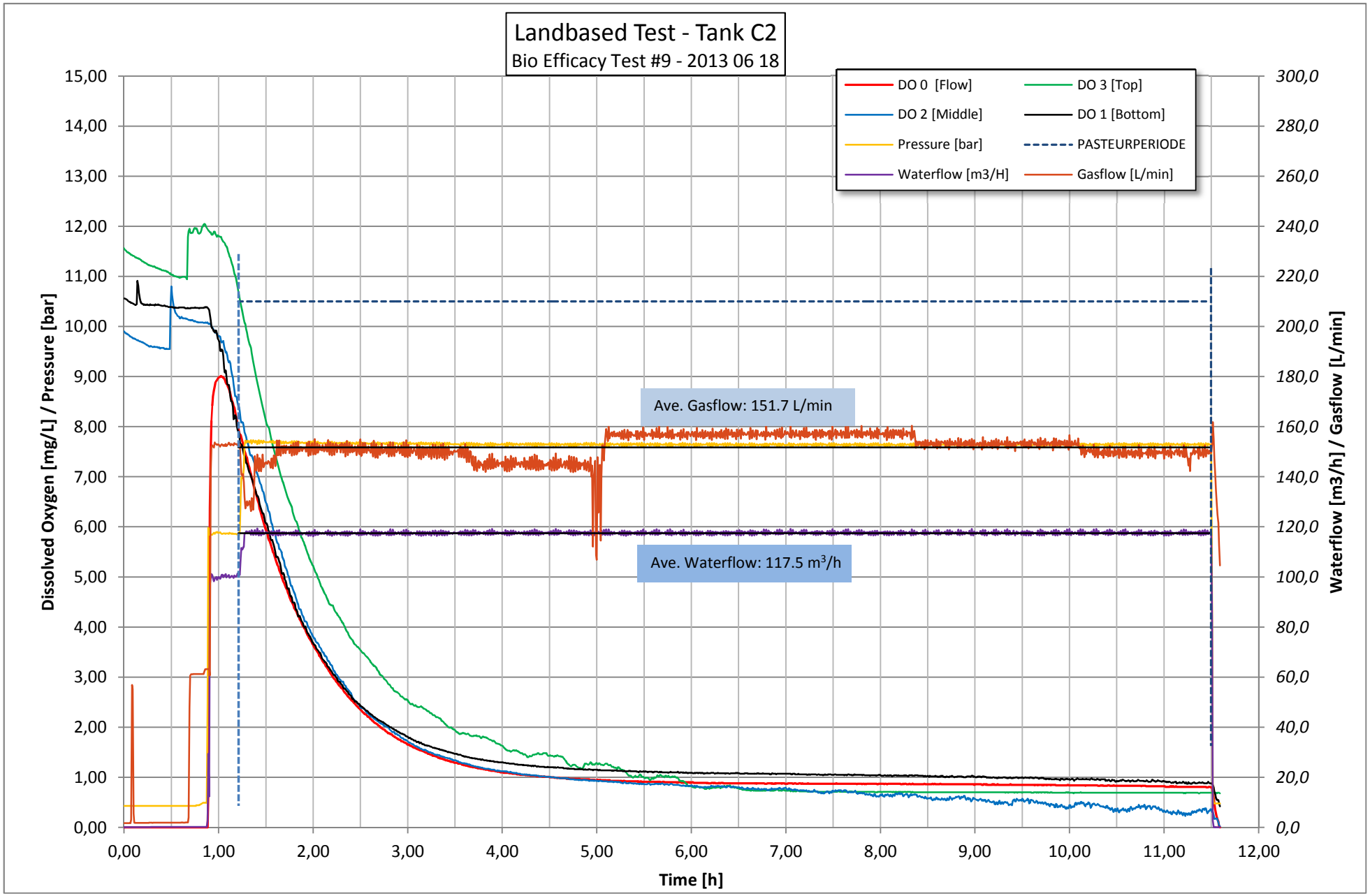
9,00
10,00
11,00
12,00



04-06-2014/2013 06 04/Pasteurization BE#8 (2)/OLC


Landbased Test - Tank C2
Bio Efficacy Test #9 - 2013 06 18
DO 0 [Flow]
DO 3 [Top]
DO 2 [Middle]
DO 1 [Bottom]
Pressure [bar]
PASTEURPERIODE
Waterflow [m3/H]
Gasflow [L/min]
Ave. Gasflow: 151.7 L/min
Ave. Waterflow: 117.5 m³/h
Dissolved Oxygen [mg/L] / Pressure [bar]
Waterflow [m3/h] / Gasflow [L/min]
Time [h]
15,00
14,00
13,00
12,00
11,00
10,00
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
300,0
280,0
260,0
240,0
220,0
200,0
180,0
160,0
140,0
120,0
100,0
80,0
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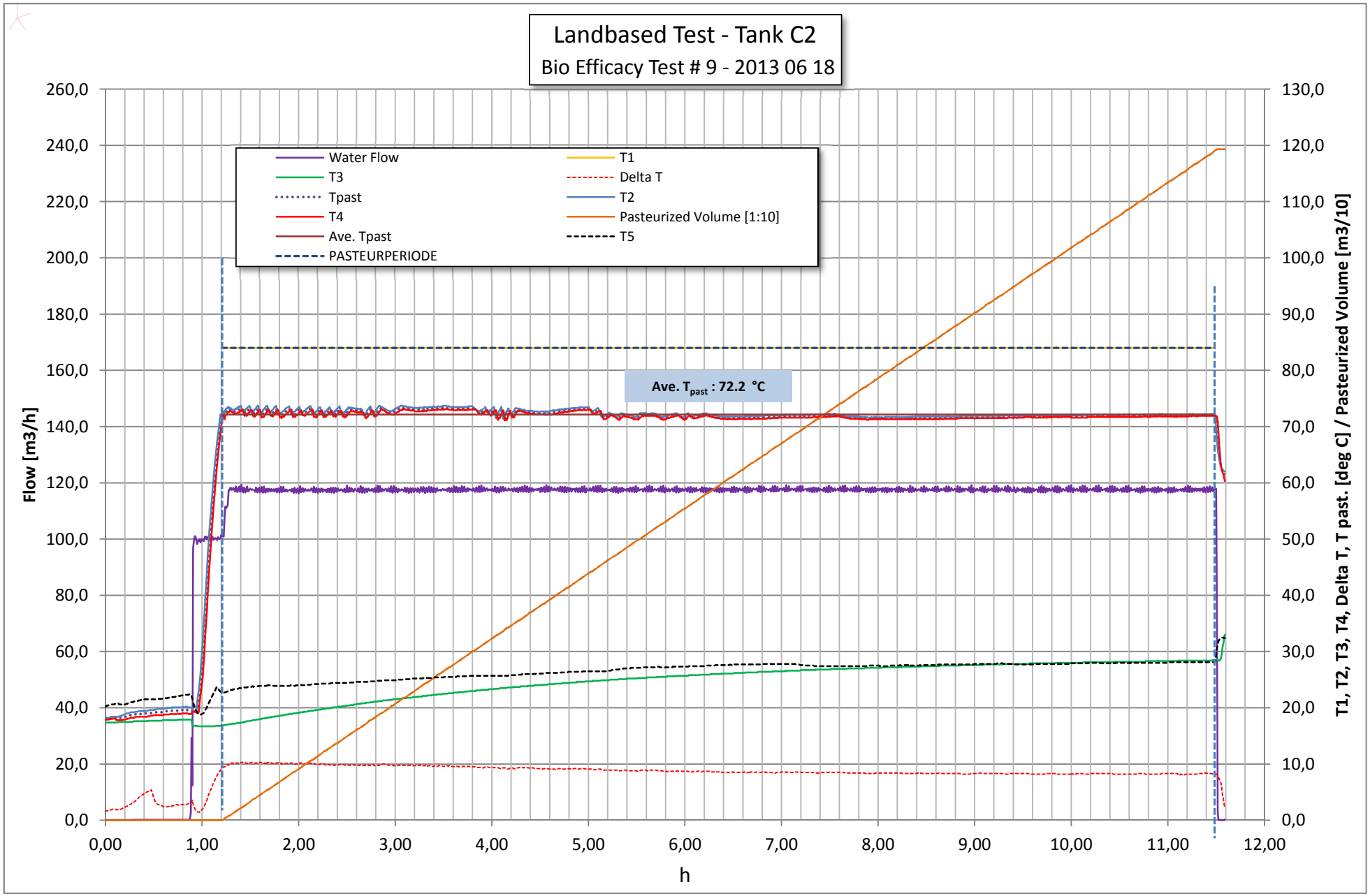
11,00
12,00


Landbased Test - Tank C2
Bio Efficacy Test # 9 - 2013 06 18
Water Flow
T1
T3
Delta T
Tpast
T2
T4
Pasteurized Volume [1:10]
Ave. Tpast
T5
PASTEURPERIODE
Ave. Tpast : 72.2 °C
Flow [m3/h]
T1, T2, T3, T4, Delta T, T past. [deg C] / Pasteurized Volume [m3/10]
h
260,0
240,0
220,0
200,0
180,0
160,0
140,0
120,0
100,0
80,0
60,0
40,0
20,0
0,0
130,0
120,0
110,0
100,0
90,0
80,0
70,0
60,0
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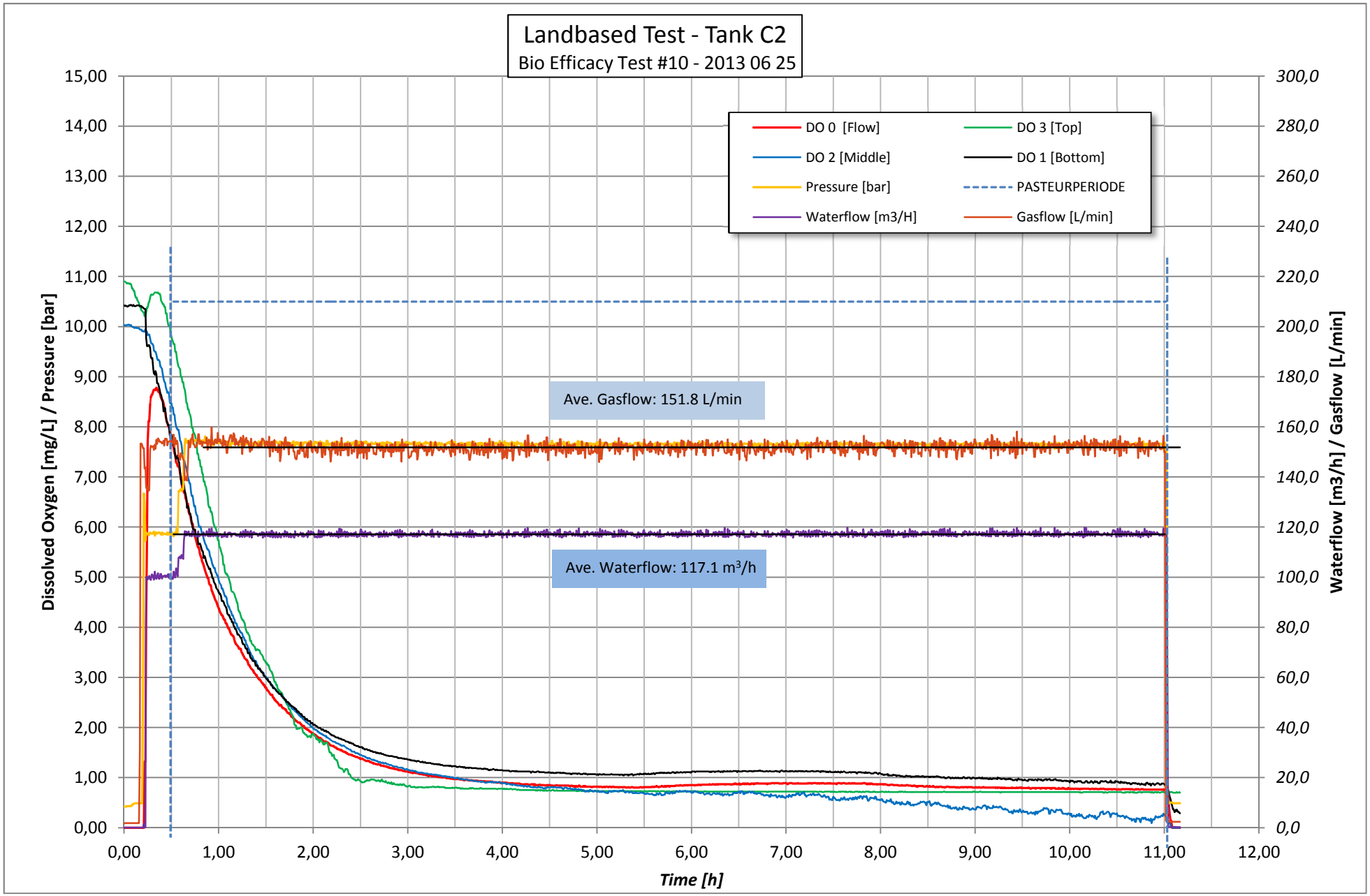
11,00
12,00


Landbased Test - Tank C2
Bio Efficacy Test #10 - 2013 06 25
DO 0 [Flow]
DO 3 [Top]
DO 2 [Middle]
DO 1 [Bottom]
Pressure [bar]
PASTEURPERIODE
Waterflow [m3/H]
Gasflow [L/min]
Ave. Gasflow: 151.8 L/min
Ave. Waterflow: 117.1 m³/h
Dissolved Oxygen [mg/L] / Pressure [bar]
Waterflow [m3/h] / Gasflow [L/min]
Time [h]
15,00
14,00
13,00
12,00
11,00
10,00
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
300,0
280,0
260,0
240,0
220,0
200,0
180,0
160,0
140,0
120,0
100,0
80,0
60,0
40,0
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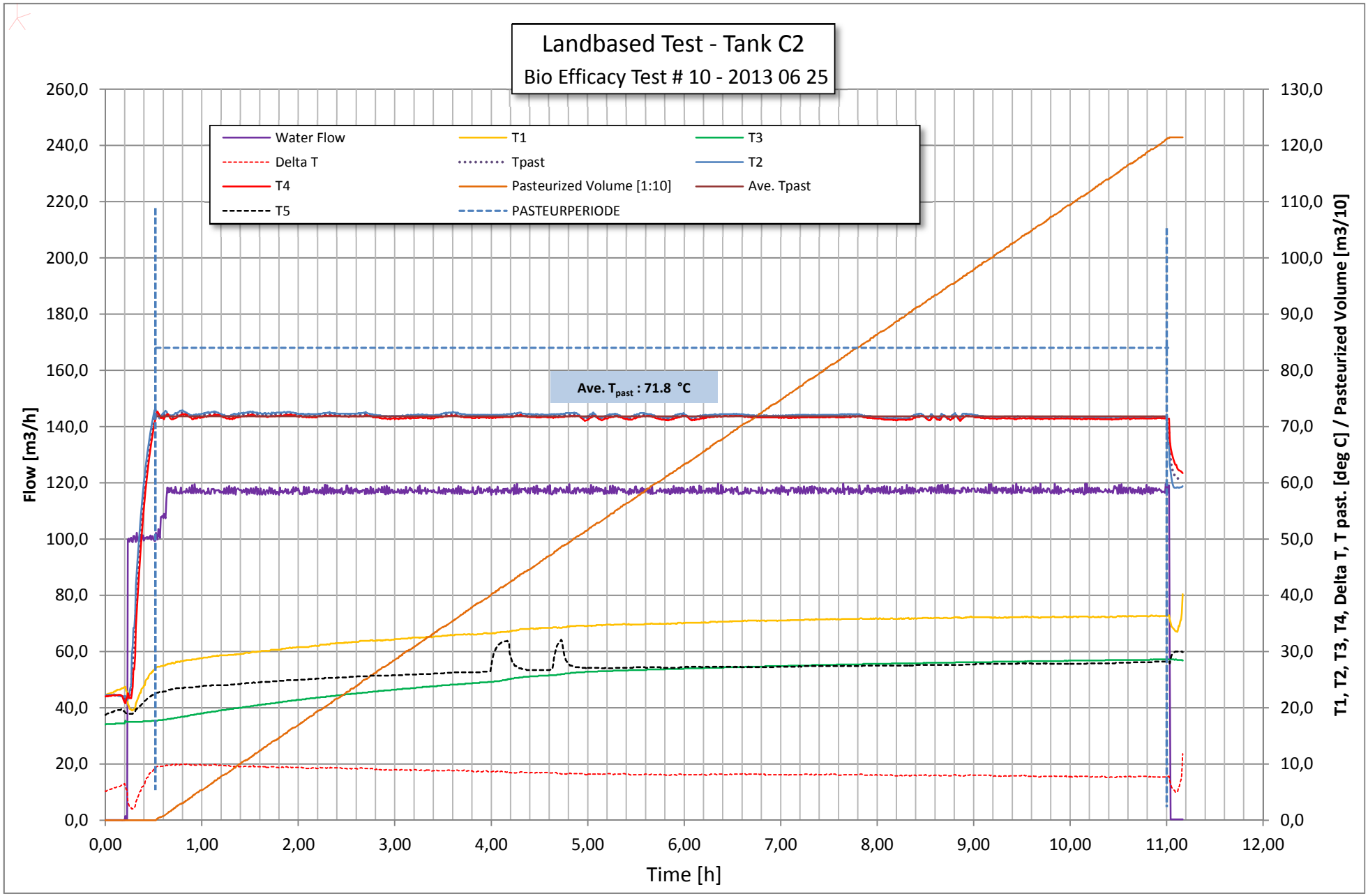
12,00


Landbased Test - Tank C2
Bio Efficacy Test # 10 - 2013 06 25
Water Flow
T1
T3
Delta T
Tpast
T2
T4
Pasteurized Volume [1:10]
Ave. Tpast
T5
PASTEURPERIODE
Ave. T_{past} : 71.8 °C
Flow [m3/h]
T1, T2, T3, T4, Delta T, T past. [deg C] / Pasteurized Volume [m3/10]
Time [h]
260,0
240,0
220,0
200,0
180,0
160,0
140,0
120,0
100,0
80,0
60,0
40,0
20,0
0,0
130,0
120,0
110,0
100,0
90,0
80,0
70,0
60,0
50,0
40,0
30,0
20,0
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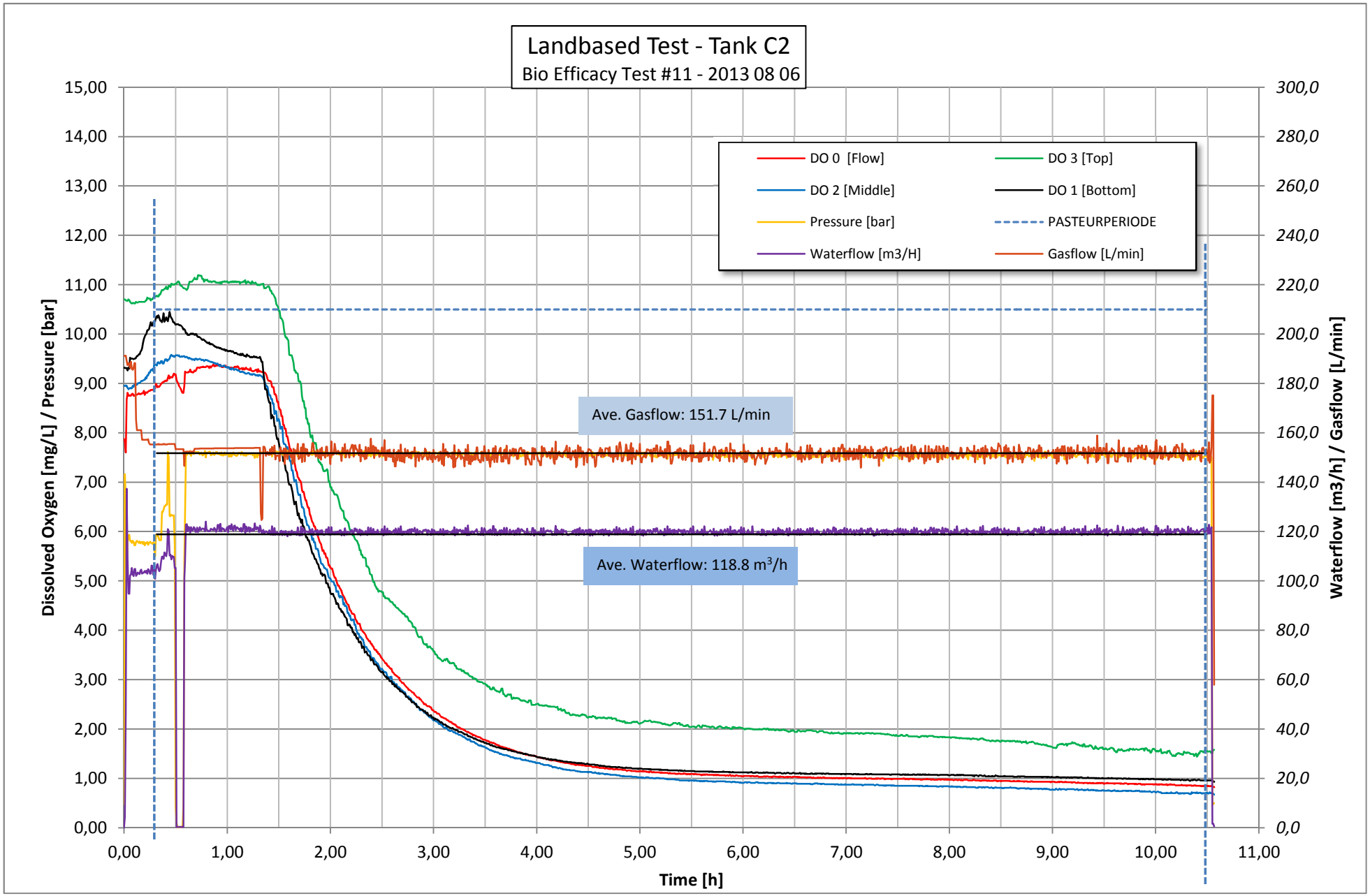
11,00
12,00


Landbased Test - Tank C2
Bio Efficacy Test #11 - 2013 08 06
DO 0 [Flow]
DO 3 [Top]
DO 2 [Middle]
DO 1 [Bottom]
Pressure [bar]
PASTEURPERIODE
Waterflow [m3/H]
Gasflow [L/min]
Ave. Gasflow: 151.7 L/min
Ave. Waterflow: 118.8 m³/h
Dissolved Oxygen [mg/L] / Pressure [bar]
Waterflow [m3/h] / Gasflow [L/min]
Time [h]
15,00
14,00
13,00
12,00
11,00
10,00
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
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0,00
300,0
280,0
260,0
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220,0
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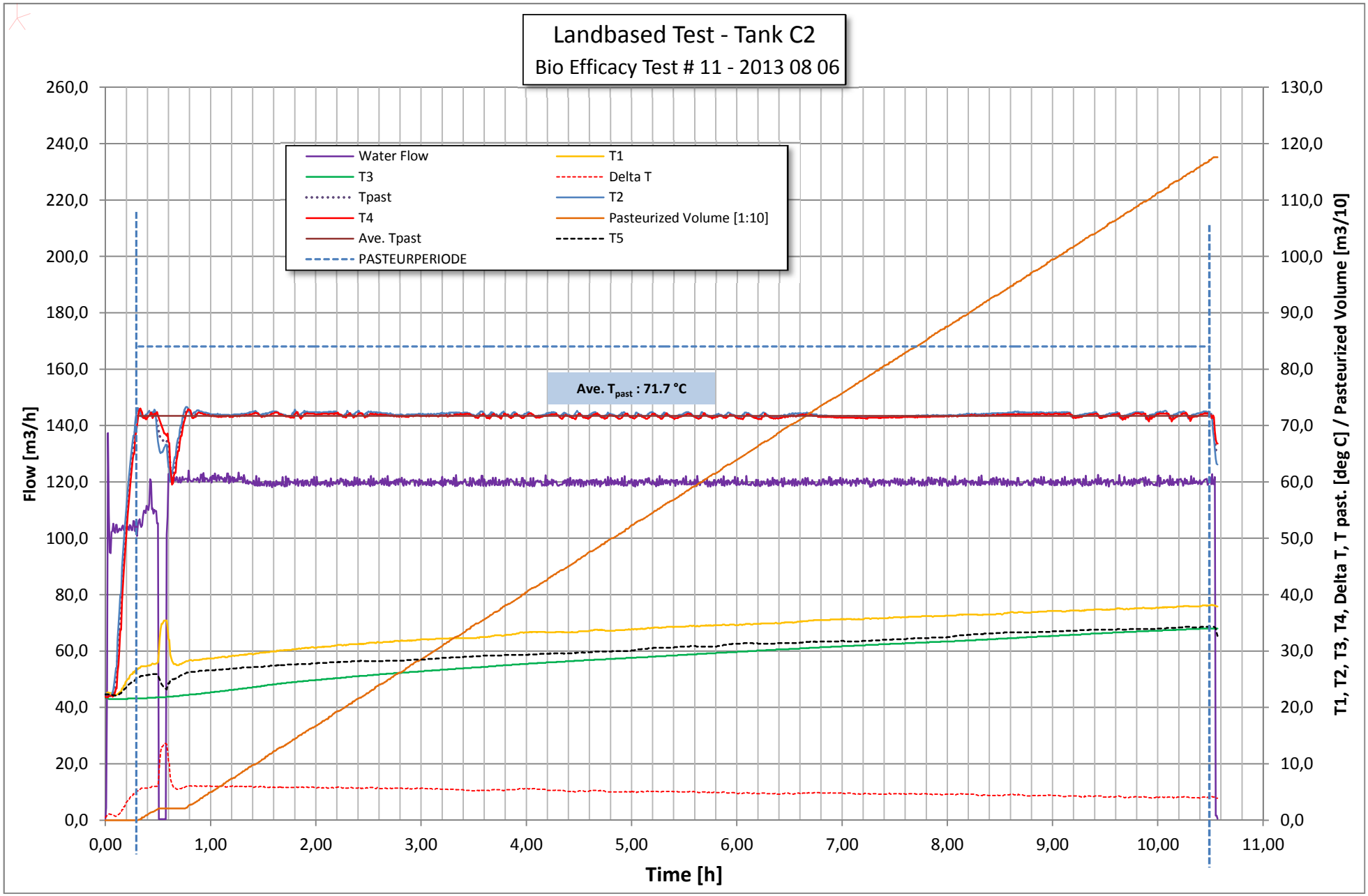
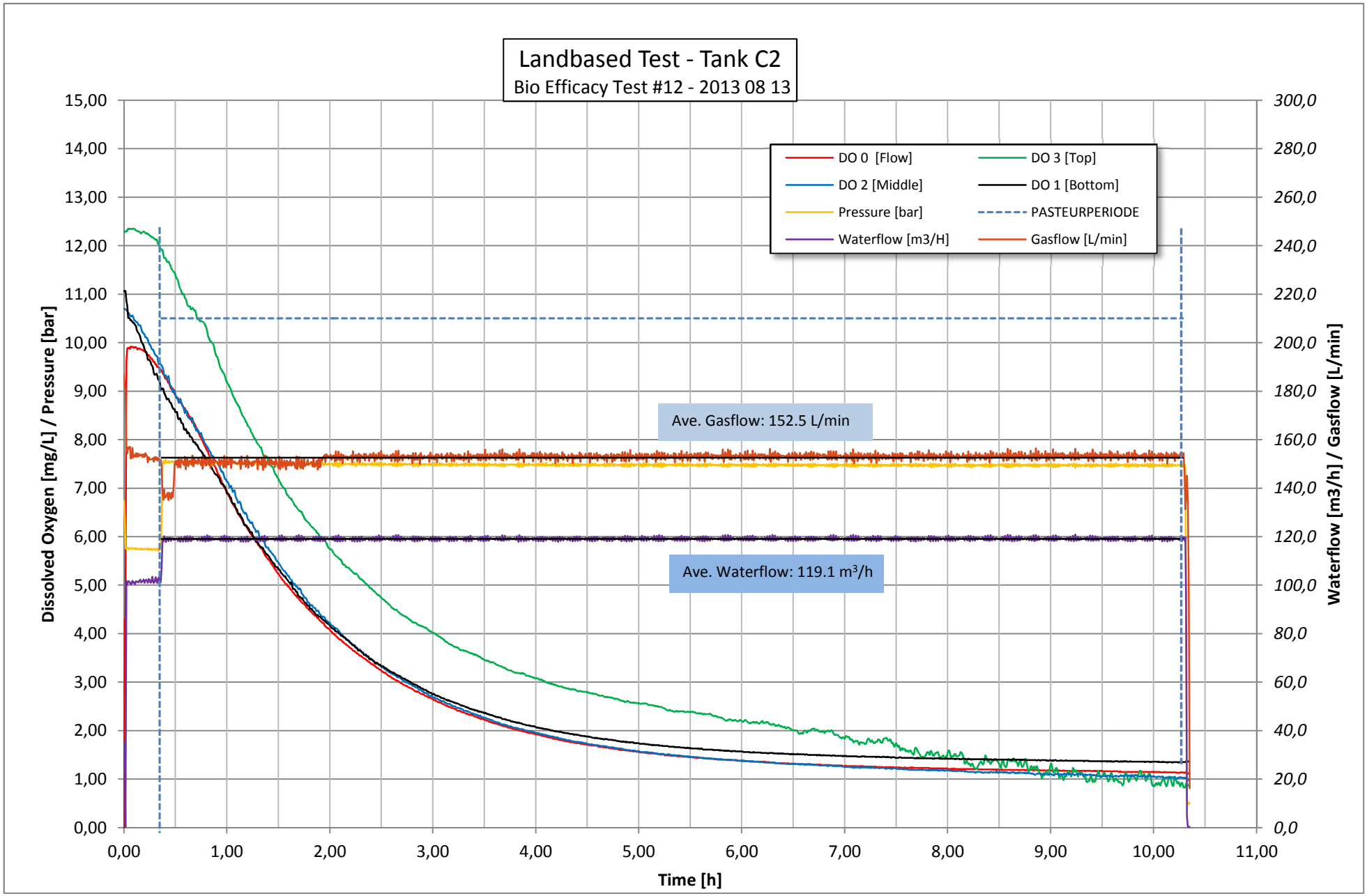
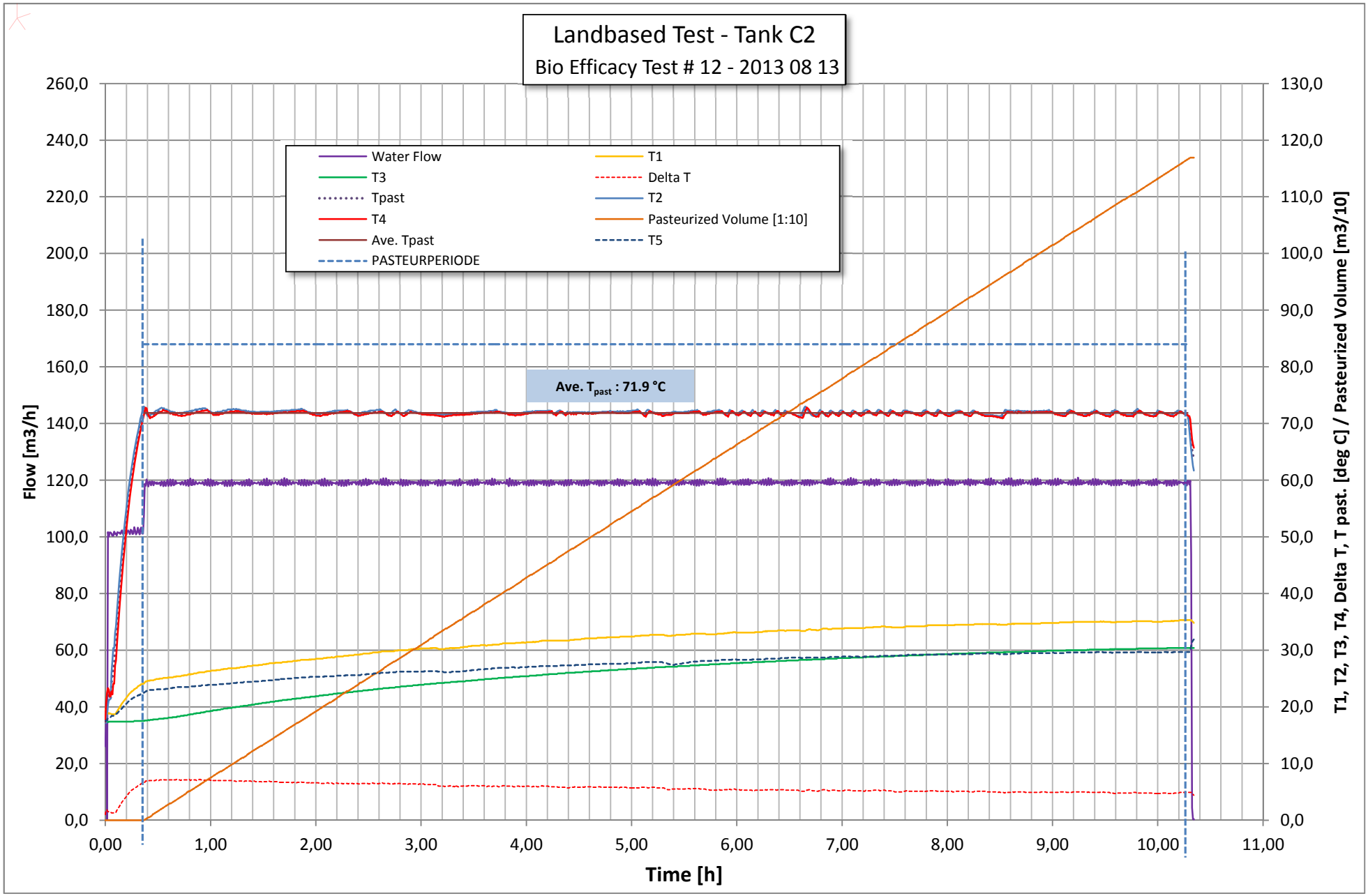
11,00

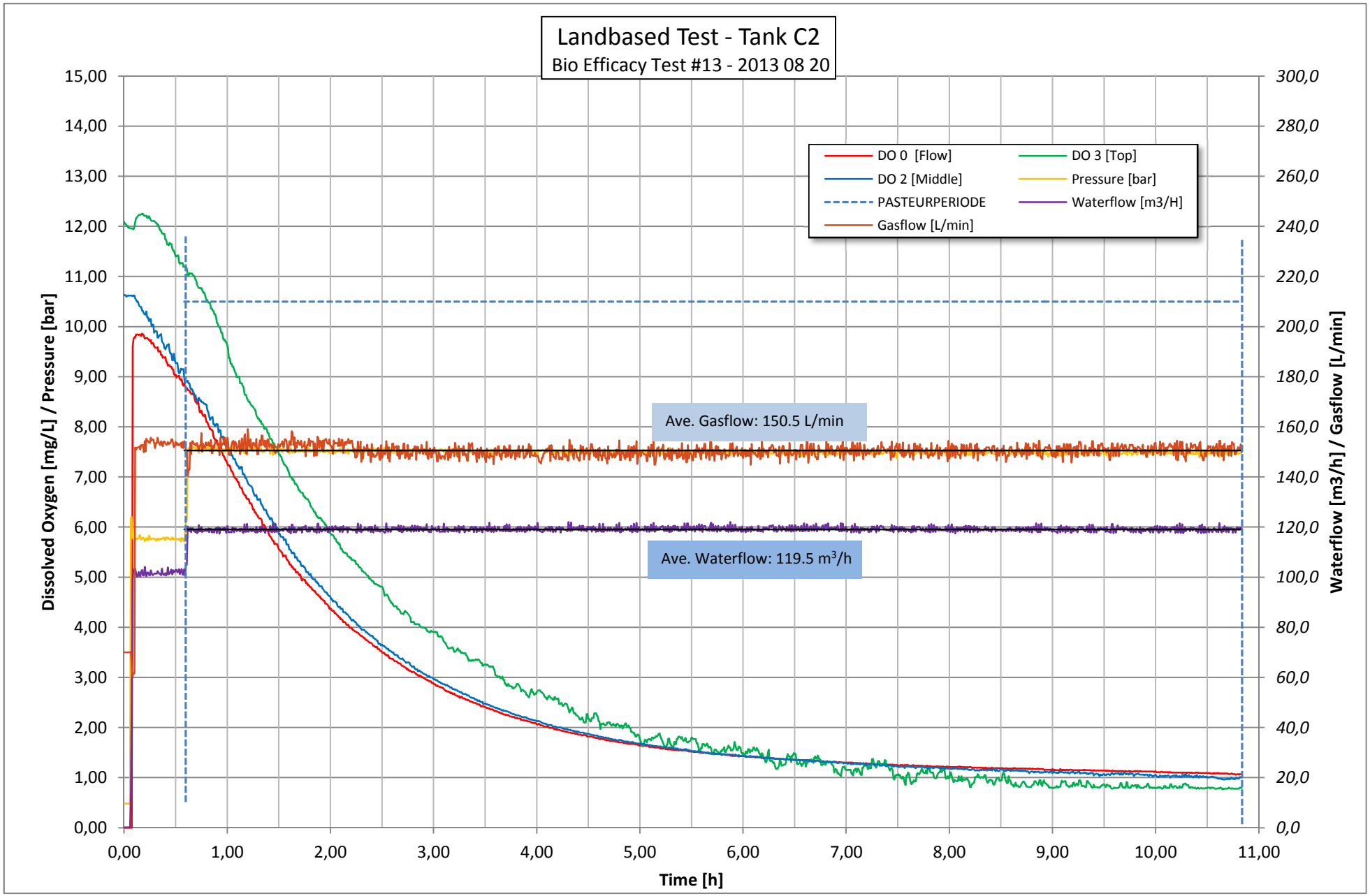


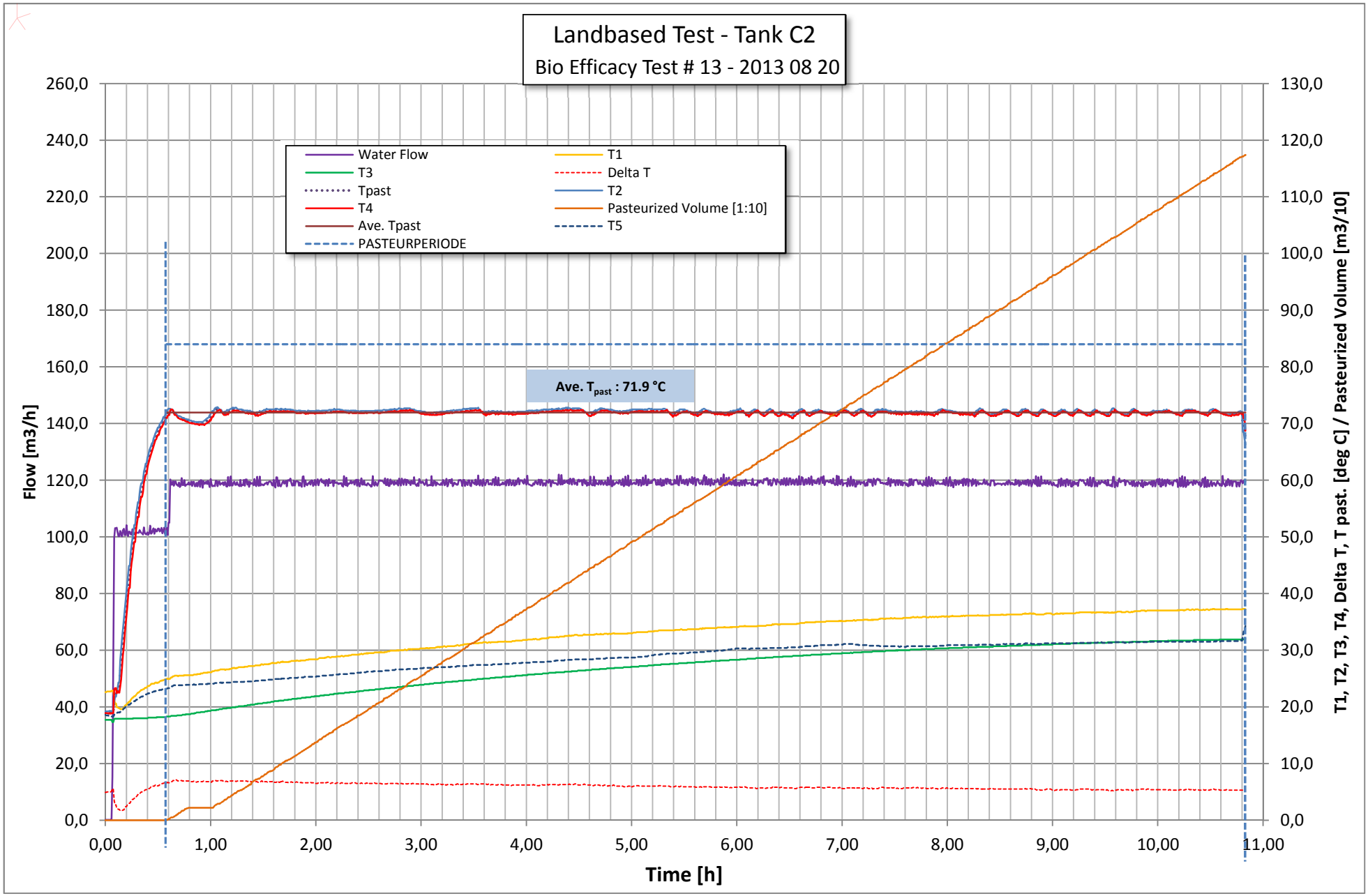
10-06-2014/2013 08 06/Pasteurization BE#11 (3)/OLC


Landbased Test - Tank C2
Bio Efficacy Test #12 - 2013 08 13
DO 0 [Flow]
DO 3 [Top]
DO 2 [Middle]
DO 1 [Bottom]
Pressure [bar]
PASTEURPERIODE
Waterflow [m3/H]
Gasflow [L/min]
Ave. Gasflow: 152.5 L/min
Ave. Waterflow: 119.1 m³/h
Dissolved Oxygen [mg/L] / Pressure [bar]
Waterflow [m3/h] / Gasflow [L/min]
Time [h]
15,00
14,00
13,00
12,00
11,00
10,00
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
300,0
280,0
260,0
240,0
220,0
200,0
180,0
160,0
140,0
120,0
100,0
80,0
60,0
40,0
20,0
0,0
0,00
1,00
2,00
3,00
4,00
5,00
6,00
7,00
8,00
9,00
10,00
11,00

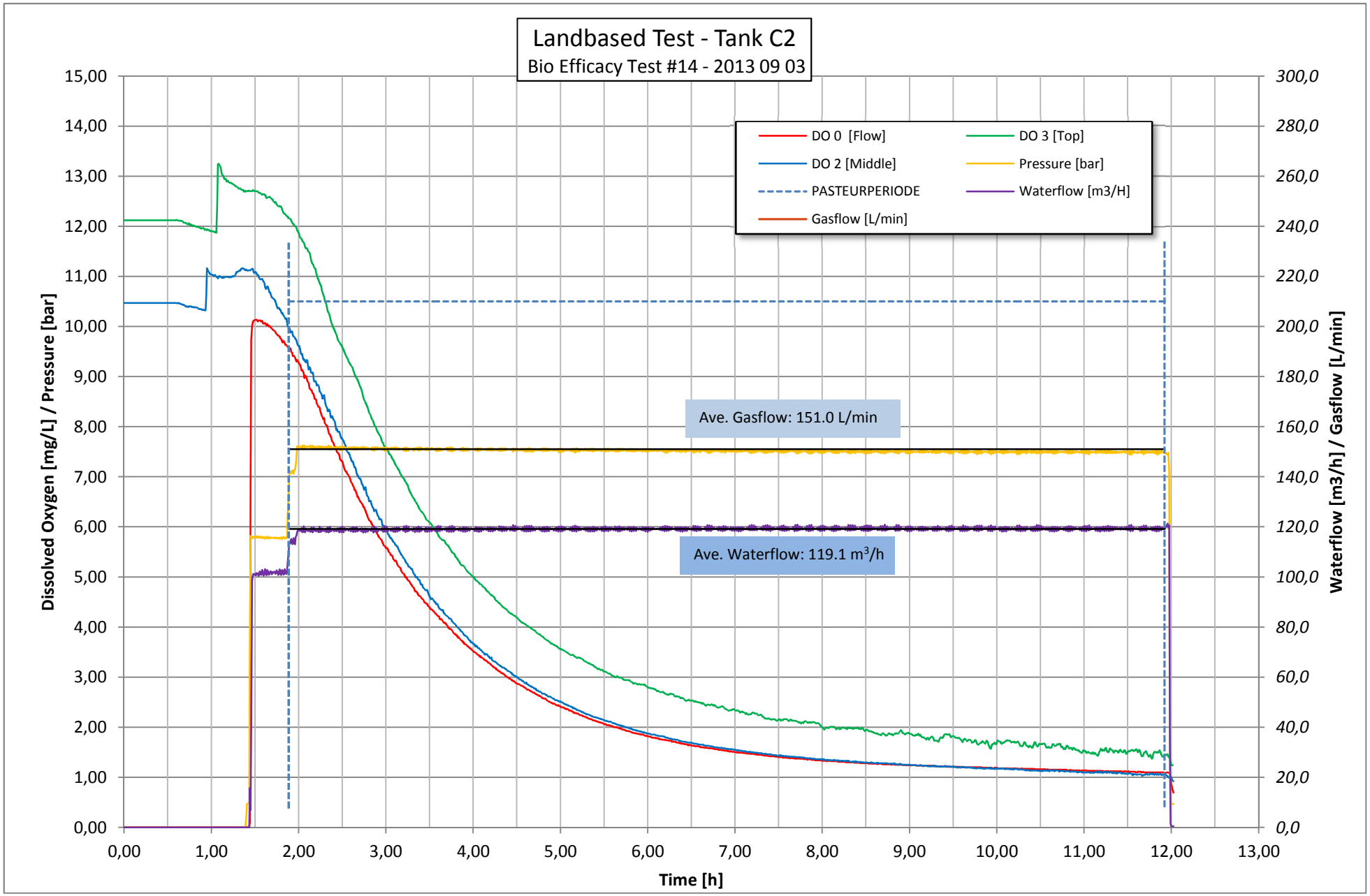


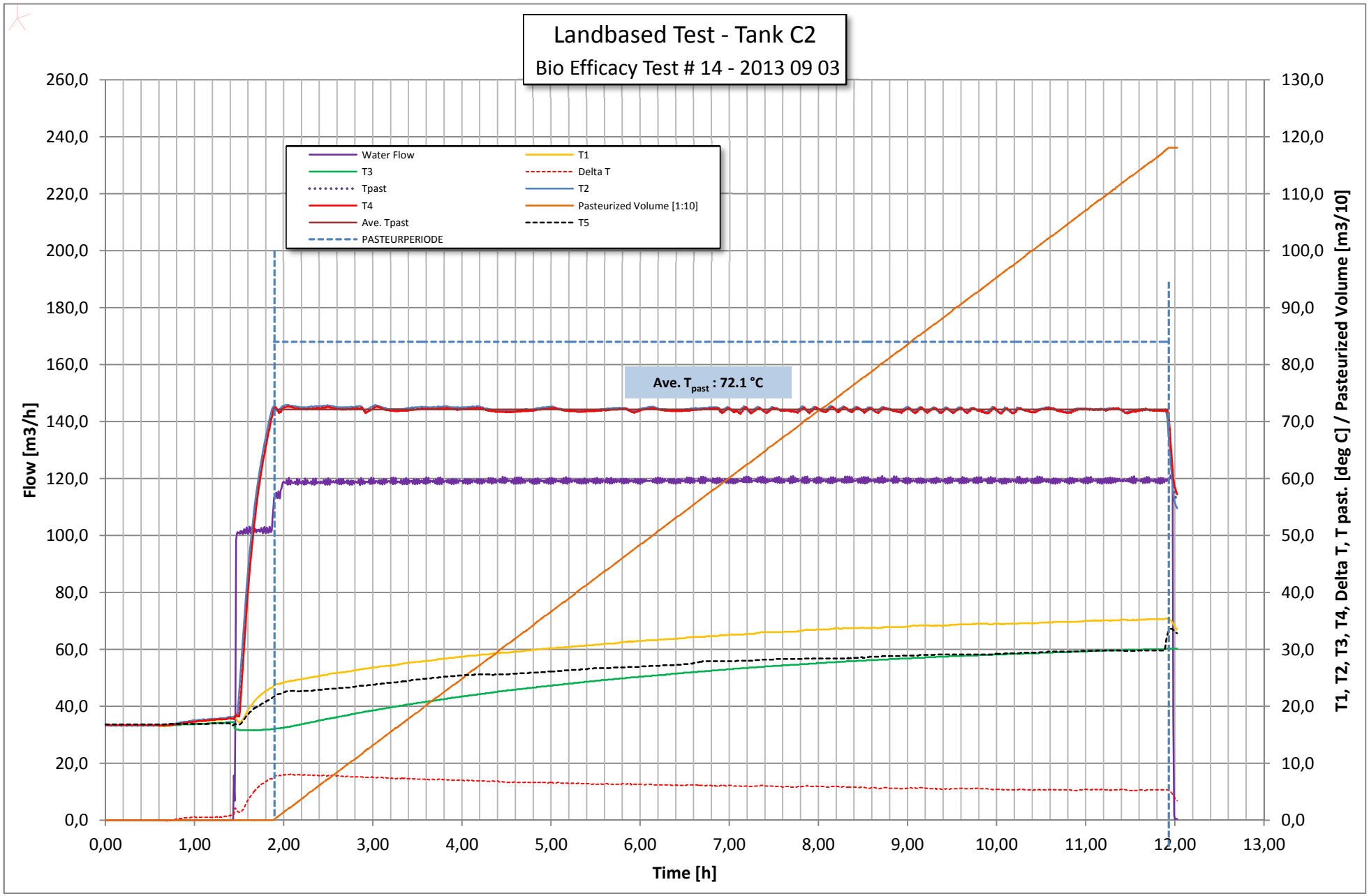
10-06-2014/2013 08 13/Pasteurization BE#12 (2)/OLC


Landbased Test - Tank C2
Bio Efficacy Test #13 - 2013 08 20
DO 0 [Flow]
DO 2 [Middle]
PASTEURPERIODE
Gasflow [L/min]
DO 3 [Top]
Pressure [bar]
Waterflow [m3/H]
Ave. Gasflow: 150.5 L/min
Ave. Waterflow: 119.5 m³/h
Dissolved Oxygen [mg/L] / Pressure [bar]
Waterflow [m3/h] / Gasflow [L/min]
Time [h]
15,00
14,00
13,00
12,00
11,00
10,00
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
300,0
280,0
260,0
240,0
220,0
200,0
180,0
160,0
140,0
120,0
100,0
80,0
60,0
40,0
20,0
0,0
0,00
1,00
2,00
3,00
4,00
5,00
6,00
7,00
8,00
9,00
10,00
11,00

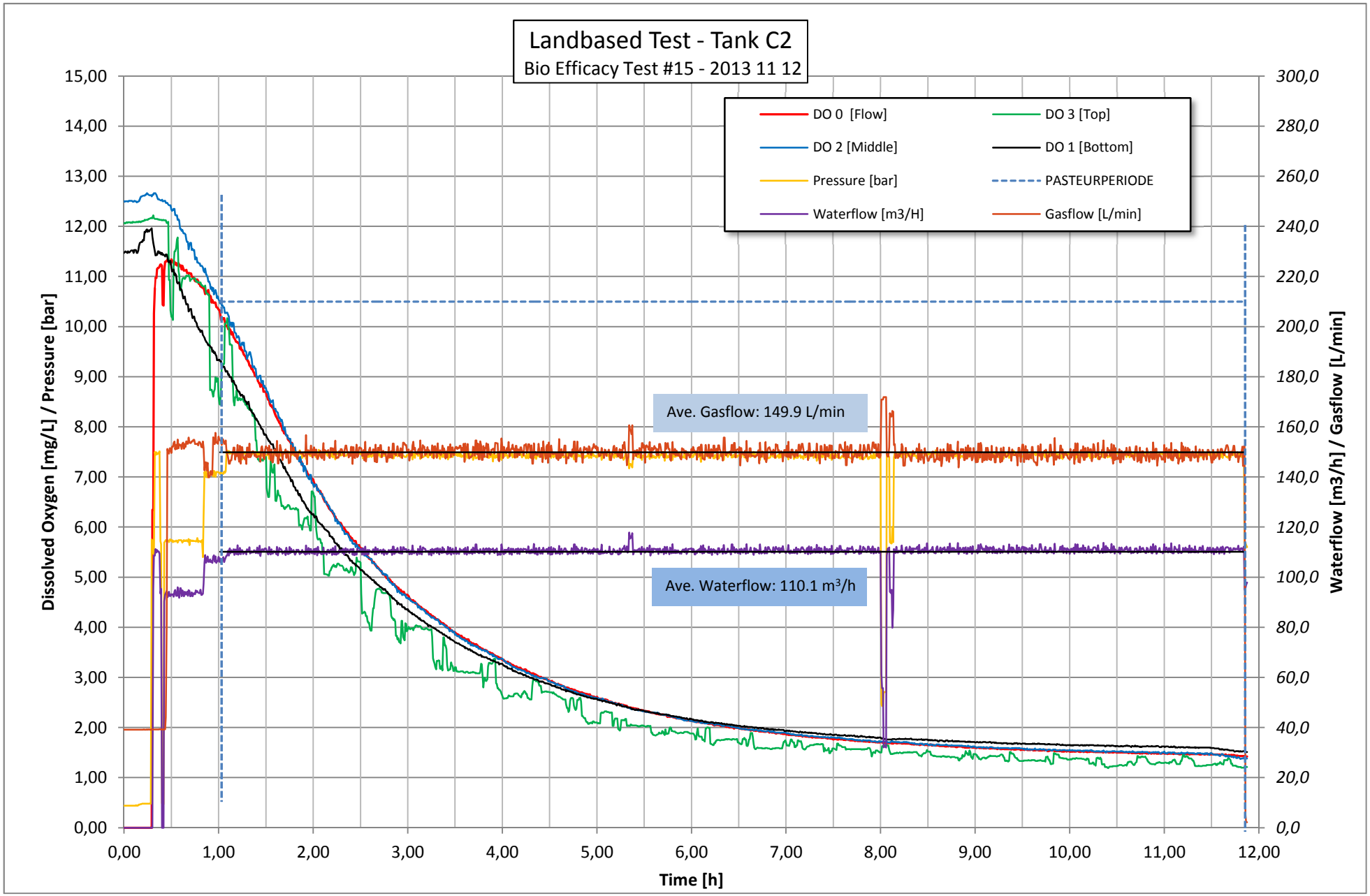


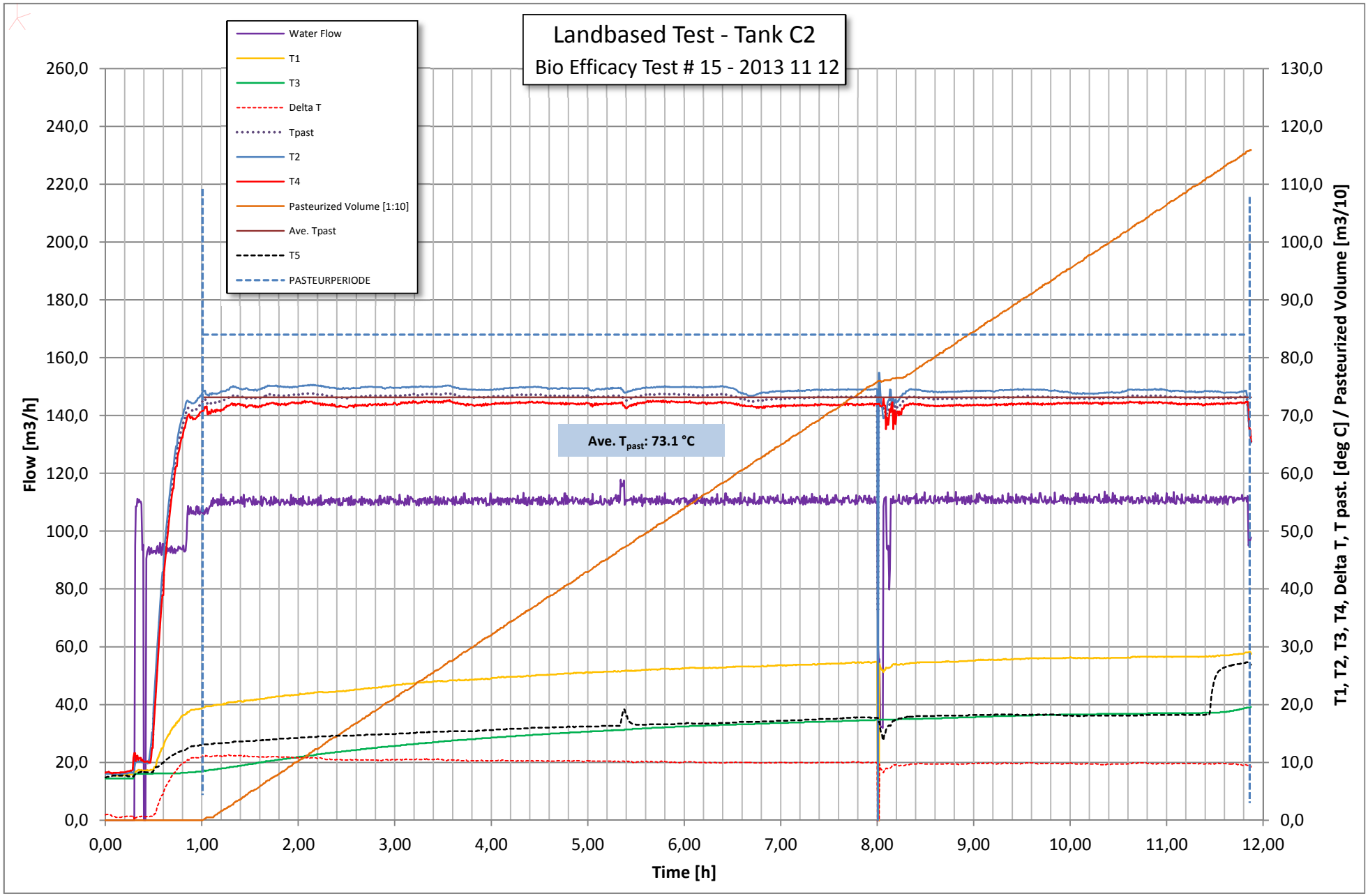
10-06-2014/2013 08 20/Pasteurization BE#13 (3)/OLC


Landbased Test - Tank C2
Bio Efficacy Test #14 - 2013 09 03
DO 0 [Flow]
DO 3 [Top]
DO 2 [Middle]
Pressure [bar]
PASTEURPERIODE
Waterflow [m3/H]
Gasflow [L/min]
Ave. Gasflow: 151.0 L/min
Ave. Waterflow: 119.1 m³/h
Dissolved Oxygen [mg/L] / Pressure [bar]
Waterflow [m3/h] / Gasflow [L/min]
Time [h]
15,00
14,00
13,00
12,00
11,00
10,00
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
300,0
280,0
260,0
240,0
220,0
200,0
180,0
160,0
140,0
120,0
100,0
80,0
60,0
40,0
20,0
0,0
0,00
1,00
2,00
3,00
4,00
5,00
6,00
7,00
8,00
9,00
10,00
11,00
12,00
13,00

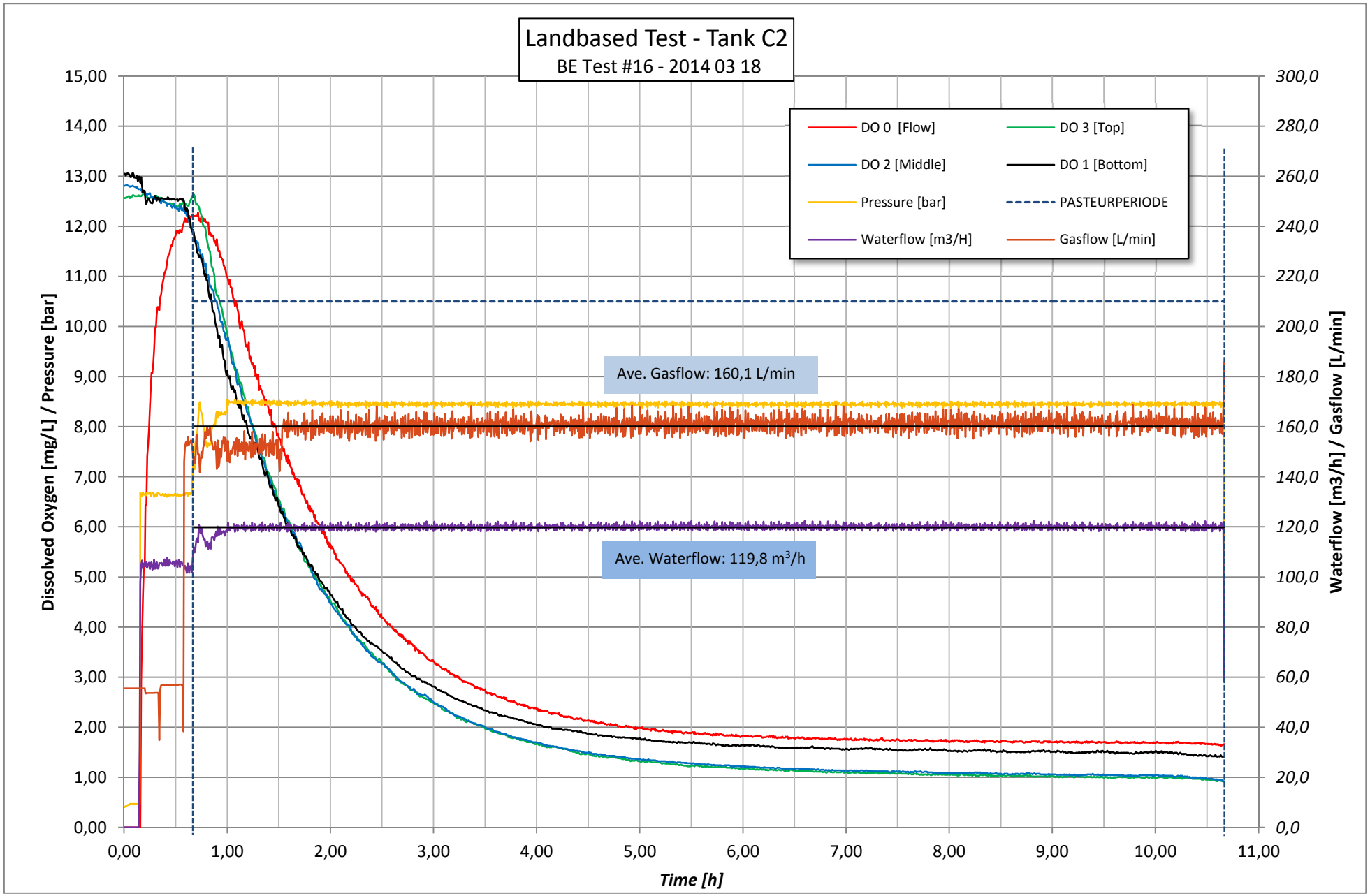


10-06-2014/2013 09 03/Pasteurization BE#14 (3)/OLC

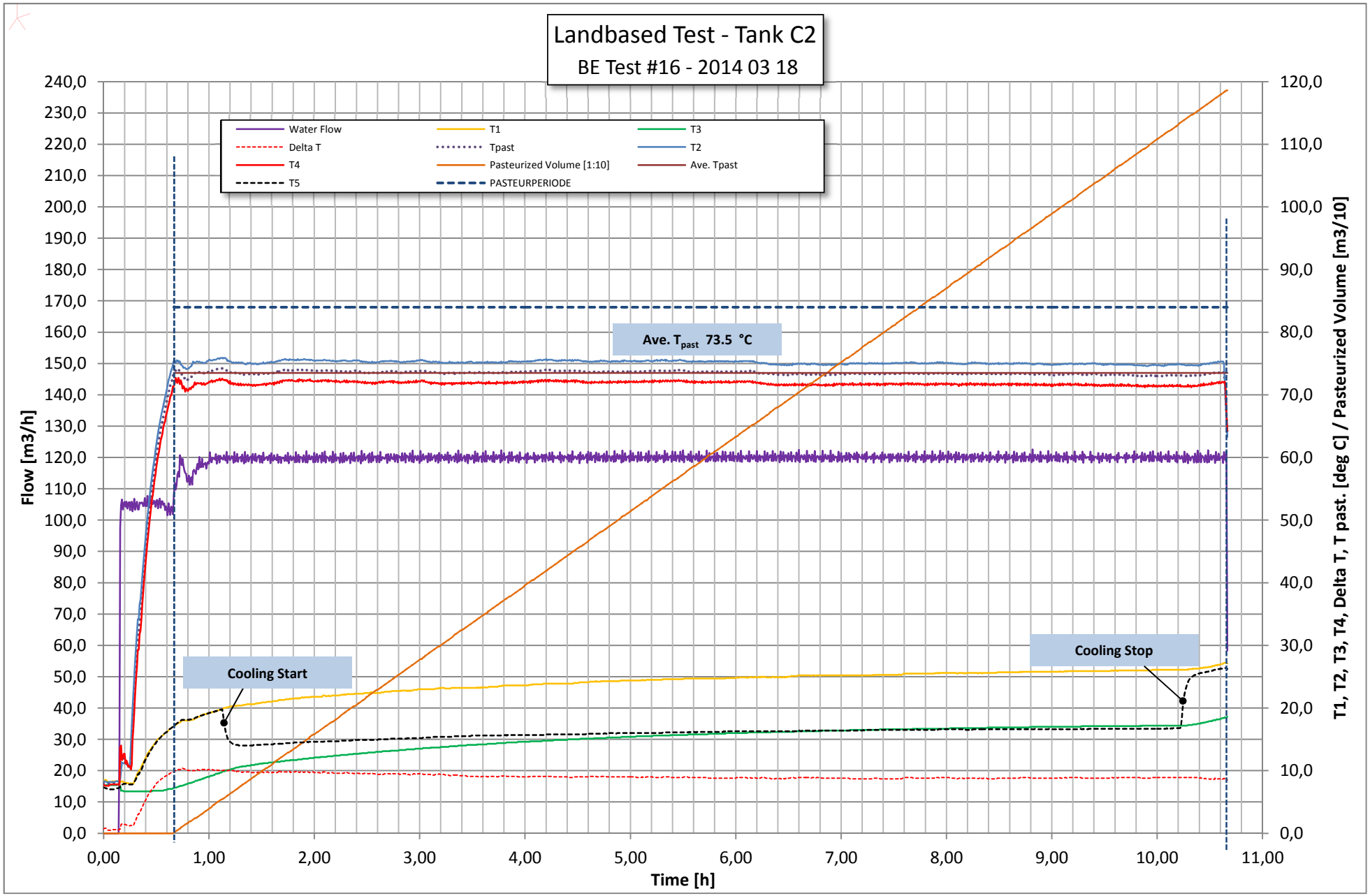

Landbased Test - Tank C2
Bio Efficacy Test #15 - 2013 11 12
DO 0 [Flow]
DO 3 [Top]
DO 2 [Middle]
DO 1 [Bottom]
Pressure [bar]
PASTEURPERIODE
Waterflow [m3/H]
Gasflow [L/min]
Ave. Gasflow: 149.9 L/min
Ave. Waterflow: 110.1 m³/h
Dissolved Oxygen [mg/L] / Pressure [bar]
Waterflow [m3/h] / Gasflow [L/min]
Time [h]
15,00
14,00
13,00
12,00
11,00
10,00
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
300,0
280,0
260,0
240,0
220,0
200,0
180,0
160,0
140,0
120,0
100,0
80,0
60,0
40,0
20,0
0,0
0,00
1,00
2,00
3,00
4,00
5,00
6,00
7,00
8,00
9,00
10,00
11,00
12,00

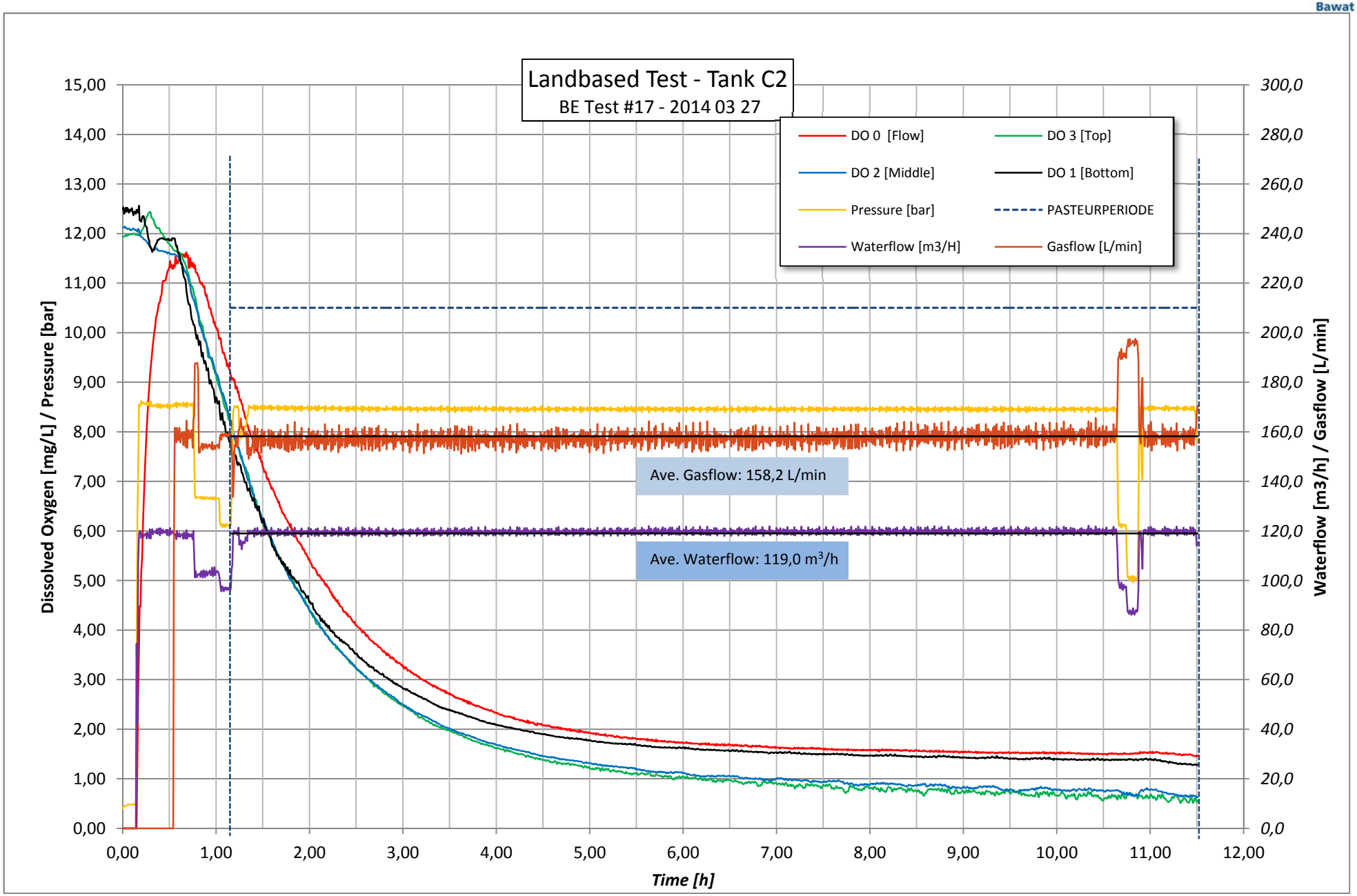


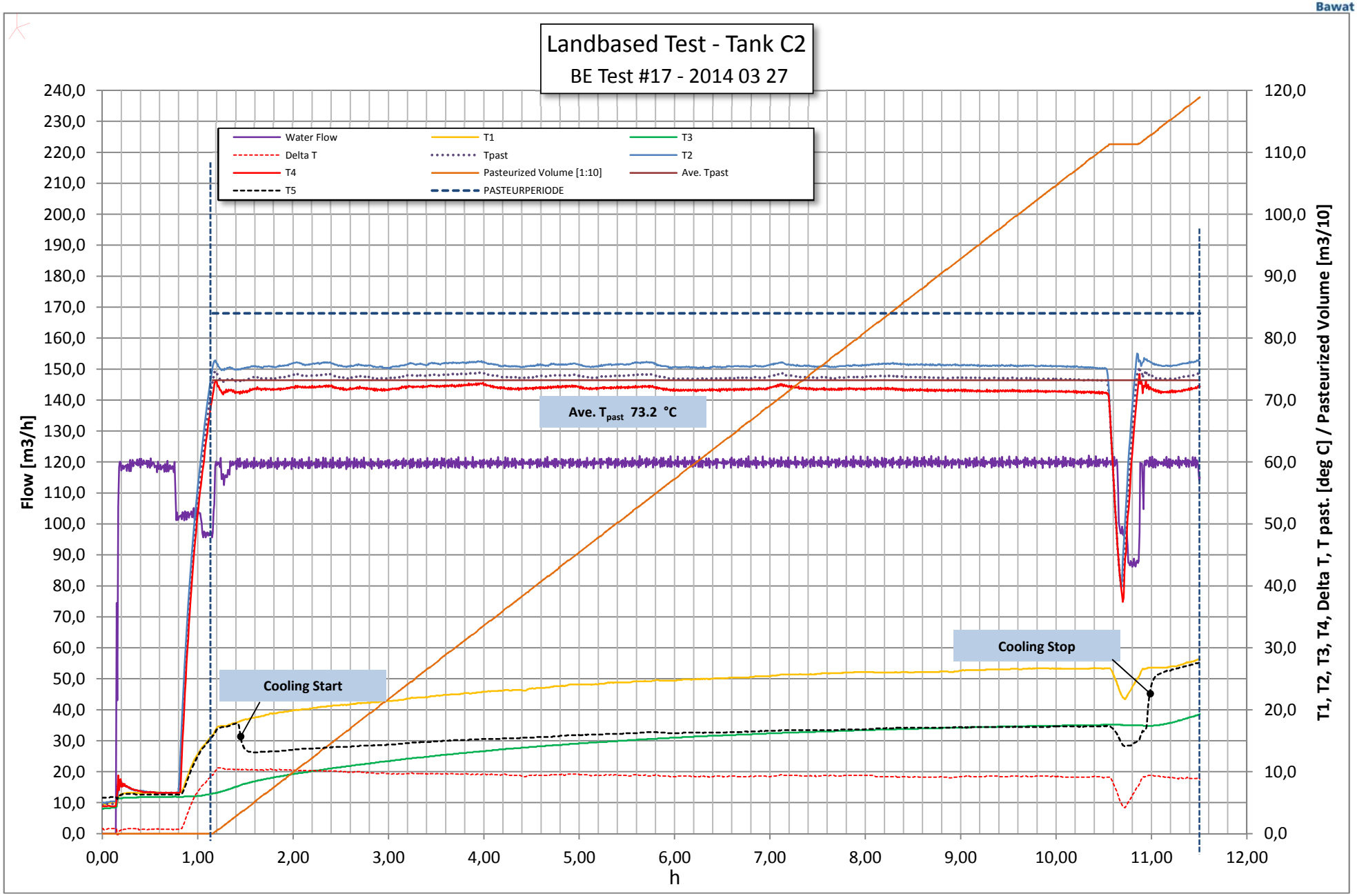
10-06-2014/2013 11 12 /Pasteurization BE#15 (4)/OLC



10-06-2014/2014 03 18 BE Test 16/Day's Runs 2014 03 18 (2)/OLC


Landbased Test - Tank C2
BE Test #16 - 2014 03 18
Water Flow
T1
T3
Delta T
Tpast
T2
T4
Pasteurized Volume [1:10]
Ave. Tpast
T5
PASTEURPERIODE
Ave. Tpast 73.5 °C
Cooling Start
Cooling Stop
Flow [m3/h]
T1, T2, T3, T4, Delta T, T past. [deg C] / Pasteurized Volume [m3/10]
Time [h]
240,0
230,0
220,0
210,0
200,0
190,0
180,0
170,0
160,0
150,0
140,0
130,0
120,0
110,0
100,0
90,0
80,0
70,0
60,0
50,0
40,0
30,0
20,0
10,0
0,0
120,0
110,0
100,0
90,0
80,0
70,0
60,0
50,0
40,0
30,0
20,0
10,0
0,0
0,00
1,00
2,00
3,00
4,00
5,00
6,00
7,00
8,00
9,00
10,00
11,00


Landbased Test - Tank C2
BE Test #17 - 2014 03 27
DO 0 [Flow]
DO 3 [Top]
DO 2 [Middle]
DO 1 [Bottom]
Pressure [bar]
PASTEURPERIODE
Waterflow [m3/H]
Gasflow [L/min]
Ave. Gasflow: 158,2 L/min
Ave. Waterflow: 119,0 m³/h
Dissolved Oxygen [mg/L] / Pressure [bar]
Waterflow [m3/h] / Gasflow [L/min]
Time [h]
15,00
14,00
13,00
12,00
11,00
10,00
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
300,0
280,0
260,0
240,0
220,0
200,0
180,0
160,0
140,0
120,0
100,0
80,0
60,0
40,0
20,0
0,0
0,00
1,00
2,00
3,00
4,00
5,00
6,00
7,00
8,00
9,00
10,00
11,00
12,00


Landbased Test - Tank C2
BE Test #17 - 2014 03 27
Water Flow
T1
T3
Delta T
Tpast
T2
T4
Pasteurized Volume [1:10]
Ave. Tpast
T5
PASTEURPERIODE
Ave. Tpast 73.2 °C
Cooling Start
Cooling Stop
Flow [m3/h]
T1, T2, T3, T4, Delta T, T past. [deg C] / Pasteurized Volume [m3/10]
h
0,00
1,00
2,00
3,00
4,00
5,00
6,00
7,00
8,00
9,00
10,00
11,00
12,00
0,0
10,0
20,0
30,0
40,0
50,0
60,0
70,0
80,0
90,0
100,0
110,0
120,0
130,0
140,0
150,0
160,0
170,0
180,0
190,0
200,0
210,0
220,0
230,0
240,0

Discussion of failed Land Based Tests

The sequence of tests performed was as follows:

Test	Date	Water	> 50 µ	10 - 50 µ	Recir-cula-tions	Comments
			Discharge	Discharge		
#1	20-03-2013	High salinity	0	1,8	4	After-treatment cooling (ATC)
#2	10-04-2013	Brackish	0	10,6	4	30 min. power loss / ATC / Leaking by-pass valve
#3	16-04-2013	Brackish	0	1,8	4	ATC
#4	23-04-2013	Brackish	3	11,6	4	ATC, WET test samples / Leaking by-pass valve
#5	30-04-2013	Brackish	0	1,9	5	ATC
#6	08-05-2013	High salinity	0	0,92	5	ATC
#7	28-05-2013	High salinity	0	20,1	5	In-line cooling / Leaking by-pass valve
#8	04-06-2013	High salinity	4	2,1	5	In-line cooling
#9	18-06-2013	High salinity	5	3,2	5	In-line cooling
#10	25-06-2013	High salinity	6	4,2	5	In-line cooling
#11	06-08-2013	Brackish	0	7,2	5	In-line cooling, WET test samples
#12	13-08-2013	Fresh	0	5,8	5	In-line cooling
#13	20-08-2013	Fresh	6	6,6	5	In-line cooling
#14	03-09-2013	Fresh	142	37,3	5	In-line cooling / Tarpaulin failure
#15	12-11-2013	Fresh	66	13,7	5	In-line cooling / Tarpaulin failure
#16	18-03-2014	Brackish	1	2,1	5	In-line cooling
#17	27-03-2014	Brackish	7	0,7	5	In-line cooling

1. The marginal failure of the of Test #2 (2013 04 10) with respect to the phytoplankton content was at the time considered as caused by approx. a 30 min. power failure half way through treatment.
   And the following successful test (#3, 2013 04 16) seemed to support the conclusion.

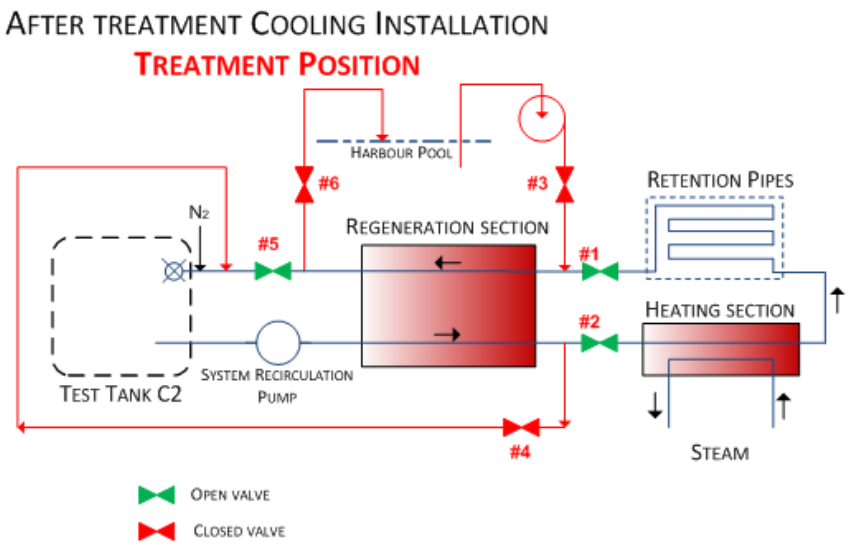
2. However, the following failure of Test #4 (2013 04 23) led to the supposition that the treatment itself was insufficient and it was decided to increase the number of recirculations from 4 to 5[1].
   It could be argued that a safety margin on the calculated number of recirculations could have been

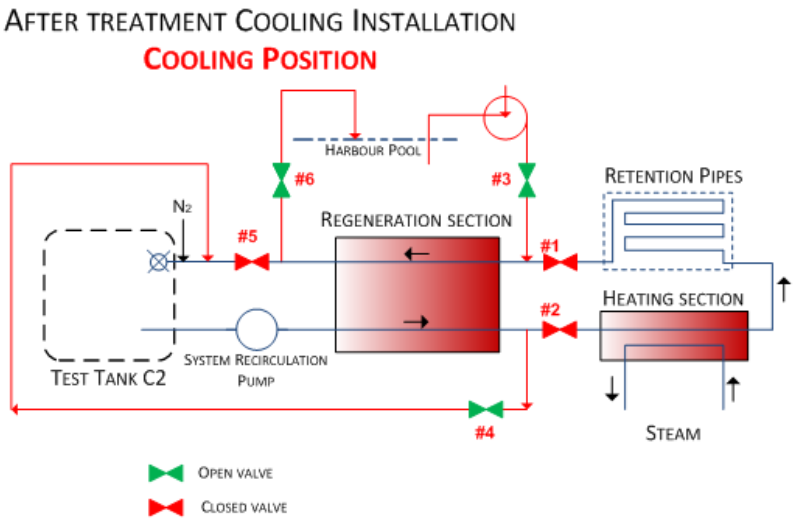
[1] The original number of recirculations (4) was calculated in accordance with the underlying model as described in the Test QAPP with the addition of a minor safety factor of 5%. The increase to a recirculation number to 5 increases the safety factor to 32 %.

optimized through a test-series, however, it was decided at the time to minimize the number of very costly tests and chose a 'sufficiently high' safety margin.

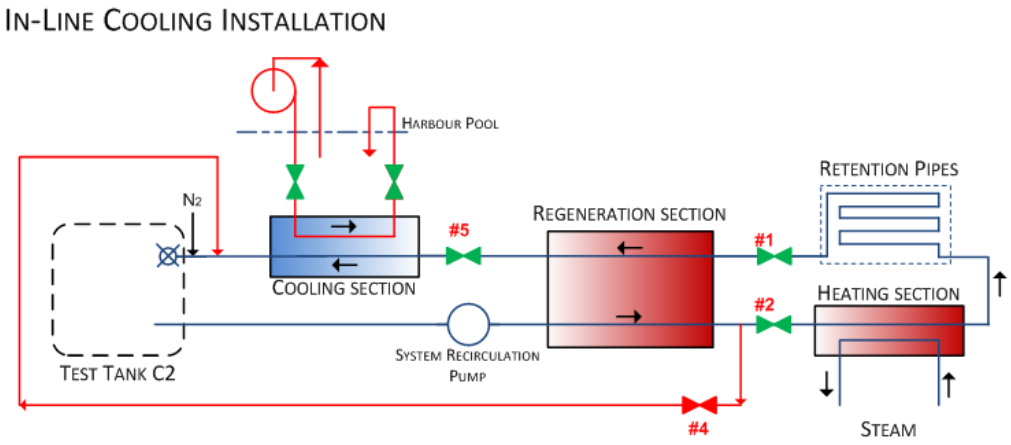
3. The failed Test #4 was followed by two successful tests, however, Test #6 (2013 05 08) failed leading to the conclusion that the failure supposition re. Test #2 and #4 was not correct.

4. Between Test #6 (2013 05 08) and Test #7 (2013 05 28) the test set-up was changed as described in the updated Test QAPP from 'After Treatment Cooling' of the test tank to an 'Inline Cooling' procedure.
   4.1. In the 'After Treatment Cooling' procedure the positions of a series of valves were changed from a treatment to a cooling position in accordance with the schematics below:





4.2. In the 'In-line cooling' procedure the valve positions were as indicated in the schematics below:



4.3. A review of the installation made it clear that valve #4 was not closing properly leading to a risk of inflow of un-treated or less-treated water into the piping before the reinjection into the tank.

4.4. A spade was inserted in the valve to block it entirely.

5. The following six tests (Tests #8 (2013 06 04) through #13 (2013 08 20)) were all successful, however, Test #14 (2013 09 03) failed with respect to both zooplankton and phytoplankton content.

5.1. Following the failed Test #14 a comprehensive troubleshooting process was initiated based on a series of test runs.

5.2. It was observed that the tarpaulins inserted in the tank to mimic a BWT onboard a ship, originally very tight and flat, were now very slack and it was obvious that they would 'balloon' when nitrogen was injected below and change the intended flow pattern in the tank. See photographs below. Consequently it was decided to insert new tarpaulins.

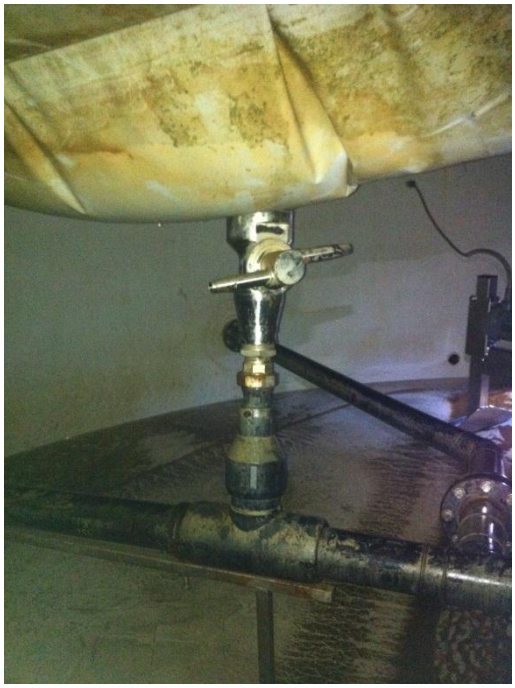
5.3. However, Test #15 (2013 11 12) also failed although an improvement was observed.

6. The troubleshooting process continued and it became clear that the new tarpaulins were not properly installed. See sketch below. Excess material was not removed from the tarpaulin along the diameter boom separating the lower and middle tank segments. Gas bubbles relished in the tank bottom would therefore close the gap intended to facilitate the bubble flow from bottom to middle section of the tank. The excess material was removed and all following tests were successful.

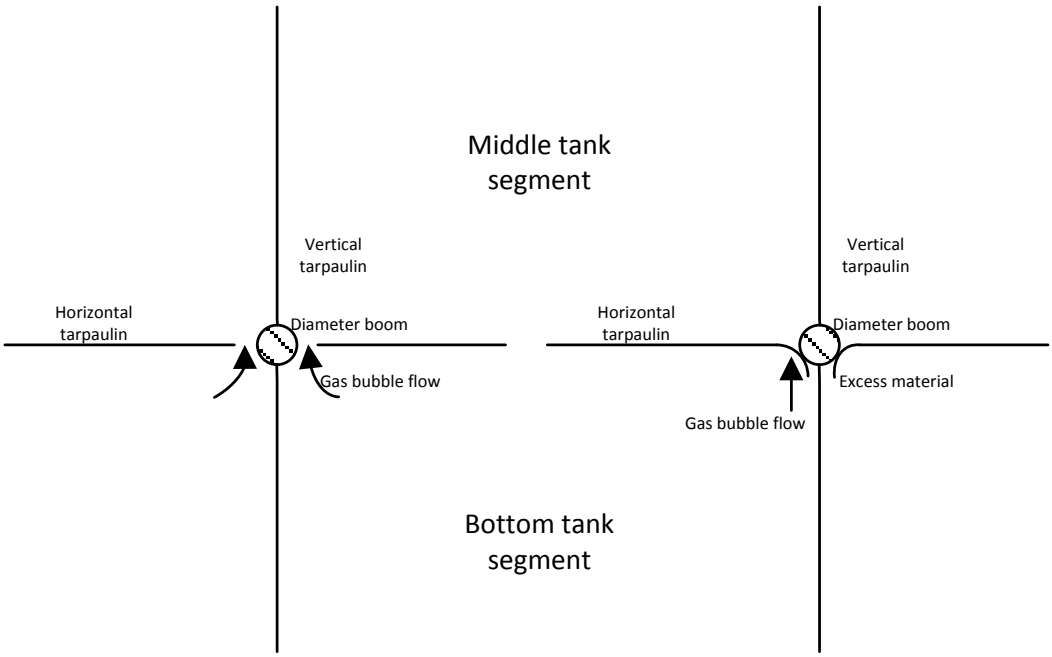
7. It can be concluded that all failed tests can be explained by mechanical failures in the test set-up necessary to as closely as possible to mimic a ship's ballast water tank and the cooling of treated ballast water through the ship's side during voyage.
   There are no indications what-so-ever that biological conditions in the test water, process execution or choice of process parameters have had any adverse effect on the system efficacy.

31 August, 2014 / Ole Lüthcke Christensen

Original installation, August 2012



Tarpaulins, September 2013



Bubble flow pattern around diameter boom

Date & time	Dis. O_2 DO 0 (mg/L)	Dis. O_2 DO 1 (mg/L)	Dis. O_2 DO 2 (mg/L)	Dis. O_2 DO 3 (mg/L)	Initials
10/4-13 22:33	0,92	1,29	1,03	0,21	SEh.

Signature: 10/4-2013 SEh

DHI

Pasteur

Date & time	Dis. O_2 DO 0 (mg/L)	Dis. O_2 DO 1 (mg/L)	Dis. O_2 DO 2 (mg/L)	Dis. O_2 DO 3 (mg/L)	Initials	
10/4-13 10 49	11,96	13,58	/	/	FK	
11 20	8,89	10,76	/	/	FK	
11 50	6,15	9,8	/	/	FK	
12 20	4,3	5,2	/	/	FK	
12 50	3,16	3,11	/	/	FK	
13 20	2,45	2,79	/	/	FK	
13 50	1,9	2,22	/	/	FK	
10/4-13 14:20	1,56	1,59	1,52	1,73	SEK.	
14:50	1,34	1,39	1,29	1,39	SEK	
15:20	1,19	1,28	1,12	1,12	SEK	
15:54	1,07	1,16	0.97	0.85	SEK	
16:20	1,02	1,13	0.91	0.75	SEK	
16:50	0,83	1,14	0.83	0.38	SEK	Pumper stoppe sikring ergael
17:18	1,09	1,08	0.73	0.70	SEK.	Pumpe startet igen.
17:51	0.96	1,03	0,78	0.61	SEK	
18:24	0.90	0,98	0,72	0,48	SEK	
18:53	0.86	0.94	0,65	0,42	SEK.	
~~D8~~ 19:20	0,84	0,92	0,62	0,27	SEK.	
19:50	0,79	0,90	0,60	0,32	SEK	
20:15	0,77	0,87	0,57	0,30	SEK	Stop pump → [illegible]
20:51	0,80	0,92	0,53	0,15	SEK	
21:21	0,71	0,85	0,52	0,13	SEK	
21:52	0,66	0,79	0,65	0,17	SEK	
22:20	0,65	0,98	0,75	0,17	SEK	

Signature: 10/4-2013 SEK

Date & time	Water flow (m^3/h)	Pressure (bar)	Gas flow (L/min)	Initials
10/4-13 22:33	128,40	1,43	1,4	SEh

Signature: 10/4-2013 SEh

Date & time	Water flow (m^3/h)	Pressure (bar)	Gas flow (L/min)	Initials	
10.49	88,6	5,96	148	RK	
1120	117,3	6,91	151,3	RK	
1150	122,56	7,33	145,1	RK	
1220	124,07	7,61	141,4	RK	
1250	124,07	7,53	144,6	RK	
1320	125,24	7,46	147,8	RK	
1350	123,7	7,53	150,4	RK	
10/4-13 14:20	127,66	7,46	149,2	SEh	
14:50	125,88	7,56	149,7	SEh	
15:20	127,98	7,43	153,8	SEh	
15:57	125,91	7,54	148,5	SEh	
16:20	126,82	7,43	150,0	SEh	
16:50	0.00	0,49	173,6	SEh	Pumpe stoppe sikringergåe
17:18	119,39	6,91	153,8	SEh	Pumpestart ig
17:51	122,01	6,83	153,7	SEh	
18:24	119,42	6,89	152,8	SEh	
18:53	118,98	6,86	155,7	SEh	
19:20	121,03	6,84	153,9	SEh	
19:50	122,55	6,82	155,6	SEh	
20:15	121,80	6,82	154,3	SEh	stop pumpe nedkøling.
20:51	131,85	6,53	~~1,8~~ ~~15~~ 1,8	SEh	
21:21	131,0	5,75	4,0	SEh	
21:52	130,42	5,69	1,5	SEh	
22:20	131,40	5,91	202,4	SEh	Satte gas til for at lave turbul i tank såled at den holde luft for neden blandes i tank

Signature: 10/4-2013 SEh

Date & time	Volume of water above set temperature (m^3)	Oxygen in N_2 flow (%)	Initials
10/4-13	920/71°C	2,3	SEh

Signature: 10/4-2013 SEh

Date & time	Volume of water above set temperature (m^3)	Oxygen in N_2 flow (%)	Initials
1049	/	2,0	FK
1120	/	2,0	FK
1150	/	2,1	FK
1220	/	2,1	FK
1250	/	2,1	FK
1320	/	2,1	FK
1350	/	2,1	FK
10/4-13 14:50	475 / 71°C	2.1	SEh.
15:20	530 / 71°C	2,1	SEh
15:57	608 / 71°C	2.1	SEh
16:20	654 / 71°C	2.2	SEh
16:50	615 / 71°C	2,2	SEh
17:18	615 / 71°C	2,1	SEh
17:51	661 / 71°C	2,1	SEh
18:24	728 / 71°C	2,1	SEh
18:53	785 / 71°C	2,1	SEh.
19:20	838 / 71°C	2,1	SEh
19:50	890 / 71°C	2,2	SEh
20:15	947 / 71°C	2,1	SEh
20:51	955 / 71°C	2,0	SEh
21:21	920 / 71°C	4,0	SEh
21:52	920 / 71°C	9,0	SEh
22:20	920 / 71°C	3,6	SEh.

Stop pumpe
Start Nedkalim.

696 m^3
615 -"-
81 m^3

STOP 16.22
Σ 696
START 17.30

Signature:
10/4-2013 SEh

Date & time	Temperature #1 (°C)	Temperature #2 (°C)	Temperature #3 (°C)	Temperature #4 (°C)	Initials
10/4-13	12,0	34,4	19,4	4,0	SEh

Signature: 10/4-2013 / SEh

Date & time	Temperature #1 (°C)	Temperature #2 (°C)	Temperature #3 (°C)	Temperature #4 (°C)	Initials	
1049	11,1	72,9	3,8	68,7	RK	
1120	15,8	71,8	5,6	70,0	RK	
1150	16,7	74,6	8,4	72,8	RK	
1220	19,6	73,6	11,2	71,5	RK	
1250	21,1	72,7	13,7	70,8	RK	
1320	22,9	72,7	15,9	72,5	RK	
1350	24,9	73,6	18,3	72,2	RK	
14:20						
10/4 14:50	28,8	74,2	22,8	72,5	SEK	
15:20	30,4	75,3	24,7	72,3	SEK	
15:57	32,3	75,0	27,1	72,0	SEK	
16:20	33,5	74,5	28,4	73,8	SEK	
16:50	40,6	73,9	50,0	62,9	SEK	Pumpe stoppet siktning er gått
17:18	32,2	51,1	30,2	47,8	SEK.	pumpe start igen
17:57	36,3	75,1	31,3	73,9	SEK.	
18:24	37,6	74,9	33,0	73,8	SEK	
18:53	38,5	74,9	34,3	73,6	SEK.	
19:21	39,5	75,2	35,5	73,4	SEK.	
19:50	40,7	75,4	36,8	73,7	SEK	
20:15	41,4	75,2	37,9	73,3	SEK.	start vedholm -
20:51	33,6	56,6	37,0	4,1	SEK.	
21:21	32,0	48,3	35,7	3,7	SEK.	
21:52	27,3	41,7	29,6	3,8	SEK.	
22:20	21,2	36,5	24,4	3,9	SEK.	

Signature: 10/4-2013 SEK

Date & time	Dis. O_2 DO 0 (mg/L)	Dis. O_2 DO 1 (mg/L)	Dis. O_2 DO 2 (mg/L)	Dis. O_2 DO 3 (mg/L)	Initials
23/4-2013 9 50	11,57	12,07	12,86	13,89	SEh
" 10 20	9,32	8,83	9,85	12,27	SEh.
" 10 50	6,18	6,00	6,70	8,45	SEh
" 11 20	4,24	4,19	4,51	5,85	SEh
" 11 52	2,96	2,99	3,10	4,14	SEh
" 12 20	2,27	2,29	2,26	3,21	SEh
" 12 51	1,79	1,83	1,73	2,51	SEh
" 13 20	1,51	1,56	1,44	2,09	SEh
" 13 50	1,30	1,36	1,18	1,74	SEh
" 14 23	1,16	1,21	1,00	1,40	SEh
" 14 50	1,08	1,13	0,88	1,17	SEh
" 15 21	1,01	1,06	0,79	1,02	SEh
" 15:52	0,95	0,99	0,68	0,98	SEh
" 16:20	0,90	0,95	0,64	0,72	SEh
" 16:50	0,86	0,91	0,59	0,71	SEh
" 17:20	0,82	0,88	0,56	0,53	SEh
" 17:50	0,77	0,85	0,52	0,55	SEh
" 18:00	0,77	0,83	0,52	0,50	SEh
" 18:05	0,76	0,89	0,51	0,54	SEh
" 18:20	0,81	0,96	0,57	0,60	SEh
" 18:50	0,90	1,06	0,66	0,66	SEh
" 19:20	0,99	1,16	0,83	0,92	SEh
" 19:50	1,10	1,24	0,95	1,35	SEh
" 20:20	1,11	1,14	0,93	0,69	SEh

START 9:50.

18:02 STOP pumpe
18:04 START nedkoling.

1. START - :

238 m^3 h = 5,19 m

A = 45,85

23/4-2013

Signature: Susanne Klem

Date & time	Dis. O_2 DO 0 (mg/L)	Dis. O_2 DO 1 (mg/L)	Dis. O_2 DO 2 (mg/L)	Dis. O_2 DO 3 (mg/L)	Initials
23/4-13 20:50	1,05	1,08	0,92	0,72	SEK
23/4-13 20:58	1,04	1,07	0,96	0,72	SEK

Signature: Susanne Klem

START 9:50

Date & time	Water flow (m^3/h)	Pressure (bar)	Gas flow (L/min)	Initials
23/4-13 9 50	124,06	7,53	154,7	SEK
" 10 22	118,84	6,93	143,2	SEK
" 10 50	119,53	6,89	141,7	SEK
" 11 20	127,53	7,45	153,5	SEK
" 11 52	126,90	7,52	147,1	SEK
" 12 20	126,03	7,44	150,3	SEK
" 12 51	125,11	7,51	147,0	SEK
" 13 20	127,46	7,50	146,6	SEK
" 13 50	127,70	7,45	147,3	SEK
" 14 23	126,82	7,44	152,3	SEK
" 14 50	127,63	7,38	150,3	SEK
" 15 21	126,37	7,48	146,1	SEK
" 15:52	127,26	7,42	146,6	SEK
" 16:20	126,05	7,45	144,9	SEK
" 16:50	126,03	7,45	146,1	SEK
" 17:20	128,36	7,41	149,0	SEK
" 17:50	127,95	7,44	146,3	SEK
" 18:00	127,64	7,42	147,1	SEK
" 18:05	147,83	6,73	183,4	SEK
" 18:20	149,03	6,76	188,7	SEK
" 18:50	146,93	6,68	194,6	SEK
" 19:20	146,90	6,71	192,2	SEK
" 19:50	145,92	6,75	189,4	SEK
" 20:20	147,94	6,70	2,0	SEK.

Signature: Susanne K

Date & time	Water flow (m^3/h)	Pressure (bar)	Gas flow (L/min)	Initials
23/4-13 20:50	149,10	6,51	1,8	SEK
23/4-13 20:58	147,89	6,58	1,8	SEK

Signature: SUSannKlen

Date & time	Volume of water above set temperature (m^3)	Oxygen in N_2 flow (%)	Initials
START 23/4-13 9:50	0 / 71°C	1,4	SEK
" 10:20	7 / 71°C	2,1	SEK
" 10:50	58 / 71°C	1,6	SEK
" 11:20	118 / 71°C	2,1	SEK
" 11:52	183 / 71°C	2,1	SEK
" 12:20	243 / 71°C	2,1	SEK
" 12:51	307 / 71°C	2,1	SEK
" 13:20	367 / 71°C	2,1	SEK
" 13:50	431 / 71°C	2,0	SEK
" 14:23	500 / 71°C	2,0	SEK
" 14:50	554 / 71°C	2,1	SEK
" 15:21	621 / 71°C	2,0	SEK
" 15:52	684 / 71°C	2,1	SEK
" 16:20	743 / 71°C	2,0	SEK
" 16:50	807 / 71°C	2,1	SEK
" 17:20	868 / 71°C	2,1	SEK
" 17:50	932 / 71°C	2,1	SEK
" 18:00	953 / 71°C	2,1	SEK
" 18:05	955 / 71°C	2,0	SEK
" 18:20	955 / 71°C	2,0	SEK
" 18:50	955 / 71°C	2,0	SEK
" 19:20	955 / 71°C	2,1	SEK
" 19:50	955 / 71°C	2,1	SEK
" 20:20	955 / 71°C	2,2	SEK

Signature: Susanne Klem

Date & time	Volume of water above set temperature (m^3)	Oxygen in N_2 flow (%)	Initials
23/4-13 20:50	955/ 71°C	2,1	SEh
20:58	955/ 71°C	2,1	SEh

Signature: Susanne Klem

START

Date & time	Temperature #1 (°C)	Temperature #2 (°C)	Temperature #3 (°C)	Temperature #4 (°C)	Initials
23/4-13 9:50	9,3	12,8	7,9	12,8	SEh
" 10:20	18,5	72,1	8,8	69,9	SEh.
" 10:50	21,0	72,2	11,3	72,0	SEh
" 11:20	23,4	73,2	14,0	72,0	SEh
" 11:52	25,4	72,1	16,6	72,1	SEh.
" 12:20	27,1	73,4	18,8	71,7	SEh.
" 12:51	29,2	73,6	21,1	72,4	SEh.
" 13:20	30,2	72,6	23,2	71,3	SEh
" 13:50	32,4	73,6	25,3	72,4	SEh
" 14:23	34,3	73,8	27,4	72,2	SEh
" 14:50	35,8	73,9	29,0	72,5	SEh.
" 15:21	37,0	73,3	30,9	72,2	SEh
" 15:52	38,4	72,9	32,6	71,3	SEh
" 16:20	39,7	73,4	34,0	72,2	SEh
" 16:50	40,9	73,0	35,5	72,2	SEh
" 17:20	42,2	73,8	36,9	72,8	SEh.
" 17:50	43,2	73,2	38,3	71,9	SEh
" 18:00	43,7	73,7	38,8	72,3	SEh
" 18:05	41,4	82,2	38,9	25,6	SEh
" 18:20	36,2	73,2	37,6	8,9	SEh
" 18:50	31,3	61,2	32,4	8,7	SEh
" 19:20	26,8	52,8	27,7	8,6	SEh
" 19:50	23,1	46,1	23,8	8,4	SEh
" 20:20	21,6	40,7	22,4	8,3	SEh.

Stoppet 18:02
Pumpe
START Nedkoly
kl: 18:04.

Signature: Susanne Klem

Date & time	Temperature #1 (°C)	Temperature #2 (°C)	Temperature #3 (°C)	Temperature #4 (°C)	Initials
23/4-2013 20:52	18,7	36,1	19,3	8,1	SEK
20:58	18.0	34,6	18,7	8,1	SEK

Ved kørning slut pumpe stop fejl.

Signature: Susanne Klyn

Date & time	Dis. O_2 DO 0 (mg/L)	Dis. O_2 DO 1 (mg/L)	Dis. O_2 DO 2 (mg/L)	Dis. O_2 DO 3 (mg/L)	Initials
30/4/13 10.46	9,99	9,27	10,24	12,9	MBJ
11.25	4,73	4,50	4,9	6,54	MBJ
12.30	2,33	2,25	2,26	3,19	MBJ
13.26	1,50	1,50	1,38	1,97	MBJ
14.25	1,43	1,55	1,28	1,57	MBJ
15.25	1,08	1,04	0,81	0,97	MBJ
16.25	0,87	0,87	0,63	0,64	MBJ
17.25	0,75	0,77	0,49	0,58	MBJ
18.25	0,69	0,70	0,41	0,55	MBJ
19.25	0,62	0,72	0,42	0,55	MBJ
20.05	0,67	0,73	0,43	0,54	MBJ
20.15	0,68	0,82	0,50	0,53	MBJ
21.19	0,64	0,67	0,41	0,64	MBJ
22.15	0,52	0,56	0,40	0,72	MBJ
22.48	0,47	0,53	0,41	0,77	MBJ
22.55	0,46	0,54	0,45	0,58	MBJ

holding sight

Signature: 30/4/13

Date & time	Water flow (m^3/h)	Pressure (bar)	Gas flow (L/min)	Initials	
30/4/13 10.26	114,34	5,90	151,5	MBJ	
11.15	125,05	7,53	147,3	MBJ	
12.30	128,79	7,49	147,4	MBJ	
13.26	125,54	7,49	145,5	MBJ	
14.25	129,36	7,44	151,4	MBJ	
15.25	126,78	7,47	148,2	MBJ	
16.25	126,15	7,45	149,1	MBJ	
17.25	128,31	7,42	149,1	MBJ	
18.25	130,01	7,33	149,1	MBJ	
19.25	127,09	7,91	151,1	MBJ	
20.05	~~77,~~	—	173,8	MBJ	HOLDING START
20.15	149,35	6,68	110,7	MBJ	
21.17	148,70	6,68	1,7	MBJ	
22.15	149,05	6,64	1,6	MBJ	
22.48	145,51	6,71	1,6	MBJ	
22.55	142,89	6,70	1,5	MBJ	

Signature: 30/4/13

Date & time	Volume of water above set temperature (m^3)	Oxygen in N_2 flow (%)	Initials	
30/4/13 10.26	7	2,0	MBJ	
11.25	121	2,0	MBJ	
12.30	256	2,1	MBJ	
13.26	374	2,1	MBJ	
14.25	498	2,6	MBJ	14.15 ~~[illegible]~~ Start Stop Modified Ladestrom
15.25	621	2.0	MBJ	
16.25	746	2.0	MBJ	
17.25	876	2.0	MBJ	
18.25	998	2,0	MBJ	
19.25	1129	2,0	MBJ	
20.05	1212	2,1	MBJ	Kiling Start
20.15	1212	2,1	MBJ	
21.19	1212	3,7	MBJ	
22.15	1212	8,5	MBJ	
22.48	1212	10,4	MBJ	
22.55	1212	101,7	MBJ	

Signature: 30/4/13

Date & time	Temperature #1 (°C)	Temperature #2 (°C)	Temperature #3 (°C)	Temperature #4 (°C)	Initials	
30/4/13 10.26	18,7	72,5	9,5	71,2	MBJ	
11.25	23,4	72,7	14,5	71,3	MBJ	
12.30	27,6	73,3	19,6	72,5	MBJ	
13.26	31,4	73,4	23,7	72,9	MBJ	
14.25	34,1	73,2	27,6	72,2	MBJ	
15.25	37,1	72,5	31,1	72,5	MBJ	
16.25	39,7	73,4	34,3	72,1	MBJ	
17.25	42,2	73,4	37,4	72,7	MBJ	
18.25	44	73,4	40	72,3	MBJ	
19.25	46,1	71,9	42,5	71,8	MBJ	
20.05	46,9	70,6	43,8	71,2	MBJ	HOLDING STEADY
20.15	41,5	64,1	43,7	9,4	MBJ	
21.19	33	47,1	34,9	8,9	MBJ	
22.15	23,5	36,1	24,5	8,7	MBJ	
22.48	19,8	30,9	20,9	8,6	MBJ	
22.55	19,2	29,7	20	8,5	MBJ	

Signature: 30/4/13

Date & time	Temperature #1 (°C)	Temperature #2 (°C)	Temperature #3 (°C)	Temperature #4 (°C)	Initials
1350	35,4	73,3	29,5	71,7	CAH
1450	38,6	73,2	32,8	71,6	CAH
1550	41,3	73,0	36,1	71,8	CAH
1650	~~39,7~~ 43,8	73,6	39,0	72,3	CAH
1750	46,0	71,7	41,7	71,5	CAH
1850	47,9	73,4	44,2	71,4	CAH
1952	49,7	79,3	46,4	70,9	CAH
2050	40,6	63,2	42,3	12,4	CAH
2150	27,6	47,7	28,3	11,8	CAH
2250	21,1	~~19,6~~ 38,0	21,8	11,6	CAH
2309	19,9	35,9	20,3	11,4	CAH

Signature:

O_2 Måler kalib til 21.090 i atm luft 945

Date & time	Dis. O_2 DO 0 (mg/L)	Dis. O_2 DO 1 (mg/L)	Dis. O_2 DO 2 (mg/L)	Dis. O_2 DO 3 (mg/L)	Initials
8.05.2013 950	~~12.01~~ 11.05	11.56	11.97	13.57	PK
1050	4,85	4,87	5,09	6,96	PK
1150	2,01	2,09	1,98	3,08	PK
1250	1,19	1,31	1,04	1,74	PK
1350	0,95	1,06	0,76	1,28	CAH
1450	0,86	0,93	0,58	0,96	CAH
1550	0,75	0,83	0,47	0,61	CAH
1650	0,67	0,71	0,31	0,58	CAH
1750	0,61	0,67	0,27	0,55	CAH
1850	0,57	0,67	0,32	0,54	CAH
1952	0,56	0,61	0,33	0,59	CAH
2050	0,56	0,53	0,08	0,61	CAH
2150	0,43	0,46	0,22	0,71	CAH
2250	0,35	0,40	0,26	0,79	CAH
23.09	0,32	0,37	0,28	0,80	CAH

900 – 930 tappet 6,5 m^3 af tk C_2 tankkoeln 235,1 m^3

Stop 23.10 (nedkøling

Signature:

Date & time	Water flow (m^3/h)	Pressure (bar)	Gas flow (L/min)	Initials
8.5.2013 11^{50}	127,7	7,37	156,9	RK
12^{50}	128,18	7,57	149,14	RK
13^{50}	108,23	5,68	153,6	CAH
14^{50}	130,00	7,42	160,1	CAH
15^{50}	128,98	7,45	158,7	CAH
16^{50}	127,86	7,46	153,1	CAH
17^{50}	129,74	7,44	154,6	CAH
18^{50}	127,17	7,47	154,2	CAH
19^{52}	128,49	7,37	155,8	CAH
20^{50}	148,48	6,61	2,4	CAH
21^{50}	147,39	6,65	2,3	CAH
22^{50}	148,00	6,61	2,1	CAH
23^{09}	147,96	6,57	2,1	CAH

Signature:

Date & time	Volume of water above set temperature (m^3)	Oxygen in N_2 flow (%)	Initials
8.5. 1150	204 m3 71°C	2,0%	RK
1250	320 °/71°C	2.0%	RK
1350	424 71°C	2,1%	CAH
1450	540 71°C	2,1%	CAH
1550	666 71°C	2,1%	CAH
1650	790 71°C	2,0%	CAH
1750	917 71°C	2,1%	CAH
1850	1045 71°C	2,1%	CAH
1952	1175 71°C	2,1%	CAH
2050	1176 71°C	2,6%	CAH
2150	"	9,6%	CAH
2250	"	12,3%	CAH
2309	"	12,6	CAH

Signature:

Start 10.04
Slut 20.~~34~~35 1157 m³

Date & time	Water flow (m³/h)	Pressure (bar)	Gas flow (L/min)	Initials
28/5-13 10.06	102,11	5,87	155,01	CAH
28/5-13 11.06	118,10	7,67	147,8	CAH
" 12.06	117,86	7,68	147,1	CAH
" 13.06	118,26	7,67	151,3	CAH
" 14.06	119,73	7,62	153,2	CAH
" 15.06	119,85	7,62	145,9	CAH
" 16.06	119,75	7,61	153,0	CAH
" 17.06	118,43	7,65	149,9	CAH
" 18.06	119,36	7,57	148,5	CAH
" 19.06	117,95	7,61	148,1	CAH
" 20.06	117,91	7,63	151,5	CAH
" 20.34	118,0	7,51	153,1	CAH

5 × 233 m³

Signature:

Date & time	Volume of water above set temperature (m^3)	Oxygen in N_2 flow (%)	Initials
28/5-13 10.06	0 m^3	1,9	CAH
" 11.06	64	2,0	CAH
" 12.06	167	2,0	CAH
" 13.06	284	2,0	CAH
" 14.06	401	2,0	CAH
" 15.06	519	2,1	CAH
" 16.06	634	2,0	CAH
" 17.06	754	2,0	CAH
" 18.06	864 ~~8674~~	~~2,0~~ 2,1	CAH
" 19.06	983	2,0	CAH
" 20.06	1100	2,0	CAH
" 20.34	1155	2,0	CAH

Signature:

Date & time	Temperature #1 (°C)	Temperature #2 (°C)	Temperature #3 (°C)	Temperature #4 (°C)	Initials
28/5-13 10.06	17.0	24.0	15.1	23.5	CAH
" 11.06	24.1	63.9	17.2	60.9	CAH
" 12.06	27.4	73.1	19.4	71.8	CAH
" 13.06	28.9	73.7	21.3	72.5	CAH
" 14.06	30.1	71.1	22.7	70.3	CAH
" 15.06	31.3	71.8	23.8	71.1	CAH
" 16.06	31.9	71.8	24.7	72.7	CAH
" 17.06	32.2	72.6	25.3	71.9	CAH
" 18.06	32.6	73.5	25.6	72.2	CAH
" 19.06	33.2	73.0	26.0	72.3	CAH
" 20.06	33.5	72.9	26.4	72.2	CAH
" 20.34	33.7	73.0	26.5	72.2	CAH

Signature:

Date & time	Dis. O_2 DO 0 (mg/L)	Dis. O_2 DO 1 (mg/L)	Dis. O_2 DO 2 (mg/L)	Dis. O_2 DO 3 (mg/L)	Initials
28/15-13 10.06	9,86	10,29	10.57	12,58	GAH
" 11.06	4,28	4,27	4,48	6,10	GAH
" 12.06	1,99	2,12	2,10	3,28	GAH
" 13.06	1,31	1,47	1,36	2,40	GAH
" 14.06	1,09	1,28	1,13	2,08	GAH
" 15.06	1,02	1,20	1,03	1,94	GAH
" 16.06	0,97	1,17	0,97	1,89	GAH
" 17.06	0,95	1,15	0,94	1,80	GAH
" 18.06	0,91	1,12	0,89	1,72	GAH
" 19.06	0,87	1,10	0,85	1,62	GAH
" 20.06	0,84	1,07	0,84	1,50	GAH
" 20.34	0,83	1,07	0,79	1,38	GAH

Signature:

DHI

Date & time	Water flow (m^3/h)	Pressure (bar)	Gas flow (L/min)	Initials
4/6/13 10.25	99,80	5,87	151,2	MBJ
11.10	100,03	5,86	149,7	MBJ
12.10	112,97	7,69	152,7	MBJ
13.10	112,95	7,62	151,1	MBJ
14.05	112,60	7,63	151,9	MBJ
15.12	119	7,63	154,6	MBJ
16.10	112,09	7,71	149,6	MBJ
17.15	118,87	7,62	154,2	MBJ
18.10	112,34	7,66	148,5	MBJ
19.05	112,51	7,64	152,5	MBJ
20.10	116,91	7,68	149,1	MBJ
21.10	119,22	7,64	155,4	MBJ
21.37	117,62	7,68	148,3	MBJ

STARTET FORPRO

AFBRUDT CA. 10.40 PGA. VENTIL DER BLEV SLUDT UD VED INDTAG TIL VAM MOVERSION FRA TK. C2.

11:30 Prøve til Pestan

Signature:

Date & time	Volume of water above set temperature (m^3)	Oxygen in N_2 flow (%)	Initials
4/6/13 10.25	4	1,6	MBJ
11.10	0	1,7	MBJ
12.10	98	1,9	MBJ
13.10	215	2,1	MBJ
14.05	323	2,1	MBJ
15.12	453	2,0	MBJ
16.10	564	2,0	MBJ
17.15	690	2,0	MBJ
18.10	798	2,1	MBJ
19.05	898	2,1	MBJ
20.10	1021	2,0	MBJ
21.10	1140	2,0	MBJ
21.33	~~11.80~~ 1182	2,0	MBJ

STAMPED FUNFND

Signature:

STORM FUNN

Date & time	Temperature #1 (°C)	Temperature #2 (°C)	Temperature #3 (°C)	Temperature #4 (°C)	Initials
4/11/13 10.25	25,9	70,5	16,2	72,3	MBJ
11.10	24,8	65,1	16,3	60,4	MBJ
12.10	28,2	72,8	19	71,1	MBJ
13.10	30,1	73,2	21	72,4	MBJ
14.05	31,12	73,5	22,5	72,8	MBJ
15.12	32	73,5	23,8	72,3	MBJ
16.10	32,7	72,9	24,7	71,5	MBJ
17.15	33,5	71,7	25,4	72,6	MBJ
18.10	33,9	73,1	26,0	72,7	MBJ
19.05	34,2	73,1	26,4	72,2	MBJ
20.10	34,5	72	26,8	71,7	MBJ
21.16	34,5	71,8	27	71,6	MBJ
21.33	34,7	73,1	27,1	72,4	MBJ

Signature:

Station Form

Date & time	Dis. O_2 DO 0 (mg/L)	Dis. O_2 DO 1 (mg/L)	Dis. O_2 DO 2 (mg/L)	Dis. O_2 DO 3 (mg/L)	Initials
26 03 10.15	7,77	7,73	8,49	10,74	MBJ
11.10	6,90	6,91	6,67	8,39	MBJ
12.10	2,96	2,90	2,97	4,31	MBJ
13.10	1,03	1,71	1,59	2,62	MBJ
14.05	1,27	1,38	1,22	2,16	MBJ
15.12	1,09	1,21	1,01	1,85	MBJ
16.10	1,05	1,16	0,92	1,72	MBJ
17.15	1,01	1,11	0,82	1,52	MBJ
18.10	0,99	1,09	0,79	1,37	MBJ
19.05	0,97	1,04	0,71	1,15	MBJ
20.10	0,95	0,99	0,69	0,99	MBJ
21.10	0,92	0,90	0,49	0,82	MBJ
21.33	0,92	0,94	0,58	1,00	MBJ

Signature:

Start 9.53

237 m³ x 5 = 1185 m³

Date & time	Water flow (m³/h)	Pressure (bar)	Gas flow (L/min) A	Initials
18/6 9.50	0,21	0,49	63,1	CAH
18/6 10.53	117,81	7,69	150,4	PBR.
18/6 11.53	117,91	7,64	153,3	PBR.
18/6 12:53	117,36	7,59	152,0	PBR.
18/6 13:53	117,20	7,66	142,5	PBR
18/6 14:53	117,31	7,62	158,5	PBR.
18/6 15:53	117,16	7,65	154,8	PBR.
18/6 16:53	118,02	7,61	160,4	PBR.
18/6 17:53	116,42	7,65	149,7	PBR.
18/6 18:53	118,4	7,62	154,7	PBR.
18/6 19:53	116,87	7,60	151,8	PBR
18/6 20:26	116,68	7,63	152,9	PBR

Signature:

Pas. status

O.Guard

Date & time	Volume of water above set temperature (m^3)	Oxygen in N_2 flow (%)	Initials
18/6 9.50	0 m^3	20,9	GAH
18/6 10:53	80 m^3	1,8	PBR
18/6 11.53	197	2,0	PBR
18/6 12:53	310	2,1	PBR
18/6 13:53	426	2,1	PBR.
18/6 14:53	543	2,1	PBR
18/6 15:53	659	2,1	PBR
18/6 16:53	774	2,1	PBR
18/6 17:53	890	2,1	PBR.
18/6 18:53	1006	2,1	PBR.
18/6 19:53	1122	2,1	PBR
18/6 20:26	1186	2,1	PBR

Signature:

Date & time	Temperature #1 (°C)	Temperature #2 (°C)	Temperature #3 (°C)	Temperature #4 (°C)	Initials
18/6 9.50	20,9	20,1	17,9	18,4	CAH
18/6 10:53	29,0	73,5	18,9	79,9	PBR
18/6 11:53	31,2	72,9	21,4	72,3	PBR
18/6 12:53	32,5	73,1	23,2	72,4	PBR
18/6 13:53	33,7	73,4	24,6	72,9	PBR
18/6 14:53	34,3	72,3	25,6	72,0	PBR
18/6 15:53	34,9	72,0	26,5	71,4	PBR
18/6 16:53	35,5	71,6	27,1	71,3	PBR
18/6 17:53	35,8	71,9	27,6	71,5	PBR
18/6 18:53	36,2	72,1	28,0	71,7	PBR
18/6 19:53	36,5	72,2	28,3	71,9	PBR
18/6 20:26	36,7	72,2	28,4	72,0	PBR

Signature:

Date & time	Dis. O_2 DO 0 (mg/L)	Dis. O_2 DO 1 (mg/L)	Dis. O_2 DO 2 (mg/L)	Dis. O_2 DO 3 (mg/L)	Initials
18/6 9.50	0,00	10,39	10,05	11,98	GH
18/6 10:53	3,95	4,00	4,11	18,70	PBR
18/6 11:53	1,71	1,87	1,78	2,60	PBR
18/6 12:53	1,12	1,31	1,14	1,69	PBR
18/6 13:53	0,96	1,16	0,93	1,27	PBR
18/6 14:53	0,90	1,10	0,84	0,91	PBR
18/6 15:53	0,88	1,07	0,78	0,73	PBR
18/6 16:53	0,87	1,04	0,62	0,71	PBR
18/6 17:53	0,86	1,02	0,58	0,70	PBR
18/6 18:53	0,84	0,97	0,46	0,70	PBR
18/6 19:53	0,82	0,92	0,39	0,69	PBR
18/6 20:26	0,81	0,89	0,33	~~0,89~~ Fail	PBR
18/6 20:26	—	—	—	shut valve 0,69	PBR

Signature:

Date & time	Water flow (m^3/h)	Pressure (bar)	Gas flow (L/min)	Initials
25-06-13 10:10	100.61	5.84	154.3	G.P.
25-06-13 11:10	116.56	7.70	151.8	G.P
25-06-13 12:10	119.08	7.61	154.1	G.P
25.06.13 13:10	116.33	7.67	152.6	G.P
25.06.13 14:10	116.76	7.66	151.0	G.P
25.06.13 15:08	117.58	7.66	151.5	G.P
25.06.13 16:10	116.70	7.66	149.6	G.P
25.06.13 17:10	116.54	7.68	152.0	G.P
25.06.13 18:10	116.58	7.62	154.5	G.P
25.06.13 19:10	117.00	7.64	152.9	G.P
25.06.13 20:10	118.12	7.63	154.0	G.P
25.06.13 20:40	116.13	7.69	151.9	G.P

Total 242 m^3

5 x 242 = 1210 m^3

Signature:

Date & time	Volume of water above set temperature (m^3)	Oxygen in N_2 flow (%)	Initials
25-06-13 10:10	0	1.9	G.P
25-06-13 11:10	102	2.1	G.P
25.06.13 12:10	206	2.0	G.P
25.06.13 13:10	324	2.0	G.P
25.06.13 14:10	440	2.0	G.P
25.06.13. 15:09	552	2.0	G.P
25.06.13 16:10	670	2.2	G.P
25.06.13 17:10	789	2.2	G.P
25.06.13 18:10	904	2.0	G.P
25.06.13 19:10	1018	2.1	G.P
25.06.13 20:10	1132	2.1	G.P
25.06.13 20:40	1192	2.1	G.P

Signature:

Date & time	Temperature #1 (°C)	Temperature #2 (°C)	Temperature #3 (°C)	Temperature #4 (°C)	Initials
25.06.13 10:10	26,2	69,7	17,6	67,3	G.P.
25.06.13 11:10	29,4	72,2	19,9	71,7	G.P
25.06.13 12:10	31,2	72,5	22,0	72,0	G.P
25.06.13 13:10	32,6	72,0	23,7	71,6	G.P
25.06.13 14:10	34,0	72,3	25,5	71,8	G.P
25.06.13 15:09	34,9	72,1	26,6	71,7	G.P
25.06.13 16:10	35,2	72,1	27,1	71,7	G.P
25.06.13 17:10	35,7	72,0	27,6	71,6	G.P
25.06.13 18:10	35,8	71,8	27,9	71,3	G.P
25.06.13 19:10	36,1	71,8	28,2	71,4	G.P
25.06.13 20:10	36,2	71,7	28,4	71,3	G.P
25.06.13 20:40	36,3	71,8	28,5	71,4	G.P

Signature:

Date & time	Dis. O_2 DO 0 (mg/L)	Dis. O_2 DO 1 (mg/L)	Dis. O_2 DO 2 (mg/L)	Dis. O_2 DO 3 (mg/L)	Initials
25.06.13 10:10	7.85	7.82	8.47	8.88	G.P
25.06.13 11:10	3.08	3.23	3.30	3.54	G.P
25.06.13 12:10	1.51	1.74	1.62	1.17	G.P.
25.06.13 13:10	1.01	1.26	1.05	0.80	G.P
25.06.13 14:10	0.86	1.11	0.80	0.74	G.P
25.06.13 15:09	0.80	1.06	0.73	0.73	G.P.
25.06.13 16:10	0.86	1.13	0.64	0.72	G.P
25.06.13 17:10	0.88	1.12	0.62	0.72	G.P.
25.06.13 18:10	0.83	1.02	0.47	0.71	G.P
25.06.13 19:10	0.80	0.97	0.33	0.71	G.P.
25.06.13 20:10	0.78	0.93	0.33	0.71	G.P
25.06.13 20:40	0.76	0.83	0.08	0.71	G.P

Signature:

Start 10.00

Date & time	Water flow (m^3/h)	Pressure (bar)	Gas flow (L/min)	Initials
6/8-13 10.07	102.88	5.77	188.2	CAH
6/8-13 10.30	STOP PCB	1 ACHAGE		MBJ
10.36	122,93	7,54	152,4	MBJ
11.43 ~~11.36~~	122	7,61	150,02	MBJ
12.40	120,65	7,54	149,7	MBJ
13.46	119,79	7,52	150,9	MBJ
14.35	118,82	7,52	148,8	MBJ
15.42	121,01	7,59	149,7	MBJ
16.34	118,9	7,58	149,8	MBJ
17.30	119,69	7,58	146,8	MBJ
18.31	119,66	7,52	152,6	MBJ
19.35	121,10	7,54	154,4	MBJ
20.25	119,57	7,50	153,9	MBJ
20.32	118,95	7,55	151,1	MBJ

Oxygen ved start 20.9

Signature:

Date & time	Volume of water above set temperature (m^3)	Oxygen in N_2 flow (%)	Initials
6/8-13 10.07	0	3,4%	GAH
10.36	21	2,2	MBJ
11.43	135	2,0	MBJ
12.40	245	1,9	MBJ
13.46	376	2,0	MBJ
14.35	471	2,0	MBJ
15.42	603	2,0	MBJ
16.34	706	2,0	MBJ
17.30	815	2,0	MBJ
18.31	934	2,0	MBJ
19.35	1062	2,0	MBJ
20.35	1160	1,9	MBJ
20.32	1172	2,0	MBJ

Signature:

Date & time	Temperature #1 (°C)	Temperature #2 (°C)	Temperature #3 (°C)	Temperature #4 (°C)	Initials
6/8.13 10.07	22,3	31,1	21,5	25,2	CAH
10.36	29	60,5	21,9	61	MBJ
11.43	30,2	71,7	24,3	71,6	MBJ
12 40	31,6	72,2	25,9	71,9	MBJ
13 46	32,7	72,2	27,4	71,9	MBJ
14.35	33,5	71,7	28,4	71,2	MBJ
15.42	34,5	72,1	29,5	72	MB.
16.34	35,1	72,2	30,9	71,6	MBJ
17.30	36	71,7	31,3	71,9	MBJ
18.31	36,5	72,2	32,2	72	MB
19.35	37,4	72,2	33,3	72	MBJ
20.25	38	72,3	34,0	71,9	MBJ
20.32	38,1	71,8	34,0	72,1	MBJ

Signature:

Date & time	Dis. O_2 DO 0 (mg/L)	Dis. O_2 DO 1 (mg/L)	Dis. O_2 DO 2 (mg/L)	Dis. O_2 DO 3 (mg/L)	Initials
6/8-13 10.07	8.77	9.51	8.95	10.66	CAH
10.36	9,26	9,97	9,51	11,07	MBJ
11.43	6,9	6,25	6,49	8,69	MBJ
12.40	3,05	2,81	2,84	4,44	MBJ
13.46	1,56	1,54	1,43	2,54	MBJ
14.35	1,22	1,27	1,11	2,22	MBJ
15.42	1,07	1,13	0,94	2,05	MBJ
16.34	1,02	1,10	0,89	1,96	MBJ
17.30	0,99	1,08	0,85	1,87	MBJ
18.31	0,96	1,05	0,81	1,78	MBJ
19.35	0,90	1,00	0,74	1,55	MBJ
20.25	0,85	0,96	0,70	1,49	MBJ
20.32	0,85	0,96	0,69	1,54	MBJ

Signature:

ilt start 20,8

Date & time	Dis. O_2 DO 0 (mg/L)	Dis. O_2 DO 1 (mg/L)	Dis. O_2 DO 2 (mg/L)	Dis. O_2 DO 3 (mg/L)	Initials
13.08.2013 9.45	0.00	11.08	10.68	12.30	CAH
13.08.2013 10:45	6.85	6,83	7.00	9.08	SEK
" 11:45	4.04	4.12	4.17	5.74	SEK
12:45	2.59	2.72	2.66	3.96	SEK
" 13.45	1.92	2.06	1.95	3.08	CAH
14:45	1.55	1.73	1.56	2.56	SEK
15:45	1.38	1.56	1.38	2.19	SEK
16:45	1.28	1.48	1.25	1.89	SEK
17:45	1.21	1.42	1.18	1.56	SEK
18:45	1.18	1.39	1.11	1.31	SEK
19:45	1.14	1.36	1.05	0.89	SEK
20:01	1.13	1.35	1.04	0.88	SEK

Signature:

10.1.11

Date & time	Water flow (m^3/h)	Pressure (bar)	Gas flow (L/min)	Initials
13.08.2013 9.45	~~0.173.85~~	5.76	158.9	CAH
13.08.2013 10:45	118.13	7.54	148.0	SEK
" 11:45	118.15	7.52	153.2	SEK
" 12:45	120.35	7.46	152.3	SEK
" 13.45	118.02	7.49	153.5	CAH
14:45	120.31	7.43	154.9	SEK
15:45	119.38	7.45	154.7	SEK
16:45	118.30	7.50	154.0	SEK
17:45	117.90	7.51	152.3	SEK
18:45	118.79	7.52	152,7	SEK
19:45	118.28	7.50	152,8	SEK
20:01	120.78	7.45	155.7	SEK

Signature:

Date & time	Volume of water above set temperature (m^3)	Oxygen in N_2 flow (%)	Initials
13.08.2013 9:45	0	8.2	CAH
13.08.2013 10:45	81	1.9	SEK
" 11:45	195	2.0	SEK
" 12:45	317	2.0	SEK
" 13:45	432	2.0	CAH
" 14:45	553	2.0	SEK
" 15:45	667	2.0	SEK
" 16:45	782	2.0	SEK
" 17:45	901	2.0	SEK
18:45	1016	2.0	SEK
19:45	1135	2.0	SEK
20:01	1167	2.0	SEK

Signature:

Date & time	Temperature #1 (°C)	Temperature #2 (°C)	Temperature #3 (°C)	Temperature #4 (°C)	Initials
13.08.2013 9.45	19.5	17.2	18.6	12.7	CAH
13.08.2013 10:45	26.5	71.9	19.5	71.6	SEK
" 11:45	28.5	71.7	22.0	~~75~~ 71.3	SEK
" 12:45	30.2	71.8	24.0	71.5	SEK
" 13.45	31.1	72.1	25.5	71.8	CAH
" 14:45	32.6	72.1	26.8	72.0	SEK
" 15:45	33.1	72.3	27.7	71.8	SEK
" 16:45	33.8	71.7	28.6	71.7	SEK
17:45	34.4	71.9	29.3	71.5	SEK
18:45	34.8	71.9	29.9	71.6	SEK
19:45	35.0	72.0	30.3	71.9	SEK
20:01	35.3	68.5	30.4	71.3	SEK

Signature:

Start pumpe kl. 9.24

Date & time	Dis. O_2 DO 0 (mg/L)	Dis. O_2 DO 1 (mg/L)	Dis. O_2 DO 2 (mg/L)	Dis. O_2 DO 3 (mg/L)	Initials
20/8-13 9.23	0.00	11.06	10.63	12.03	CAH
" 10.23	7.22	7.35	7.55	9.43	CAH
11.16	4,42	4,69	4,71	6,05	MBJ
12.15	2,92	3,15	3,06	3,99	MBJ
13.16	2,13	2,34	2,19	2,64	MBJ
14.15	1,68	1,91	1,70	1,99	MBJ
15.14	1,45	1,68	1,46	1,53	MBJ
16.15	1,31	1,55	1,30	1,15	MBJ
17.15	1,22	1,48	1,21	1,12	MBJ
18.13	1,17	1,41	1,12	0,95	MBJ
19.15	1,12	1,34	1,05	0,81	MBJ
20.05	1,04	1,35	0,98	0,78	MBJ

234 m^3 +5

= 1170 m^3

Signature:

Date & time	Water flow (m^3/h)	Pressure (bar)	Gas flow (L/min)	Initials
20/8-13 9.23	0.13	0.48	70	GAH
" 10.23	117.79	7.58	150.5	GAH
11.16	117,97	7,52	154,8	MBJ
12.15	118,06	7,52	148,7	MBJ
13.16	118,42	7,52	149,5	MBJ
14.15	118,28	7,54	149,1	MBJ
15.14	119,72	7,58	148,5	MBJ
16.15	119,93	7,51	147,0	MBJ
17.15	118,98	7,52	148,3	MBJ
18.13	119,94	7,49	149,5	MBJ
19.15	119,8	7,51	150,6	MBJ
20.05	119,6	7,48	151,8	MBJ

Signature:

Date & time	Volume of water above set temperature (m^3)	Oxygen in N_2 flow (%)	Initials
20/8-13 9.23	0	3,4	CAH
10.23	23	1,9	CAH
11.17	133	2,1	MBJ
12.15	292	2,0	MBJ
13.16	363	2,0	MBJ
14.15	490	2,0	MBJ
15.14	594	2,1	MBJ
16.15	714	2,1	MBJ
17.15	831	2,1	MBJ
18.13	946	2,1	MBJ
19.15	1066	2,0	MBJ
20.05	1165	2,1	MBJ

Signature:

Date & time	Temperature #1 (°C)	Temperature #2 (°C)	Temperature #3 (°C)	Temperature #4 (°C)	Initials
2018-13 9.23	22.7	19.2	17.7	18.9	GAH
" 10.23	26.1	72.3	19.3	71.8	GAH
11.16	28,3	72,2	21,8	71,8	MBJ
12.15	30,2	72,5	23,4	72,1	MBJ
13.16	31,7	72,0	25,5	71,2	MBJ
14.15	32,9	72,2	27,0	71,7	MBJ
15.14	34,1	71,9	28,2	71,6	MBJ
16.15	35,1	71,8	29,4	71,4	MBJ
17.15	35,8	72,2	30,3	71,6	MBJ
18.13	36,4	72,3	31,0	71,7	MBJ
19.15	37,0	71,8	31,5	71,5	MBJ
20.05	37,2	71,8	31,9	71,5	MBJ

Signature:

Σ 234 m³
234 × 5 = 1170 m³

Date & time	Dis. O_2 DO 0 (mg/L)	Dis. O_2 DO 1 (mg/L)	Dis. O_2 DO 2 (mg/L)	Dis. O_2 DO 3 (mg/L)	Initials
03.09.2013 925	10,03	11,47	11,15	11,71	[illegible]
03.09.2013 1025	7,53	10,75	7,92	9,86	PBR
03.09.2013 1125	4,54	4,71	4,75	6,25	PBR
" 1225	2,94	13,14	3,08	4,27	PBR
" 1325	2,11	7,98	2,18	3,17	PBR
" 1425	1,66	2,08	1,70	2,53	PBR
" 1525	1,42	4,71	1,44	2,16	PBR
" 1625	1,29	5,68	1,31	1,97	PBR
" 1725	1,21	1,66	1,21	1,85	PBR
" 1825	1,17	7,35	1,13	1,69	PBR
" 1925	1,11	4,29	1,07	1,51	PBR
" 1950	1,09	4,57	1,05	1,49	PBR
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Date & time	Water flow (m^3/h)	Pressure (bar)	Gas flow (L/min)	Initials
03.09.2013 9:25	101,55	5,79	133,4	[illegible]
03.09.2013 1025	119,41	7,53	151,5	PBR
" 1125	118,74	7,61	148,6	PBR
" 1225	118,57	7,57	155,5	PBR
" 1325	119,64	7,54	154,2	PBR
" 1425	120,46	7,48	148,5	PBR
" 1525	119,80	7,51	150,1	PBR
" 1625	120,38	7,49	150,1	PBR
" 1725	118,18	7,63	150,1	PBR
" 1825	~~1005~~ 117,76	7,52	151,5	PBR
" 1925	119,26	7,51	149,5	PBR
" 1950	119,76	7,44	153,6	PBR

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Date & time	Volume of water above set temperature (m^3)	Oxygen in N_2 flow (%)	Initials
03.09.2013 9.25	0	2,4	[illegible]
03.09.2013 1025	68	2,1	PBR
" 1125	185	2,0	PBR
" 1225	303	2,0	PBR
" 1325	420	1,8	PBR
" 1425	537	2,0	PBR
" 1525	654	2,0	PBR
" 1625	771	2,0	PBR
" 1725	888	2,0	PBR
" 1825	1005	2,0	PBR
" 1925	1124	2,0	PBR
" 1950	1171	2,0	PBR

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Date & time	Temperature #1 (°C)	Temperature #2 (°C)	Temperature #3 (°C)	Temperature #4 (°C)	Initials
03.09.2013 0945	17,4	18,7	15,9	18,2	MBJ
03.09.2013 1025	25,5	72,8	17,7	72,5	PBR
" 1125	27,7	72,4	20,5	72,1	PBR
" 1225	29,4	71,9	22,7	71,7	PBR
" 1325	30,8	72,1	24,4	71,9	PBR
" 1425	31,9	72,1	25,8	71,9	PBR
" 1525	33,0	73	27,0	72,0	PBR
" 1625	33,7	72,3	28,0	72,2	PBR
" 1725	34,3	72,0	28,7	72,1	PBR
" 1825	34,6	72,1	29,3	72,0	PBR
" 1925	35,2	71,5	29,9	71,5	PBR
" 1950	35,3	71,9	30,1	71,9	PBR

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Date & time	Water flow (m^3/h)	Pressure (bar)	Gas flow (L/min)	Initials
2023.11.12 10.55	106,00	7,10	143,9	CAH
– 11.55	109,77	7,45	151,6	MBJ
– 12.55	111'30	7,47	150,6	MBJ
– 13.55	112,33	7,40	150,9	MBJ
– 14.55	109,74	7,41	159	MBJ
– 15.57	113,29	7,38	152,9	MBJ
– 16.55	110,68	7,42	150,8	MBJ
– 17.58	111,44	7,36	152,3	MBJ
– 19.05	111,34	7,47	148,4	MBJ
19,55	110,16	7,44	147,4	MBJ
20.55	110'46	7,38	151,5	MBJ
21.45	110,77	7,45	148,6	MBJ

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Date & time	Volume of water above set temperature (m^3)	Oxygen in N_2 flow (%)	Initials
2013.11.12 10.55	0	2,2	CAH
— 11.55	95	1,1	MBJ
— 12.55	202	2,2	MBJ
— 13.55	312	2,2	MBJ
— 14.55	422	2,0	MBJ
— 15.52	528	2,1	MBJ
— 16.55	641	2,1	MBJ
— 17.58	756	2,1	MBJ
— 19.05	644	2,1	MBJ
— 19.55	734	2,1	MBJ
20.55	843	2,1	MBJ
21.45	935	2,1	[illegible]

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↳ 546 m^3
(+214 from 18.00)

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Date & time	Temperature #1 (°C)	Temperature #2 (°C)	Temperature #3 (°C)	Temperature #4 (°C)	Initials
2013.11.12 10.55	19,2	72,5	8,4	69,5	OAH
— 11,55	21,7	74,9	10,4	72,3	MBJ
— 12.55	23,1	74,7	12,7	72,0	MBJ
— 13:55	24,5	74,4	14,2	72,0	MBJ
— 14.55	25,5	74,7	15,2	72,1	MBJ
— 15.55	26,1	74,9	16,1	72,5	MBJ
— 16.55	26,7	74,0	16,8	72,7	MBJ
— 17.55	27,4	74,5	17,3	72,0	MBJ
— 19.05	27,7	74,3	17,9	71,8	MBJ
— 19.55	27,9	74,1	18,3	72,0	MBJ
20.55	28,3	74,4	18,5	72,4	MBJ
21.45	28,7	74,1	19,1	72,1	MBJ

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Date & time	Dis. O_2 DO 0 (mg/L)	Dis. O_2 DO 1 (mg/L)	Dis. O_2 DO 2 (mg/L)	Dis. O_2 DO 3 (mg/L)	Initials
19/5/19 10.49	12,40	10,71	11,01	11,56	MB
11.50	6,07	5,10	4,96	5,02	—
12.48	3,60	3,01	2,77	2,73	—
13.50	2,45	2,15	1,76	1,74	—
14.49	2,01	1,80	1,41	1,37	—
16.10	1,81	1,62	1,19	1,17	—
16.51	1,79	1,57	1,14	1,11	—
17.49	1,69	1,56	1,10	1,03	—
18.50	1,70	1,52	1,09	1,01	—
19.49	1,68	1,51	1,03	1,00	—
20.26	1,69	1,43	0,98	0,96	—
20.34	1,62	1,45	0,97	0,93	—

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Date & time	Water flow (m^3/h)	Pressure (bar)	Gas flow (L/min)	Initials
14/13/19 10.49	112,24	7,56	161,2	MA
11.50	122,36	8,45	167,2	—
12.49	119,50	8,39	166,5	—
13.50	120,63	8,32	170,2	—
14.49	121,55	8,43	166,2	—
16.10	121,53	8,41	167,8	—
16.51	119,59	8,40	165,8	—
17.49	121,44	8,44	160,6	—
18.50	120,39	8,40	159,5	—
19.49	119,94	8,46	160,5	—
20.24	114,35	8,37	159,3	—
2:38	123,63	8,32	175,5	—

Signature:

Date & time	Volume of water above set temperature (m^3)	Oxygen in N_2 flow (%)	Initials
14/3/19 10.49	19	1,9	MJS
11.50	141	2,0	—
12.49	255	2,0	—
13.50	378	2,1	—
14.49	494	2,0	—
15.50	654	2,0	—
16.51	735	2,0	—
17.49	851	2,0	—
18.50	971	2,1	—
19.49	1080	2,0	—
20.26	1161	2,0	—
20.35	1187	2,0	—

Signature:

Date & time	Temperature #1 (°C)	Temperature #2 (°C)	Temperature #3 (°C)	Temperature #4 (°C)	Initials
14/3/19 10.49	19,1	74,6	9,1	71,3	MBJ
11.50	21,5	75,5	11,4	72,6	—
12.48	22,7	75,2	13,3	71,9	—
13.50	23,6	75,3	14,5	72,0	—
14.49	24,3	75,4	15,3	72,1	—
16.10	24,9	75,3	16,1	72,0	—
16.51	25,2	74,8	16,4	71,4	—
17.49	25,4	75,0	16,7	71,6	—
18.50	25,8	75,0	17,0	71,8	—
19.49	26,1	74,7	17,1	71,2	—
20.26	26,5	74,9	17,7	71,7	—
20.38	27,2	70,6	18,5	72,2	—

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Date & time	Dis. O_2 DO 0 (mg/L)	Dis. O_2 DO 1 (mg/L)	Dis. O_2 DO 2 (mg/L)	Dis. O_2 DO 3 (mg/L)	Initials
27/3-14 10.45	11,55	10,16	10,68	10,83	CAH
11.45	6,10	5,25	5,15	5,15	CAH
12.45	3,64	3,13	2,82	2,74	MJ
13.45	2,54	2,23	1,89	1,72	—
14.44	2,04	1,83	1,39	1,31	—
15.44	1,76	1,64	1,19	1,06	—
16.44	1,67	1,54	1,00	0,95	—
17.46	1,57	1,47	0,89	0,80	—
18.48	1,55	1,44	0,86	0,79	—
19.44	1,53	1,41	0,79	0,66	—
20.49	1,52	1,37	0,66	0,67	—
20.56	1,50	1,40	0,78	0,61	—
21	1,49	1,29	0,66	0,62	—

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Date & time	Water flow (m^3/h)	Pressure (bar)	Gas flow (L/min)	Initials
27/3-14 10.45	120,7	8,57	153,8	CAH
11.45	121,48	8,44	157,2	CAH
12.45	118,76	8,41	155,9	MBJ
13.45	119,97	8,45	160,3	—
14.44	118,44	8,50	159,4	—
15.44	120,97	8,42	160,1	—
16.44	119,56	8,40	161,1	—
17.46	123,18	8,39	161,8	—
18.48	118,99	8,42	160,6	—
19.44	122,26	8,47	160,3	—
20.44	86,85	5,17	196,6	—
20.56	120,22	8,41	162,2	—
21.26	117,77	8,23	150,1	—

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Date & time	Volume of water above set temperature (m^3)	Oxygen in N_2 flow (%)	Initials
27/3/14 10.45	0	1.6	CAH
11.45	72	2.1	CAH
12.45	191	2.1	MMJ
13.45	307	2.1	—
14.44	424	2.1	—
15.44	543	2.1	—
16.44	662	2.1	—
17.46	784	2.1	—
18.48	907	2.1	—
19.44	1018	2.1	—
20.44	1113	2.0	—
20.56	1124	2.1	—
21.26	1132	2.1	—

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Date & time	Temperature #1 (°C)	Temperature #2 (°C)	Temperature #3 (°C)	Temperature #4 (°C)	Initials
27/3-14 10.45	6,6	6,6	5,9	6,6	CAH
11.45	19,3	75,3	9,0	71,8	CAH
12.45	21,1	75,6	11,3	71,9	[illegible]
13.45	22,6	76,0	13,0	73,5	—
14.44	23,8	75,8	14,3	72,0	—
15.44	24,6	76,1	15,3	72,0	—
16.44	25,3	75,5	16,0	71,8	—
17.46	26,0	75,5	16,6	72,0	—
18.48	26,2	75,6	17,0	71,6	—
19.49	26,6	75,6	17,4	71,4	—
20.49	24,7	76,0	17,5	69,3	—
21.56	26,8	76,2	~~79~~ 17,4	72,8	—
21.26	27,8	76,2	19,0	71,8	—

Damp [illegible] [illegible] [illegible] [illegible]

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APPENDIX 4

Detailed data on physical-chemical parameters and biological efficacy analyses in land-based testing with the BAWAT BWMS

Physical-chemical parameters

Table A4.1 Measurements of total suspended solids (TSS)

Test cycle	Water type	TSS (mg/L)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	57	57	60	58	±1.8
	Treated discharge	18	18	20	19	±1.2
	Control discharge	10	9.4	7.1	8.9	±1.6
B-2	Inlet	38	38	38	38	±0.31
	Treated discharge	13	14	15	14	±1.4
	Control discharge	3.8	2.1	1.9	2.6	±1.0
B-3	Inlet	63	59	61	61	±1.9
	Treated discharge	11	13	13	12	±0.90
	Control discharge	2.7	2.6	1.5	2.3	±0.69
B-4	Inlet	61	61	62	61	±0.25
	Treated discharge	20	18	16	18	±1.9
	Control discharge	4.1	2.9	3.3	3.4	±0.62
B-5	Inlet	56	56	58	56	±1.1
	Treated discharge	16	14	21	17	±3.3
	Control discharge	1.3	0.36	3.0	1.6	±1.4
B-6	Inlet	67	70	67	68	±2.0
	Treated discharge	14	13	12	13	±0,96
	Control discharge	2.2	1.6	1.1	1.7	±0.54
B-7	Inlet	69	72	72	71	±1.8
	Treated discharge	14	14	15	14	±0.77
	Control discharge	5.1	4.6	4.5	4.8	±0.34
M-1	Inlet	74	69	73	72	±2.7
	Treated discharge	15	21	27	21	±6.0
	Control discharge	5.0	5.0	4.6	4.8	±0.25
M-2	Inlet	42	92	45	60	±28
	Treated discharge	8.6	14	13	12	±2.9
	Control discharge	2.9	4.2	2.0	3.1	±1.1
M-3	Inlet	62	62	63	62	±0.50
	Treated discharge	15	15	10	13	±3.2
	Control discharge	1.4	1.0	1.4	1.3	±0.23
M-4	Inlet	44	43	47	45	±2.2
	Treated discharge	63	12	55	43	±27
	Control discharge	2.0	2.7	2.9	2.5	±0.44
M-5	Inlet	52	55	58	55	±2.6
	Treated discharge	15	11	11	12	±2.1
	Control discharge	0.10	0.75	0.78	0.54	±0.38
M-6	Inlet	45	48	47	46	±1.5
	Treated discharge	17	18	18	18	±0.75
	Control discharge	0.23	0.27	0.71	0.40	±0.27
F-1	Inlet	56	61	60	59	±2.5
	Treated discharge	19	18	24	20	±3.5
	Control discharge	6.1	5.1	4.3	5.2	±0.90
F-2	Inlet	63	61	59	61	±2.3
	Treated discharge	12	14	14	13	±1.0
	Control discharge	4.4	3.2	4.1	3.9	±0.58
F-3	Inlet	65	70	69	68	±2.4
	Treated discharge	13	13	21	16	±4.5
	Control discharge	9.9	8.0	7.9	8.6	±1.1
F-4	Inlet	69	70	69	69	±0.56
	Treated discharge	16	17	23	19	±3.9
	Control discharge	16	17	14	16	±1.1

FR Field replicate
AVG Average
STD Standard deviation

Table A4.2 Measurements of particulate organic carbon (POC)

Test cycle	Water type	POC (mg/L)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	6.5	6.1	6.3	6.3	±0.21
	Treated discharge	1.3	1.5	1.1	1.3	±0.18
	Control discharge	1.5	0.64	0.39	0.83	±0.56
B-2	Inlet	11	6.4	11	9.3	±2.5
	Treated discharge	1.2	<0.10	1.2	0.84	±0.64
	Control discharge	0.69	3.1	1.0	1.6	±1.3
B-3	Inlet	6.6	5.4	7.3	6.4	±0,98
	Treated discharge	1.9	1.5	1.9	1.8	±0.18
	Control discharge	0.76	0.64	0.85	0.75	±0.11
B-4	Inlet	8.6	8.6	8.7	8.7	±0.05
	Treated discharge	2.7	2.1	2.2	2.3	±0.32
	Control discharge	0.70	0.78	1.3	0.91	±0.30
B-5	Inlet	7.9	8.1	7.7	7.9	±0.21
	Treated discharge	1.2	0.91	1.2	1.1	±0.19
	Control discharge	0.99	0.89	0.89	0.92	±0.06
B-6	Inlet	7.2	7.3	7.1	7.2	±0.12
	Treated discharge	1.9	1.3	1.4	1.5	±0.31
	Control discharge	0.76	0.58	0.72	0.69	±0.09
B-7	Inlet	10	9.4	10	9.9	±0.40
	Treated discharge	1.0	1.9	1.8	1.5	±0.49
	Control discharge	1.3	1.1	1.0	1.1	±0.14
M-1	Inlet	6.0	6.2	9.8	7.3	±2.1
	Treated discharge	0.32	1.2	1.8	1.1	±0.77
	Control discharge	1.6	1.3	0.10	1.0	±0.81
M-2	Inlet	11	9.7	10	10	±0.40
	Treated discharge	1.8	2.7	2.5	2.4	±0.47
	Control discharge	1.2	1.4	1.5	1.4	±0.14
M-3	Inlet	6.2	6.2	6.7	6.4	±0.28
	Treated discharge	2.3	3.7	3.0	3.0	±0.72
	Control discharge	2.0	2.0	2.6	2.2	±0.34
M-4	Inlet	10	11	13	11	±1.6
	Treated discharge	1.2	1.5	1.4	1.4	±0.18
	Control discharge	0.56	0.92	0.93	0.80	±0.21
M-5	Inlet	10	11	11	11	±0.65
	Treated discharge	0.97	0.99	0.52	0.83	±0.26
	Control discharge	<0.10	0.15	0.65	0.30	±0.30
M-6	Inlet	7.3	5.9	5.3	6.2	±1.0
	Treated discharge	1.3	1.6	2.2	1.7	±0.47
	Control discharge	1.6	2.0	1.7	1.8	±0.22
F-1	Inlet	6.3	6.3	6.0	6.2	±0.19
	Treated discharge	<0.10	<0.10	<0.10	<0.10	-
	Control discharge	0.16	0.26	0.48	0.30	±0.17
F-2	Inlet	7.5	7.7	7.4	7.5	±0.17
	Treated discharge	<0.10	<0.10	<0.10	<0.10	-
	Control discharge	0.22	0.24	0.52	0.33	±0.17
F-3	Inlet	6.7	6.6	6.2	6.5	±0.28
	Treated discharge	<0.10	<0.10	<0.10	<0.10	-
	Control discharge	0.43	<0.10	0.18	0.24	±0.17
F-4	Inlet	7.9	7.9	7.7	7.8	±0.12
	Treated discharge	<0.10	0.20	0.23	0.18	±0.07
	Control discharge	0.23	0.24	0.47	0.31	±0.13

FR Field replicate
AVG Average
STD Standard deviation

Table A4.3 Measurements of dissolved organic carbon (DOC)

Test cycle	Water type	DOC (mg/L)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	5.1	5.0	5.5	5.2	±0.28
	Treated discharge	6.9	6.3	6.8	6.7	±0.35
	Control discharge	4.7	4.5	4.6	4.6	±0.12
B-2	Inlet	8.3	8.5	7.9	8.3	±0.31
	Treated discharge	12	13	10	12	±1.2
	Control discharge	7.5	7.4	7.3	7.4	±0.11
B-3	Inlet	4.7	5.9	5.7	5.4	±0.62
	Treated discharge	8.5	8.9	8.3	8.6	±0.34
	Control discharge	6.0	5.8	5.9	5.9	±0.10
B-4	Inlet	6.4	6.4	6.6	6.5	±0.08
	Treated discharge	9.3	9.4	9.3	9.4	±0.05
	Control discharge	6.4	6.1	6.0	6.2	±0.20
B-5	Inlet	7.0	6.7	6.8	6.8	±0.13
	Treated discharge	9.6	9.3	8.6	9.2	±0.50
	Control discharge	7.0	5.9	5.5	6.1	±0.78
B-6	Inlet	5.4	5.5	5.6	5.5	±0.09
	Treated discharge	10	7.9	7.6	8.6	±1.5
	Control discharge	6.0	5.7	5.7	5.8	±0.16
B-7	Inlet	6.5	6.4	6.2	6.4	±0.16
	Treated discharge	12	8.8	8.5	9.7	±1.9
	Control discharge	6.0	5.7	5.5	5.7	±0.26
M-1	Inlet	6.6	6.4	5.0	6.0	±0.87
	Treated discharge	8.5	8.2	7.3	8.0	±0.60
	Control discharge	4.4	5.1	5.0	4.9	±0.37
M-2	Inlet	8.2	8.8	8.9	8.7	±0.37
	Treated discharge	8.0	7.7	8.2	8.0	±0.24
	Control discharge	5.4	4.7	4.5	4.9	±0.48
M-3	Inlet	5.8	5.1	5.2	5.4	±0.36
	Treated discharge	7.1	6.5	6.7	6.8	±0.27
	Control discharge	5.6	5.2	5.1	5.3	±0.25
M-4	Inlet	6.4	6.4	6.2	6.3	±0.08
	Treated discharge	7.0	6.7	6.5	6.7	±0.27
	Control discharge	5.4	4.7	4.9	5.0	±0.33
M-5	Inlet	6.1	6.2	5.9	6.1	±0.16
	Treated discharge	6.5	5.5	5.3	5.8	±0.62
	Control discharge	4.7	4.0	3.9	4.2	±0.40
M-6	Inlet	7.0	7.1	7.2	7.1	±0.07
	Treated discharge	7.4	7.3	6.5	7.0	±0.47
	Control discharge	6.3	5.2	4.8	5.4	±0.79
F-1	Inlet	7.3	7.3	7.2	7.2	±0.06
	Treated discharge	9.9	9.8	9.8	9.8	±0.07
	Control discharge	7.5	7.3	7.1	7.3	±0.23
F-2	Inlet	6.4	6.4	6.4	6.4	±0.02
	Treated discharge	10	9.6	9.5	9.8	±0.42
	Control discharge	6.6	6.6	6.2	6.5	±0.20
F-3	Inlet	7.5	7.5	7.7	7.5	±0.10
	Treated discharge	9.8	9.8	9.6	9.8	±0.12
	Control discharge	7.0	7.2	7.0	7.0	±0.12
F-4	Inlet	8.6	8.4	8.5	8.5	±0.09
	Treated discharge	13	12	12	12	±0.24
	Control discharge	8.5	8.5	8.2	8.4	±0.13

FR Field replicate
AVG Average
STD Standard deviation

Table A4.5 Measurements of UV transmittance (UV-T)

Test cycle	Water type	UV-T (%)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	55	54	54	55	±0.44
	Inlet 0.45-µm filtered	78	77	77	77	±0.32
B-2	Inlet	55	55	55	55	±0.15
	Inlet 0.45-µm filtered	66	66	67	67	±0.10
B-3	Inlet	54	53	53	53	±0.12
	Inlet 0.45-µm filtered	77	76	76	76	±0.12
B-4	Inlet	52	52	52	52	±0.15
	Inlet 0.45-µm filtered	77	77	77	77	±0.21
B-5	Inlet	50	50	50	50	±0.21
	Inlet 0.45-µm filtered	76	76	76	76	±0.15
B-6	Inlet	64	67	65	65	±1.3
	Inlet 0.45-µm filtered	78	78	78	78	±0.20
B-7	Inlet	49	49	48	49	±0.61
	Inlet 0.45-µm filtered	76	76	76	76	±0.35
M-1	Inlet	53	52	51	52	±0.57
	Inlet 0.45-µm filtered	78	79	79	79	±0.21
M-2	Inlet	61	60	60	60	±0.17
	Inlet 0.45-µm filtered	79	78	79	79	±0.31
M-3	Inlet	53	53	52	52	±0.35
	Inlet 0.45-µm filtered	78	78	78	78	±0.15
M-4	Inlet	62	62	62	62	±0.06
	Inlet 0.45-µm filtered	79	79	79	79	±0.12
M-5	Inlet	60	60	60	60	±0.32
	Inlet 0.45-µm filtered	78	78	78	78	±0.23
M-6	Inlet	58	58	58	58	±0.15
	Inlet 0.45-µm filtered	75	75	75	75	±0.10
F-1	Inlet	47	47	47	47	±0.21
	Inlet 0.45-µm filtered	71	71	71	71	±0.06
F-2	Inlet	49	49	49	49	±0.15
	Inlet 0.45-µm filtered	74	73	74	74	±0.10
F-3	Inlet	44	44	43	43	±0.21
	Inlet 0.45-µm filtered	70	70	70	70	±0.06
F-4	Inlet	39	39	39	39	±0.12
	Inlet 0.45-µm filtered	68	68	68	68	±0.17

FR Field replicate
AVG Average
STD Standard deviation

Organism size class ≥50 µm

Table A4.6 Enumeration of organisms ≥50 µm. Inlet sample volume: ≥20 L per field replicate. Treated sample volume: 1,000 L per field replicate.

Test cycle	Water type	Organisms ≥50 µm (organisms/m³)							
		FR1	FR2	FR3	FR4	FR5	FR6	AVG	STD
B-1	Inlet	789,750	777,450	699,000	591,867	741,150	700,900	716,686	±71,793
	Treated discharge	0	0	0	-	-	-	0	±0.00
	Control discharge	88,696	104,013	102,841	-	-	-	98,517	±8,525
B-2	Inlet	696,600	604,733	723,600	680,400	581,765	-*	657,420	±61,120
	Treated discharge**	0	0	0	-	-	-	0	±0.00
	Control discharge	105,488	90,996	108,899	-	-	-	101,794	±9,506
B-3	Inlet	317,067	490,867	310,302	391,400	303,000	412,550	370,864	±74,468
	Treated discharge**	4.0	4.0	1.0	-	-	-	3.0	±1.7
	Control discharge	96,141	104,103	94,308	-	-	-	98,184	±5,207
B-4	Inlet	469,200	360,767	479,250	392,667	456,450	422,300	430,106	±46,708
	Treated discharge**	0	0	0	-	-	-	0	±0.00
	Control discharge	131,706	148,701	123,880	-	-	-	134,762	±12,690
B-5	Inlet	475,950	578,550	537,767	675,800	618,000	417,500	550,594	±94,289
	Treated discharge**	1.0	0	0	-	-	-	0.33	±0.58
	Control discharge	35,187	37,245	26,880	-	-	-	33,104	±5,487
B-6	Inlet	387,200	428,667	681,600	646,800	592,733	526,633	543,939	±118,377
	Treated discharge**	3.0	0	0	-	-	-	1.0	±1.7
	Control discharge	115,103	108,680	107,991	-	-	-	110,591	±3,922
B-7	Inlet	979,133	1,232,400	1,253,750	950,133	1,036,433	1,228,450	1,113,383	±139,788
	Treated discharge**	2.0	11	8.0	-	-	-	7.0	±4.6
	Control discharge	158,600	168,025	169,150	-	-	-	165,258	±5,794
M-1	Inlet	237,350	203,490	219,067	244,200	180,550	238,333	220,498	±24,702
	Treated discharge***	0	0	0	-	-	-	0	±0.00
	Control discharge	33,088	40,635	41,940	-	-	-	38,554	±4,779
M-2	Inlet	210,700	189,783	218,400	239,867	220,000	130,467	201,536	±38,386
	Treated discharge**	0	0	0	-	-	-	0	±0.00
	Control discharge	42,880	51,675	41,042	-	-	-	45,199	±5,683
M-3	Inlet	266,500	243,000	289,000	276,250	322,667	240,500	272,986	±30,763
	Treated discharge****	0	0	0	-	-	-	0	±0.00
	Control discharge	33,672	33,170	37,893	-	-	-	34,912	±2,594
M-4	Inlet	329,000	201,250	217,000	201,250	164,000	169,000	213,583	±60,138
	Treated discharge**	3.0	3.0	6.0	-	-	-	4.0	±1.7
	Control discharge	60,915	58,847	80,960	-	-	-	66,907	±12,214
M-5	Inlet	382,500	281,250	265,500	168,000	233,333	241,500	262,014	±70,684
	Treated discharge**	3.0	8.0	4.0	-	-	-	5.0	±2.6
	Control discharge	40,080	45,863	50,800	-	-	-	45,581	±5,366

Test cycle	Water type	Organisms ≥50 µm (organisms/m³)							
		FR1	FR2	FR3	FR4	FR5	FR6	AVG	STD
M-6	Inlet	269,500	332,000	285,000	344,500	320,000	357,750	318,125	±34,419
	Treated discharge**	0	2.0	5.0*****	-	-	-	2.3	±2.5
	Control discharge	13,950	11,830	10,440	-	-	-	12,073	±1,768
F-1	Inlet	265,200	231,917	235,600	237,650	200,700	221,250	232,053	±21,177
	Treated discharge**	0	1.0	0	-	-	-	0.33	±0.58
	Control discharge	61,152	58,653	57,671	-	-	-	59,159	±1,795
F-2	Inlet	614,400	535,517	446,900	470,400	413,333	367,950	474,750	±88,507
	Treated discharge*	4.0	6.0	6.0	-	-	-	5.3	±1.2
	Control discharge	62,805	84,607	82,877	-	-	-	76,763	±12,119
F-3	Inlet	682,000	743,167	775,000	604,333	302,222	-*	621,344	±189,907
	Treated discharge******	64	105	257	-	-	-	142	±102
	Control discharge	151,953	144,807	172,813	-	-	-	156,524	±14,552
F-4	Inlet	210,250	258,750	145,000	187,500	192,500	166,750	193,458	±39,097
	Treated discharge******	93	53	52	-	-	-	66	±24
	Control discharge	119,673	100,620	106,090	-	-	-	108,794	±9,810

FR Field replicate
AVG Average
STD Standard deviation
* Sample not collected due to loss of pressure before the ballast pump
** The whole treated discharge sample was counted
*** Treated discharge samples were not counted in full. The counted volume corresponded to: FR1: 273 L, FR2: 294 L, FR3: 269 L. A total volume of 836 L was analysed within 6 hours of sampling. Observed counts were significantly lower than 10 org/m³ (Chi-sq p-value = 0) with a mean of 0 org/m³. An exact test confirms this result (p=0). All subsamples analysed were observed to contain no organisms. The results of the statistical tests clearly show that the concentration of viable organisms in the ≥50 µm size range from the treated discharge samples during test cycle M-1 was significantly lower than the threshold value defined in the ballast water discharge standard.
**** Treated discharge samples were not counted in full. The counted volume corresponded to: FR1: 417 L, FR2: 417 L, FR3: 471 L. The test cycle failed to meet the ballast water discharge standard due to the number of organisms in the size range ≥10 and <50 µm. Therefore, no statistical test was performed to verify the results of the observed the observed counts of organisms≥50 µm
***** 900 L sampled
****** Due to failed test cycle, only part of the samples analyzed

Table A4.7 Organisms ≥50 µm identified in inlet and control discharge water for brackish water and marine water test cycles

Phylum/ subphylum	Species	Test cycle												
		B-1	B-2	B-3	B-4	B-5	B-6	B-7	M-1	M-2	M-3	M-4	M-5	M-6
Annelida	*Capitella capitata*													x
	Nereididae sp.						x							
	Non-spionid sp.										x			
	Polychaeta sp.		x	x	x	x	x	x	x		x		x	x
	Polydora sp.				x	x				x	x	x		
	Spionida sp.								x					
Bryozoa	*Bryozoa* sp.					x		x				x		
Cilliophora	*Cilliophora* sp.	x		x						x		x		
	Tintinnid sp.		x	x		x	x	x	x		x		x	
Crustacea	*Acartia clausi*	x	x	x	x	x	x	x	x	x	x	x	x	x
	Acartia longiremis					x								
	Amphipoda sp.		x						x					
	Artemia	x	x	x	x	x	x		x	x	x	x	x	x
	Balanus sp.					x		x		x	x	x	x	x
	Carcinus zoea													x
	Centropages hamatus	x	x			x	x	x						x
	Eurytemora affinis					x								x
	Evadne nordmanni												x	
	Evadne spinifera													x
	Harpacticoid sp.	x					x		x					x
	Isopoda sp.							x						x
	Isopoda, Portunion sp.					x							x	
	Mysidacea sp.			x					x					x
	Oithona similis	x	x	x	x	x	x	x	x	x		x	x	x
	Oncaea borealis				x				x				x	
	Paracalanus parvus	x				x								x
	Paracalunus sp.							x						
	Podon leuckarti			x	x							x		x
	Pseudocalanus minutus	x	x	x	x	x	x	x	x	x		x		
	Temora longicornis	x	x	x			x	x	x					x
Dinophyceae	*Ceratium* sp.		x			x	x	x			x	x		x
Mollusca	*Bivalve veliger, Mytilus*					x				x	x	x	x	x
	Gastropod veliger (egg capsules)							x						
	Gastropod veliger, sp.		x	x	x	x				x	x	x	x	x
Nematoda	*Nematoda* sp.						x	x						
Platyhelminthes	*Plathyhelminth* sp.											x		
Rotifera	*Ascomorpha sp.*						x	x			x	x		
	Keratella sp.	x		x	x						x		x	
	Synchaeta sp.	x			x	x	x	x		x				
	Trichocerca							x						
Urochordata	*Tadpole larvae*					x								

Table A4.8 Organisms ≥50 µm identified in inlet and control discharge water for freshwater test cycles

Phylum/ subphylum	Species	Test cycle			
		F-1	F-2	F-3	F-4
Annelida	*Hirudinea* sp.		x		
Cilliophora	*Cilliophora* sp.		x		
	Tintinnid sp.			x	x
Crustacea	*Bosmina longirostris*	x	x	x	
	Chydorus sphaericus	x	x	x	x
	Cyclopoida sp.	x	x	x	x
	Daphnia cucculata/longispina	x	x	x	x
	Diaptomus sp.		x	x	x
Dinophyceae	*Ceratium* sp.			x	
	Dinophyceae sp.	x			
Platyhelminthes	*Trematoda* sp.	x			
	Turbellaria sp.			x	
Rotifera	*Asplanchna* sp.	x	x		
	Brachionus sp.		x		
	Keratella sp.	x	x	x	x
	Polyarthra sp.			x	x
	Rattulus sp.	x	x	x	
	Synchaeta sp.	x	x	x	x
	Triarthra sp.	x	x	x	

Organism size class ≥10 and <50 µm

Table A4.9 Enumeration of organisms ≥10 µm and <50 µm by microscopy after staining with CMFDA and FDA. The motile organisms without chlorophyll are included in the total number of organisms.

Test cycle	Water type	Organisms ≥10 µm and <50 µm (organisms/mL)				
		Total number of organisms				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	2,356	1,982	1,963	2,100	±221
	Treated discharge	8.0	11.8	12	11	±2.2
	Control discharge	353	360	387	367	±18
B-2	Inlet	1,610	1,847	1,711	1,723	±119
	Treated discharge	2.5	2.0	1.0	1.8	±0.76
	Control discharge	798	725	790	771	±40
B-3	Inlet	3,333	2,426	2,019	2,593	±673
	Treated discharge	21	12	1.8	12	±9.6
	Control discharge	327	323	352	334	±15
B-4	Inlet	3,444	2,827	3,222	3,164	±313
	Treated discharge	1.0	3.8	1.0	1.9	±1.6
	Control discharge	140	144	152	145	±6.1
B-5	Inlet	3,333	3,263	3,105	3,234	±117
	Treated discharge	5.0	6.5	10	7.2	±2.6
	Control discharge	95	238	145	159	±72
B-6	Inlet	974	1,079	1,032	1,028	±53
	Treated discharge	2.3	1.0	3.0	2.1	±1.0
	Control discharge	503	480	540	508	±30
B-7	Inlet	1,226	1,253	1,178	1,219	±38
	Treated discharge	0.50	1.5	0	0.67	±0.76
	Control discharge	1,180	1,268	1,460	1,303	±143
M-1	Inlet	4,509	4,852	4,719	4,693	±173
	Treated discharge	1.3	2.0	2.0	1.8	±0.43
	Control discharge	332	455	507	431	±90
M-2	Inlet	3,487	2,568	2,219	2,758	±655
	Treated discharge	1.3	0	1.5	0.92	±0.80
	Control discharge	1,405	1,700	1,370	1,492	±181
M-3	Inlet	2,115	2,111	1,855	2,027	±149
	Treated discharge	20	16	25	20	±4.3
	Control discharge	729	690	750	723	±30
M-4	Inlet	1,300	1,289	1,256	1,281	±23
	Treated discharge	2.5	1.0	2.8	2.1	±0.95
	Control discharge	193	420	590	401	±199
M-5	Inlet	2,750	2,618	3,094	2,821	±245
	Treated discharge	3.0	1.5	5.0	3.2	±1.8
	Control discharge	490	525	468	494	±29

Test cycle	Water type	Organisms ≥10 µm and <50 µm (organisms/mL)				
		Total number of organisms				
		FR1	FR2	FR3	AVG	STD
M-6	Inlet	3,228	3,061	3,105	3,132	±86
	Treated discharge	2.0	5.5	5.0	4.2	±1.9
	Control discharge	318	493	630	480	±157
F-1	Inlet	3,912	3,886	3,965	3,921	±40
	Treated discharge	5.0	6.8	5.5	5.8	±0.90
	Control discharge	295	515	665	492	±186
F-2	Inlet	4,224	3,816	4,184	4,075	±225
	Treated discharge	9.0	2.5	8.3	6.6	±3.6
	Control discharge	186	286	178	217	±60
F-3	Inlet	3,246	3,333	3,035	3,205	±153
	Treated discharge	22	23	67	37	±26
	Control discharge	670	710	890	757	±117
F-4	Inlet	9,421	8,789	8,618	8,943	±423
	Treated discharge	8.0	14	19	14	±5.6
	Control discharge	1,135	1,187	982	1,101	±107

FR Field replicate
AVG Average
STD Standard deviation

Table A4.10 Algal taxa and species identified in inlet water in brackish water and marine water test cycles

Phylum/ subphylum	Species	Test cycle												
		B-1	B-2	B-3	B-4	B-5	B-6	B-7	M-1	M-2	M-3	M-4	M-5	M-6
Bacillariophyceae	*Amphiprora sp.*							x						
	Cerataulina pelagica							x						
	Chaetoceros affinis							x					x	
	Chaetoceros compressus											x		x
	Chaetoceros curvisetus	x												
	Chaetoceros danicus								x				x	x
	Chaetoceros debilis		x						x					
	Chaetoceros decipiens								x					
	Chaetoceros didymus										x			
	Chaetoceros socialis													x
	Chaetoceros subtilis					x			x					
	Coscinodiscus radiata							x						
	Cyclotella sp.							x						
	Dactyliosen fragilissimus					x		x						x
	Gyrosigma sp.												x	
	Leptocylindrus danicus		x			x			x	x				x
	Leptocylindrus minimus	x							x					
	Licmophora sp.	x		x	x			x	x	x	x	x	x	x
	Navicula crabo	x		x										
	Navicula sp.							x						
	Paralia sulcata					x								
	Phaeodactylum tricornutum						x							
	Pleurosigma elongatum													x
	Porosira stelliger					x								
	Rhizosolenia hebetata													x
	Rhizosolenia setigera					x								
	Rhizosolenia styliformis		x						x					
	Skeletonema costatum	x						x	x	x	x	x	x	x
	Stephanopyxis turris								x					
	Suriella linearis												x	
	Thalassionema nitzschioides	x	x	x										
	Thalassiosira sp.							x						
Chlorophyceae	*Tetraselmis* sp.	x	x	x	x	x		x	x	x	x	x	x	x
Chrysophyceae	*Dinobryon balticum*				x	x								
Cilliophora	*Cilliophora* sp.						x	x						
Cryptophyceae	*cf. Cryptomonas* sp.	x			x			x						
Dictyocophyceae	*Dictyocha speculum*							x						

Phylum/ subphylum	Species	Test cycle												
		B-1	B-2	B-3	B-4	B-5	B-6	B-7	M-1	M-2	M-3	M-4	M-5	M-6
Dinophyceae	*Amphidinium carterae*						x	x						
	Alexandrium sp.							x						
	Amphidinium crassum											x		
	Amphidinium sp.	x		x	x				x	x				
	Ceratium fusus					x								
	Ceratium longipes							x						
	Ceratium tripos					x								
	Dinophysis acuminata							x			x	x	x	
	Dinophysis acuta							x						
	Gymnodinium aureolum										x			
	Gymnodinium sp.							x						
	Gyrodinium glaucum										x			
	Gyrodinium spirale						x	x						
	Gyrodinium sp.							x						
	Heterocapsa triquetra							x						
	Katodinium glaucum		x			x								
	Katodinium rotundatum									x				
	Katodinium sp.							x						
	Prorocentrum micans					x							x	x
	Prorocentrum minimum										x		x	
	Protoceratium reticulatum												x	
	Protoperidinium depressum	x											x	
	Protoperidinium steinii					x	x							
	Protoperidiunium cf. pellucidum							x		x				

Table A4.11 Algal taxa and species identified in inlet water in fresh water test cycles

Phylum/ subphylum	Species	Test cycle			
		F-1	F-2	F-3	F-4
Bacillariophyceae	*Asterionella formosa*		x		x
	Aulacoseira granulata		x		
	Cyclotella sp.	x		x	x
	Cyclotella stelligera		x		
	Fragilaria berolinensis	x	x	x	x
	Fragilaria crotonensis		x		
	Fragilaria spp.	x			
	Nitzschia acicularis			x	
	Nitzschia sp.	x	x		
	Stephanodiscus hantzschii		x		
	Tabellaria fenestrata		x		
Cilliophora	*Cilliophora* sp.			x	x

Phylum/ subphylum	Species	Test cycle			
		F-1	F-2	F-3	F-4
Chlorophyceae	*Actinastrum hantzschii*	x	x	x	x
	Ankistrodesmus fusiforme	x		x	
	Ankistrodesmus spiralis		x		
	Botryococcus sp	x	x	x	
	cf. Monoraphidium griffithii		x		
	Chlamydomonas sp	x			
	Chlorotetraedron incus		x		
	Closterium glacile			x	
	Closterium sp.		x		
	Coelastrum astroideum	x	x		
	Cosmarium abbreviatum				x
	Cosmarium depressum		x		
	Cosmarium subdepressum	x		x	
	Crucigenia fenestra	x	x	x	
	Crucigenia quadrata			x	
	Crucigenia tetrapedia	x		x	x
	Crucigeniella apiculata	x	x		
	Crucigeniella rectangularis			x	x
	Dictyosphaerium sp.				x
	Elakatothrix genevensis	x	x	x	x
	Golenkinia radiata	x	x	x	x
	Kirchneriella lunaris	x			x
	Lagerheimia cf. citriformis				x
	Lagerheimia sp.			x	
	Lagerheimia subsalsa		x		
	Micratinium pusillum	x			
	Monoraphidium griffithii	x			
	Oocystis borgei		x		
	Oocystis lacustris	x			x
	Oocystis solitaria		x		
	Oocystis spp.			x	
	Pediastrum biradiatum				x
	Pediastrum cf. boryanum	x	x	x	x
	Pediastrum duplex	x		x	x
	Pediastrum tetras	x	x	x	x
	Phacotus lenticularis		x		
	Scenedesmus acuminatus	x	x	x	x
	Scenedesmus arcuatus				x
	Scenedesmus cf armatus	x	x	x	
	Scenedesmus cf obtusus	x		x	
	Scenedesmus cf. subspicatus		x		
	Scenedesmus dimorphus	x			
	Scenedesmus linearis	x	x	x	x
	Scenedesmus quadricauda	x	x	x	
	Scenedesmus subspicatus	x	x	x	
	Selenastrum (Ankistrodesmus) gracilis	x			x
	Staurastrum boreale			x	
	Staurastrum chaetoceras		x		
	Staurastrum sp.	x			

Phylum/ subphylum	Species	Test cycle			
		F-1	F-2	F-3	F-4
	Tetraedron caudatum	x	x	x	x
	Tetraedron minimum				x
	Tetrastrum heterocanthum	x			
	Tetrastrum staurogeniaeforme	x	x	x	
	Tetrastrum triangulare/komarekii		x	x	
	Treubaria triappendiculata		x	x	
Chrysophyceae	*Mallomonas caudata*	x	x		
	Mallomonas spp.	x			
	Sphaerellopsis fluviatilis		x		
	Synura aff. Uvella				x
	Thracelomonas sp.	x		x	x
Conjugatophyceae	*Hyalotheca mucosa*	x			
Cryptophyceae	*Cryptomonas ovata*	x		x	x
	Phacotus angustus			x	
Cyanophyceae	*Anabaena planctonica*		x		
	Anabaena sp.	x	x	x	x
	Cyanophyceae spp.	x			
	Microcystis sp.				x
Dinophyceae	*Diplopsalis acuta*			x	
	Peridiniopsis polonicum	x			
	Peridinium bipes		x		
Euglenophyceae	*Euglena proxima*	x			
	Euglena sanguinea	x	x	x	
	Phacus pyrum	x	x	x	
Xanthophyceae	*Goniochloris fallax*		x		
	Goniochloris laevis pascher	x			

Organism size class <10 µm (bacteria)

Table A4.12 Enumeration of heterotrophic bacteria

Test cycle	Water type	Heterotrophic bacteria (CFU/mL)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	73,200	46,850	60,500	60,183	±13,178
	Treated discharge	>2,000,000	>2,000,000	>2,000,000	>2,000,000	-
	Control discharge	100,450	92,300	90,000	94,250	±5,491
B-2	Inlet	57,050	72,300	75,900	68,417	±10,007
	Treated discharge	>2,000,000	>2,000,000	>2,000,000	>2,000,000	-
	Control discharge	51,800	42,300	47,700	47,267	±4,765
B-3	Inlet	77,000	81,400	74,500	77,633	±3,493
	Treated discharge	>2,000,000	>2,000,000	>2,000,000	>2,000,000	-
	Control discharge	94,150	83,600	65,900	81,217	±14,275
B-4	Inlet	54,500	56,800	49,750	53,683	±3,595
	Treated discharge	>2,000,000	>2,000,000	>2,000,000	>2,000,000	±0.0
	Control discharge	175,000	163,000	178,000	172,000	±7,937
B-5	Inlet	18,650	19,100	21,400	19,717	±1,475
	Treated discharge	1,525,000	1,560,000	1,720,000	1,601,667	±103,963
	Control discharge	515,000	255,000	270,000	346,667	±145,974
B-6	Inlet	48,000	25,500	30,000	34,500	±11,906
	Treated discharge	>2,000,000	>2,000,000	>2,000,000	>2,000,000	-
	Control discharge	74,750	75,000	79,500	76,417	±2,673
B-7	Inlet	190,000	103,200	131,000	141,400	±44,325
	Treated discharge	>200,000	>200,000	>200,000	>200,000	-
	Control discharge	33,600	26,400	26,400	28,800	±4,157
M-1*	Inlet	25,000	32,300	41,400	32,900	±8,216
	Treated discharge	-	-	-	-	-
	Control discharge	>200,000	>200,000	200,000	>200,000	-
M-2	Inlet	104,000	144,000	157,000	135,000	±27,623
	Treated discharge	>2,000,000	>2,000,000	>2,000,000	>2,000,000	-
	Control discharge	432,500	330,000	390,000	384,167	±51,498
M-3	Inlet	154,500	165,000	163,000	160,833	±5,575
	Treated discharge	1,330,000	>2,000,000	1,560,000	1,630,000	±340,441
	Control discharge	200,000	315,000	455,000	323,333	±127,704
M-4	Inlet	116,500	106,000	85,500	102,667	±15,767
	Treated discharge	1,210,000	1,090,000	1,120,000	1,140,000	±62,450
	Control discharge	482,500	495,000	535,000	504,167	±27,424
M-5	Inlet	442,500	545,000	670,000	552,500	±113,935
	Treated discharge	1,280,000	1,325,000	1,180,000	1,261,667	±74,218
	Control discharge	214,500	350,000	270,000	278,167	±68,118
M-6	Inlet	390,000	370,000	390,000	383,333	±11,547
	Treated discharge	1,895,000	1,630,000	1,630,000	1,718,333	±152,998
	Control discharge	550,000	425,000	540,000	505,000	±69,462
F-1	Inlet	410,000	196,000	139,000	248,333	±142,879
	Treated discharge	>2,000,000	>2,000,000	>2,000,000	>2,000,000	-
	Control discharge	45,500	42,300	39,550	42,450	±2,978
F-2	Inlet	152,500	130,000	133,000	138,500	±12,217
	Treated discharge	>2,000,000	>2,000,000	>2,000,000	>2,000,000	-
	Control discharge	35,700	42,700	43,200	40,533	±4,193
F-3	Inlet	66,400	58,200	68,100	64,233	±5,294
	Treated discharge	>1,000,000	>1,000,000	>1,000,000	>1,000,000	-
	Control discharge	44,900	39,100	35,200	39,733	±4,881
F-4	Inlet	22,350	24,200	25,500	24,017	±1,583
	Treated discharge	>2,000,000	>2,000,000	>2,000,000	>2,000,000	-
	Control discharge	13,150	11,400	10,000	11,517	±1,578

* Samples not analysed at treated discharge
CFU Colony-forming units
FR Field replicate
AVG Average
STD Standard deviation

Table A4.13 Enumeration of enterococci

Test cycle	Water type	Enterococci (CFU/100 mL)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	32	37	54	41	±12
	Treated discharge	2.5	<1.0	<1.0	1.5	±0.87
	Control discharge	6.0	14	13	11	±4.3
B-2	Inlet	<1.0	<1.0	<1.0	<1.0	-
	Treated discharge	<1.0	<1.0	<1.0	<1.0	-
	Control discharge	<1.0	<1.0	<1.0	<1.0	-
B-3	Inlet	1.0	2.0	1.0	1.3	±0.58
	Treated discharge	1.0	<1.0	<1.0	1.0	±0.0
	Control discharge	<1.0	<1.0	<1.0	<1.0	-
B-4	Inlet	3.0	2.0	5.0	3.3	±1.5
	Treated discharge	1.0	<1.0	<1.0	1.0	±0.0
	Control discharge	<1.0	<1.0	<1.0	<1.0	-
B-5	Inlet	50	43	45	46	±3.8
	Treated discharge	5.0	1.0	1.0	2.3	±2.3
	Control discharge	1.0	1.0	1.0	1.0	±0.00
B-6	Inlet	4.0	8.0	10	7.3	±3.1
	Treated discharge	<1.0	<1.0	<1.0	<1.0	-
	Control discharge	<1.0	<1.0	<1.0	<1.0	-
B-7	Inlet	<1.0	<1.0	<1.0	<1.0	-
	Treated discharge	<1.0	<1.0	<1.0	<1.0	-
	Control discharge	<1.0	<1.0	<1.0	<1.0	-
M-1	Inlet	22	40	39	34	±10
	Treated discharge	3.0	2.0	4.0	3.0	±1.0
	Control discharge	19	18	24	20	±3.2
M-2	Inlet	11	7.5	7.0	8.5	±2.2
	Treated discharge	1.0	4.0	7.0	4.0	±3.0
	Control discharge	<1.0	<1.0	<1.0	<1.0	-
M-3	Inlet	30	32	30	31	±1.2
	Treated discharge	1.0	2.0	1.0	1.3	±0.58
	Control discharge	1.0	1.0	2.0	1.3	±0.58
M-4	Inlet	5.0	4.0	5.0	4.7	±0.58
	Treated discharge	1.5	5.0	10	5.5	±4.3
	Control discharge	<1.0	<1.0	<1.0	<1.0	-
M-5	Inlet	3.0	2.0	1.0	2.0	±1.0
	Treated discharge	<1.0	<1.0	<1.0	<1.0	-
	Control discharge	<1.0	<1.0	<1.0	<1.0	-
M-6	Inlet	5.0	5.0	4.0	4.7	±0.58
	Treated discharge	<1.0	<1.0	<1.0	<1.0	-
	Control discharge	<1.0	<1.0	<1.0	<1.0	-
F-1	Inlet	59	56	82	66	±14
	Treated discharge	3.0	13	5.0	7.0	±5.3
	Control discharge	3.0	3.5	2.0	2.8	±0.76
F-2	Inlet	82	109	109	100	±16
	Treated discharge	1.0	1.0	<1.0	1.0	-
	Control discharge	2.5	3.0	2.0	2.5	±0.50
F-3	Inlet	67	88	75	77	±11
	Treated discharge	2.0	1.5	1.0	1.5	±0.50
	Control discharge	1.0	3.0	8.0	4.0	±3.6
F-4	Inlet	33	38	41	37	±4.0
	Treated discharge	2.0	2.0	<1.0	1.7	±0.58
	Control discharge	10	6.0	11	9.0	±2.6

CFU Colony-forming units
FR Field replicate
AVG Average
STD Standard deviation

Table A4.14 Enumeration of *E. coli*

Test cycle	Water type	*E.coli* (CFU/100 mL)				
		FR1	FR2	FR3	AVG	STD
B-1	Inlet	<1.0	<1.0	<1.0	<1.0	-
	Treated discharge	<1.0	<1.0	<1.0	<1.0	-
	Control discharge	<1.0	<1.0	<1.0	<1.0	-
B-2	Inlet	9.0	40	17	22	±16
	Treated discharge	<1.0	<1.0	<1.0	<1.0	-
	Control discharge	1.0	<1.0	<1.0	<1.0	-
B-3	Inlet	<1.0	<1.0	<1.0	<1.0	-
	Treated discharge	<1.0	<1.0	<1.0	<1.0	-
	Control discharge	<1.0	<1.0	<1.0	<1.0	-
B-4	Inlet	<1.0	<1.0	<1.0	<1.0	-
	Treated discharge	<1.0	<1.0	<1.0	<1.0	-
	Control discharge	<1.0	<1.0	<1.0	<1.0	-
B-5	Inlet	<1.0	6.0	<1.0	2.7	±2.9
	Treated discharge	<1.0	<1.0	<1.0	<1.0	-
	Control discharge	<1.0	<1.0	<1.0	<1.0	-
B-6	Inlet	<1.0	<1.0	<1.0	<1.0	-
	Treated discharge	<1.0	<1.0	<1.0	<1.0	-
	Control discharge	<1.0	<1.0	<1.0	<1.0	-
B-7	Inlet	<1.0	<1.0	<1.0	<1.0	-
	Treated discharge	<1.0	<1.0	<1.0	<1.0	-
	Control discharge	<1.0	<1.0	<1.0	<1.0	-
M-1	Inlet	18	<1.0	<1.0	6.7	±9.8
	Treated discharge	<100	<100	<100	<100	-
	Control discharge	<100	<100	<100	<100	-
M-2	Inlet	<1.0	<1.0	<1.0	<1.0	-
	Treated discharge	<1.0	<1.0	<1.0	<1.0	-
	Control discharge	<1.0	<1.0	<1.0	<1.0	-
M-3	Inlet	<1.0	<1.0	<1.0	<1.0	-
	Treated discharge	<1.0	<1.0	<1.0	<1.0	-
	Control discharge	<1.0	<1.0	<1.0	<1.0	-
M-4	Inlet	<1.0	<1.0	<1.0	<1.0	-
	Treated discharge	<1.0	<1.0	<1.0	<1.0	-
	Control discharge	<1.0	<1.0	<1.0	<1.0	-
M-5	Inlet	<1.0	<1.0	<1.0	<1.0	-
	Treated discharge	<1.0	<1.0	<1.0	<1.0	-
	Control discharge	<1.0	<1.0	<1.0	<1.0	-
M-6	Inlet	<1.0	<1.0	<1.0	<1.0	-
	Treated discharge	<1.0	<1.0	<1.0	<1.0	-
	Control discharge	<1.0	<1.0	<1.0	<1.0	-
F-1	Inlet	<1.0	<1.0	<1.0	<1.0	-
	Treated discharge	<1.0	<1.0	<1.0	<1.0	-
	Control discharge	<1.0	<1.0	<1.0	<1.0	-
F-2	Inlet	<1.0	<1.0	<1.0	<1.0	-
	Treated discharge	<1.0	<1.0	<1.0	<1.0	-
	Control discharge	<1.0	<1.0	<1.0	<1.0	-
F-3	Inlet	<1.0	9.0	6.0	5.3	±4.0
	Treated discharge	<1.0	34	23	19	±17
	Control discharge	<1.0	<1.0	<1.0	<1.0	-
F-4	Inlet	23	60	73	52	±26
	Treated discharge	<1.0	<1.0	<1.0	<1.0	-
	Control discharge	6.5	3.0	4.0	4.5	±1.8

CFU Colony-forming units
FR Field replicate
AVG Average
STD Standard deviation

Table A4.15 Enumeration of *Vibrio cholerae*

Test cycle	Water type	Vibrio cholerae (CFU/100 mL)				
		FR1	FR2	FR3	AVG	STD
B-1	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
B-2	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
B-3	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
B-4	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
B-5	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
B-6	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
B-7	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
M-1	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
M-2	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
M-3	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
M-4	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
M-5	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
M-6*	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
F-1	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
F-2	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
F-3**	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-
F-4	Treated discharge	Absent	Absent	Absent	-	-
	Control discharge	Absent	Absent	Absent	-	-

* Send to SSI for analysis – *Vibrio alginolyticus* detected

** Send to SSI for analysis – *Vibrio cholerae* non-O1 detected

CFU Colony-forming units
FR Field replicate
AVG Average
STD Standard deviation

APPENDIX 5

Whole Effluent Toxicity (WET) tests for the BAWAT BWMS

Performance evaluation in land-based test facility

BAWAT BWMS

Whole Effluent Toxicity (WET) tests

BAWAT A/S

Final report

September 2014

The expert in **WATER ENVIRONMENTS**

This report has been prepared under the DHI Business Management System
certified by DNV to comply with ISO 9001 (Quality Management)

QUALITY SYSTEM CERTIFICATION
DNV·GL
ISO 9001
DNV GL BUSINESS ASSURANCE DENMARK A/S

Approved by
16-09-2014 X Approved by Signed by: Jens Tørsløv

Performance evaluation in land-based test facility

BAWAT BWMS

Whole Effluent Toxicity (WET) tests

Prepared for BAWAT A/S

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Project number	11812682
Date of approval	2014.09.16
Revision	Final report
Classification	Confidential

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APPENDIX D
Certificate of compliance, ISO 9001 certificate, accreditation and GLP authorization

1 Executive summary

In order to minimize the risk of spreading invasive species, the International Maritime Organization (IMO) has set out a mandatory framework for treatment of ballast water.

From March 2013 through April 2014, DHI conducted a land-based test of the BAWAT BWMS with DNV GL as classification society.

For BWMS using an active substance, bioassays have to be conducted to assess the possible toxic effects of treated ballast water on the receiving ecosystems (Resolution MEPC.169(57) (G9) /1/). The basic treatment principles of BAWAT are pasteurization and deoxygenation, and, thus, the BWMS does not make use of an active substance that would imply an evaluation according to Resolution MEPC.169(57) (G9) /1/. BAWAT A/S was requested by the Danish Nature Agency to conduct a whole effluent toxicity (WET) test conducted according to G9 /1/.

The potential residual toxic effects of BAWAT-treated discharge water were analysed in WET tests with aquatic species representing three trophic levels. One primary producer (algae), one consumer (crustacean) and one predator (fish) were used for the tests. For each toxicity test, dilution series were made by mixing treated discharge water with control discharge water. Each test includes two control series, one with 100% control discharge water and one laboratory control prepared from natural seawater.

A summary of the obtained results is presented in Table 1.1.

Table 1.1 Chronic aquatic toxicity of treated discharge water

Test organism	Standard/ guideline	NOEC (mL/L)	LOEC (mL/L)	L(E)C10 (mL/L)	L(E)C25 (mL/L)	L(E)C50 (mL/L)
Alga (*Skeletonema costatum*)	ISO 10253 /4/	≥910	>910	>910	>910	>910
Crustacean (*Acartia tonsa*)	ISO/FDIS 16778:2014 /5/	≥1,000	>1,000	>1,000	>1,000	>1,000
Fish (*Cyprinodon variegatus*)	OECD 212 /6/	≥1,000	>1,000	>1,000	>1,000	>1,000

The WET tests with algae, crustaceans and fish showed no toxic effects in the highest tested concentrations (910 mL/L and 1,000 mL/L, respectively) of the treated discharge water. For the test with algae the no observed effect concentration (NOEC) and lowest observed effect concentration (LOEC) were thus estimated to be ≥910 mL/L and >910 mL/L, respectively (Table 1.1). For the tests with crustaceans and fish the NOEC and LOEC) were thus estimated to be ≥1,000 mL/L and >1,000 mL/L, respectively (Table 1.1).

Based on the results summarized above, no environmental toxicity is expected upon discharge of ballast water treated with BAWAT BMWS..

2 Introduction

From March 2013 through April 2014, DHI conducted a land-based test of the BAWAT BWMS with DNV GL as classification society.

The potential residual toxic effects of BAWAT-treated discharge water were analysed in WET tests with aquatic species representing three trophic levels. One primary producer (algae), one consumer (crustacean) and one predator (fish) were used for the tests.

All toxicity tests were performed by experienced personnel in the DHI Environmental Laboratory. DHI holds an accreditation according to ISO 17025 /2/ to perform the specific ecotoxicological tests and is authorized to carry out studies in compliance with the OECD Principles of Good Laboratory Practice (GLP) /3/.

The WET test with algae was conducted with treated discharge water at the following concentrations: 250; 500 and 910 mL/L; the WET tests with crustaceans and fish were conducted at the following concentrations: 250; 500 and 1,000 mL/L. All WET tests included a control with control discharge water and a laboratory control prepared from natural seawater without addition of any discharge water.

3 Materials and methods

3.1 Samples

Treated discharge water and control discharge water were collected from a test cycle with brackish water (test cycle No. B-5) by personnel from DHI at the DHI Maritime Technology Evaluation Facility in Hundested, Denmark. The samples were filtered using GF/C filters and, subsequently, divided into subsamples for the WET tests and stored at DHI at -20°C until initiation of the tests. A DHI lab No. was assigned to each sample and used to identify the samples during testing, data analysis and reporting. Details of the sampling are summarized in Table 3.1.

Table 3.1 Dates of inlet and discharge operation for the test cycle B-5, from which WET test samples (treated discharge and control discharge) were collected and DHI lab Nos

Treatment	Test cycle	Inlet	Discharge	Salinity (PSU)	DHI lab No.
BAWAT	B-5	2013.08.06	2013.08.12	18	13-0991
Control (no treatment)	B-5	2013.08.06	2013.08.12	18	13-0992

PSU Practical salinity unit

For each toxicity test, dilution series were made by mixing treated discharge water with control discharge water. Control discharge water was used both as control and dilution water as the purpose was to examine whether the treated discharge water was toxic to aquatic organisms after treatment by the BWMS. The possible effect of the treatment on the water is the only difference between the control and the treated discharge water.

Each test included two control series, one with control discharge water and one laboratory control prepared from natural seawater. The seawater used for the laboratory control was collected in the North Sea by the Danish Institute for Fisheries Research and brought to DHI by tank lorry. The natural seawater (salinity: 31 PSU) was filtered through Millipore filters (10; 5.0; 0.5 and 0.22 µm) and heated to 73 °C before use. This seawater was diluted to attain a salinity of 18-20 PSU in the WET tests.

The concentrations of treated discharge water used for the WET tests are given in Table 3.2.

Table 3.2 Chronic toxicity tests performed with treated discharge water samples

Trophic level	Species	Test	Standard/ guideline	Test duration	Tested concentrations (mL/L)
Alga	*Skeletonema costatum*	Growth inhibition test	ISO 10253 /4/	72 h	0; 250; 500 and 910
Crustacean	*Acartia tonsa*	Larval development ratio test	ISO/FDIS 16778:2014 /5/	5 d	0; 250; 500 and 1,000
Fish	*Cyprinodon variegatus* (sheepshead minnow)	Fish, short-term toxicity test on embryo and sac-fry stages	OECD 212 /6/	12 d	0; 250; 500 and 1,000

3.2 Aquatic toxicity tests

3.2.1 Growth inhibition test with *Skeletonema costatum*

The toxicity of the treated discharge water and the control discharge water samples was determined as the growth inhibition of the marine alga *Skeletonema costatum* (clone: NIVA-BAC 1) according to the ISO International Standard 10253 “Water Quality - Marine algal growth inhibition test with *Skeletonema costatum* and *Phaeodactylum tricornutum*” /4/. The algae used in the test were cultured at a salinity of 20 PSU.

The test mixtures were prepared as serial dilutions of the treated discharge water with the control discharge water. No pH adjustment was necessary as the pH was within the required range. Nutrients and algae were added to each of the test mixtures (i.e. each concentration of samples) according to ISO 10253 /4/. The solutions of nutrients and added algae accounted for 90 mL/L of the test mixtures. The concentrations of the treated discharge water applied in the test were: 0 (laboratory control); 0 (control discharge water); 250; 500 and 910 mL/L.

The tests were performed in 250-mL glass flasks with wide neck, each containing 100 mL of test mixture. The design included triplicate test flasks of each concentration of treated discharge water, six test flasks containing control discharge water and algae, six laboratory controls containing seawater and algae and one blank control of each concentration (similar to dilution series of the treated discharge water, but without algae). The test mixtures were incubated for approx. 72 hours under continuous shaking and constant illumination from a panel of fluorescent light.

The density of the algae in the laboratory control was measured at test start by use of a Beckman Coulter Multisizer™ 4 Coulter Counter®. At the beginning of the test and after 24, 48 and 72 ± 2 hours of incubation, the algal growth was measured as in-vivo fluorescence in triplicate test flasks, the blanks and the two times six controls by use of a Turner TD-700 Laboratory Fluorometer. The test conditions are summarized in Table 3.3.

The identity and normal appearance of *Skeletonema costatum* in the laboratory control was confirmed by microscopy at the end of the test.

A test with the reference substance 3,5-dichlorophenol (3,5-DCP) was performed in order to verify the sensitivity of the algae.

Table 3.3 Summary of test conditions for the growth inhibition test with *Skeletonema costatum.* Control means control discharge sample 910 mL/L.

Test guideline	ISO 10253 /4/
Test organism	*Skeletonema costatum*
Test organism source	Niva, Norway, cultured at DHI (clone: NIVA, BAC 1)
Test organism life stage	Log phase growth for approx. 3 days
Test duration	72 ± 2 hours
Test containers	250-mL conical flasks with air permeable lid
Initial concentration	940 particles/mL (in lab. control)
Replicates	6 × laboratory control 6 × control discharge water 3 × test concentration (treated discharge water) 1 × blank control for each concentration
Method	Determine reduction of specific growth rate by fluorescence measurements
End point	Growth rate
Preparation of test sample	The samples were filtered through GF/C filters and frozen. Thawed at 4°C immediately before test initiation
Laboratory control medium	Seawater (salinity 32 PSU) filtered through Millipore filters (10; 5.0; 0.5 and 0.22 µm), adjusted to 19.5 PSU with MQ water and heated to 73 °C herafter nutirents were added.
Nutrient media	According to ISO 10253
Photoperiod	Constant fluorescent light (60-120 µmol × m^{-2} × sec^{-1})
Shaking	120 rpm
Temperature	18.7 ± 0.1°C
pH end of tests	8.2-8.3
Salinity (test start)	17.4-19.5 PSU
Validity criteria	72 hours specific growth rate in controls ≥0.9 d^{-1} 72 hours pH increase in controls <1.0 Control variation coefficient ≤7%
Reference test	Verification of organism sensitivity with 3,5-DCP. Requirement EC50 = 1.6 mg/L (1.0-2.2)

3.2.2 Calanoid copepod development test with *Acartia tonsa*

The treated discharge water sample was tested for chronic toxic effects on *Acartia tonsa* according to ISO/FDIS 16778:2014 “Water quality - Calanoid copepod development test with *Acartia tonsa*” /5/.

The test mixtures were prepared as serial dilutions of the treated discharge water with the control discharge water. For the treated discharge water, no pH adjustment was necessary as the pH was within the required range. The control discharge water was adjusted with NaOH to reach the required range. The concentrations of the treated discharge water applied in the test were: 0 (laboratory control); 0 (control discharge water); 250; 500 and 1,000 mL/L.

A strain of *Acartia tonsa* (DANA), Copepoda, Crustacea, collected in the North Sea by the Danish Institute for Fisheries Research has been cultured at DHI since 1987. The test was initiated with eggs collected from this culture. The eggs used for the test were cultured at 20 PSU.

The test was performed in 250-mL glass beakers. At the initiation of the test, 40 mL of test mixture and between 60-90 eggs/newly hatched nauplii were added to each beaker. *Rhodomonas salina* algae at 50,000 cells/mL were added as feed. On day 2, 40 mL of freshly prepared test mixture and *Rhodomonas salina* to a final concentration of approx. 50,000 cells/mL were added. The test was continued for 5 days. On day 5, the test mixtures were filtered through 10-µm filters after fixation with a Lugol’s solution. The filters were transferred to petri dishes with marked graduations and the numbers of nauplii, copepodites and non-hatched eggs were counted.

The larval development test was performed with 10 replicates for each test concentration and 12 control replicates (control discharge water) and 6 laboratory control replicates.

The test was carried out at 20.2 ± 0.1°C in a climate room with normal laboratory light having a daily light/dark period of 16:8 hours. The test conditions are summarized in Table 3.4.

The pH, salinity and dissolved oxygen were measured at the test start, before and after renewal on day 2 and at the end of the test.

The effect parameter determined and used for evaluation of possible toxic effects is the larval development rate. Furthermore, hatching success and mortality of hatched animals were determined.

The larval development rate was calculated from the number of surviving larvae (the ratio of copepodites to the sum of nauplii and copepodites).

Table 3.4 Summary of test conditions for the larval development test with *Acartia tonsa.* Control means control discharge sample 1,000 mL/L.

Test guideline	ISO/FDIS 16778:2014 "Water quality - Calanoid copepod early-life stage test with *Acartia tonsa* /5/
Test organism source	DHI (collected in the North Sea by the Danish Institute for Fisheries Research, cultured at DHI since 1987)
Test organism life stage	Eggs collected from the *Acartia tonsa* culture maintained at DHI laboratory
Test duration	5 days
Test containers	250-mL glass beakers
Replicates	12 × control discharge water 10 × test concentration (treated discharge water) 6 × laboratory control
Test organisms/ test container	60-90
End points	Early Life Stage Mortality in the control (ELM) Hatching Success (HS) Larval Development Ratio (LDR)
Preparation of test sample	The samples were filtered through GF/C filters and frozen. Thawed at 4°C immediately before test initiation
Laboratory control medium	Seawater (salinity 32 PSU) filtered through Millipore filters (10; 5.0; 0.5 and 0.22 µm) and adjusted to a salinity of 20 PSU with M7 medium /7/.
Food regime	*Rhodomonas salina* 50,000 cells/mL
Photoperiod	16:8 h
Temperature	20 °C ± 1 °C
pH during testing	8.1 ± 0.3 pH units
Salinity	17.8-18.0 PSU
Validity criteria	Early Life Stage Mortality in the control: <30% Hatching Success in the control: >75% Larval Development Ratio (LDR) in the control: ≥60% ± 20% Dissolved oxygen concentration (DO): >70% throughout test Control pH variation: <1 unit from the initial control pH Temperature: 20 °C ± 1 °C Salinity variation from the control start value: ± 2‰

3.2.3 Fish, short-term toxicity test on embryo and sac-fry stages with *Cyprinodon variegatus*

The treated discharge water sample was tested for the chronic toxic effects on embryo and sac-fry stages of *Cyprinodon variegatus* (sheepshead minnow) by exposure of the life stages from the fertilized egg to the end of the sac-fry stage in accordance with the

OECD Guideline for the Testing of Chemicals No. 212 /6/. The eggs were deposited at a salinity of 24-25 PSU. Upon arrival at DHI the salinity of the transport water was measured to a salinity of 24.5 PSU.

The test mixtures were prepared as serial dilutions of the treated discharge water with the control discharge water. No pH adjustment was necessary as the pH was within the required range. The concentrations of treated discharge water applied in the test were: 0 (laboratory control); 0 (control discharge water); 250; 500 and 1,000 mL/L.

The test was started with fertilized eggs in the test chambers and was terminated just before the yolk-sac of any larvae in any of the test chambers was completely absorbed or before mortality by starvation started in laboratory controls. The test was carried out as a semi-static test in 175-mL crystallization dishes with 150 mL of test mixture. Thirty eggs, equally distributed between three replicates, were exposed at each concentration of treated discharge water, control discharge water and in the parallel laboratory control.

The test was carried out at a water temperature between 24.0-26.8°C in a climate room with normal laboratory light having a daily light/dark period of 12:12 hours.

Test mixtures were renewed on day 4 and, subsequently, three times a week by preparing fresh test mixtures in clean vessels, after which surviving eggs and larvae were gently transferred to the new vessels in a small volume of old solution, avoiding exposure to air.

The salinity, pH, water temperature and dissolved oxygen were measured at the test start, before and after each water renewal and at the end of the test. The room temperature was measured continuously by a thermologger. The test conditions are summarized in Table 3.5.

No feed was provided in the embryo and sac-fry test as the test was terminated while the fry were still nourished from the yolk sac.

Table 3.5 Summary of test conditions for the chronic toxicity test with *Cyprinodon variegatus.* Control means control discharge sample 1,000 mL/L.

Test guideline	OECD 212 "Fish, Short-term Toxicity Test on Embryo and Sac-fry Stages" /6/	
Test organism	*Cyprinodon variegatus* (sheepshead minnow)	
Test organism source	Aquatic Research Organisms, Inc. (ARO), USA	
Test organism life stage	Eggs (deposited 3 days before test start at approx. 24.5 PSU)	
Test duration	12 days	
Test container	175-mL crystallization dishes (150 mL test solution)	
Replicates	3	
Test eggs/test vessel	10	
Test eggs/concentration	30	
End points	Hatching, mortality, malformation and visible abnormalities, length	
Preparation of test sample	The samples were filtered through GF/C filters and frozen. Thawed at 4°C immediately before test initiation	
Laboratory control medium	Seawater (salinity 32 PSU) filtered through Millipore filters (10; 5.0; 0.5 and 0.22 µm) and adjusted to a salinity of 18.2 PSU with zebrafish test medium /8/.	
Food regime	No food during testing	
Photoperiod	12:12 h	
Temperature	24.0-26.8°C	
pH during testing	7.7-8.2	
Salinity	17.8-18.7 PSU	
Validity criteria	Survival of hatched larvae in the control	>80 %
	Hatching Success in the control	>75 %
	Dissolved oxygen concentration	>60
	Water temperature differing between test chambers or between successive days	±1.5°C

4 Statistical calculations

In the algae test the LOEC/NOEC values was determined by use of the computer program Dunnett's procedure /9/. The EC values were calculated by use of the computer program TOXEDO /10/.

The NOEC values in the tests with crustaceans and fish were determined by use of a students t-test ($p<0.05$) as the highest tested concentration, at which no significant effect was observed compared with the control and the LOEC is the concentration just above the NOEC.

5 Results

5.1 Algal growth inhibition test with *Skeletonema costatum*

The primary data from the growth inhibition test with the alga *Skeletonema costatum* are presented in Appendix A and the results are summarized in Table 5.1.

All validity criteria for the test were fulfilled (see the table in Appendix A).

The reference test with 3,5-DCP resulted in an EC50 of 1.40 (1.32-1.53) mg/L which is within the expected range set in the ISO standard (1.6 (1.0-2.2) mg/L). This indicates good test procedures and normal sensitivity of test organisms.

The validity criteria described in Table 3.3 were fulfilled.

Table 5.1 Results of the Skeletonema costatum growth inhibition test with treated discharge water

Test water	NOEC (mL/L)	LOEC (mL/L)	EC10 (mL/L)	EC25 (mL/L)	EC50 (mL/L)
Treated discharge water	≥910	>910	>910	>910	>910

5.2 Calanoid copepod development test with the crustacean *Acartia tonsa*

The primary data from the chronic toxicity test with the crustacean *Acartia tonsa* are presented in Appendix B and the results are summarized in Table 5.2.

No effects were observed on the larval development ratio nor the early life-stage mortality (ELM) for the treated discharge water when compared with control discharge water. For the hatching success a significant lower hatching was observed only at the lowest concentration and as no dose-respons was observed this is not expected to be due to toxicity of the ballast water treatment. Hence, the no observed effect concentration (NOEC) is estimated to be ≥1,000 mL/L (Table 5.2 and Appendix B.2-B.4).

All validity criteria described in Table 3.4 were fulfilled except for the ELM in the control, which was slightly higher (31%) than the validity criterion of max. 30% mortality. This difference was considered to be negligible, and, the test is regarded as valid as all other validity criteria were fulfilled (see the tables in Appendices B.1 - B.6).

Table 5.2 Effect concentrations obtained in the Acartia tonsa test with treated discharge water

Test water	NOEC (mL/L)	LOEC (mL/L)	L(E)C10 (mL/L)	L(E)C25 (mL/L)	L(E)C50 (mL/L)
Treated discharge water	≥1,000	>1,000	>1,000	>1,000	>1,000

5.3 Fish, short-term toxicity test on embryo and sac-fry stages with *Cyprinodon variegatus*

The primary data from the chronic toxicity test with the fish *Cyprinodon variegatus* are presented in Appendix C and the results are summarized in Table 5.3.

No effect were observed for any of the effect parameters evaluated (embryonic mortality; hatching and larval mortality) for the discharge water and, hence, the NOECs were determined to be ≥1,000 mL/L.

The validity criteria discribed in Table 3.5 were fulfilled.

Table 5.3 Results of the Cyprinodon variegatus toxicity test with treated discharge water

Test water	NOEC (mL/L)	LOEC (mL/L)	L(E)C10 (mL/L)	L(E)C25 (mL/L)	L(E)C50 (mL/L)
Treated discharge water	≥1,000	>1,000	>1,000	>1,000	>1,000

6 Conclusions

The results obtained in the toxicity tests were used to derive the no observed effect concentration (NOEC), lowest observed effect concentration (LOEC) and, if possible, the lethal concentrations (LC) or effect concentrations (EC) causing 10, 25 and 50% effect in comparison with the control (i.e. L(E)C10, L(E)C25 or L(E)C50, respectively).

A summary of the results of the toxicity tests with treated discharge water is presented in Table 6.1.

Table 6.1 Chronic aquatic toxicity of treated discharge water

Test organism	Standard/ guideline	NOEC (mL/L)	LOEC (mL/L)	L(E)C10 (mL/L)	L(E)C25 (mL/L)	L(E)C50 (mL/L)
Alga (*Skeletonema costatum*)	ISO 10253 /4/	≥910	>910	>910	>910	>910
Crustacean (*Acartia tonsa*)	ISO/FDIS 16778:2014 /5/	≥1,000	>1,000	>1,000	>1,000	>1,000
Fish (*Cyprinodon variegatus*)	OECD 212 /6/	≥1,000	>1,000	>1,000	>1,000	>1,000

The WET tests with algae, crustaceans and fish all showed no toxic effects in the highest tested concentrations (910 mL/L and 1,000 mL/L, respectively) of the treated discharge water. For the test with algae the NOEC and LOEC were estimated to be ≥910 mL/L and >910 mL/L, respectively (Table 1.1 and Table 6.1). For the tests with crustaceans and fish the NOEC and LOEC were estimated to be ≥1,000 mL/L and >1,000 mL/L, respectively (Table 1.1 and Table 6.1).

7 References

/1/ IMO (2008). Procedure for approval of ballast water management systems that make use of active substances (G9). Resolution MEPC.169(57).

/2/ EN ISO/IEC 17025 (2005): General requirements for the competence of testing and calibration laboratories.

/3/ OECD Principles of Good Laboratory Practice. ENV/MC/CHEM (98)17.

/4/ DS/EN ISO 10253 (2006): ”Water Quality - Marine algal growth inhibition test with Skeletonema costatum and Phaeodactylum tricornutum”. Second edition. 2006.04.15.

/5/ ISO/FDIS 16778:2014 ”Water quality - Calanoid copepod early-life stage test with *Acartia tonsa*”.

/6/ OECD Guideline for Testing of Chemicals No. 212 (1998): ”Fish, Short-term Toxicity Test on Embryo and Sac-fry Stages”. Adopted 1998.09.21.

/7/ OECD Guideline for Testing of Chemicals No. 211 (2006): *Daphnia magna* Reproduction Test. Adopted 2012.10.02.

/8/ OECD Guidelines for Testing of Chemicals No. 203 (1992): ”Fish, acute toxicity test”. Adopted 1992.07.07.

/9/ US-EPA (1994): Dunnett Program Version 1.5. US Environmental Protection Agency, Cincinnati.

/10/ VKI (1999): TOXEDO Ver. 1.5. Program for statistical estimation of EC values, based on experimental data from ecotoxicological assays

Appendix A

Primary data on growth inhibition tests with the marine alga *Skeletonema costatum*

A.1 Inhibition of the growth of *Skeletonema costatum* with treated discharge water

Statistical parameters calculated from continuous responses based on continuous mean
Test type: Growth inhibition test

Control values

Control discharge	Growth per hour	Inhibition in per cent
Control 1	0.073	-
Control 2	0.072	-
Control 3	0.071	-
Control 4	0.071	-
Control 5	0.069	-
Control 6	0.070	-
Control mean	0.071	0

Experimental data

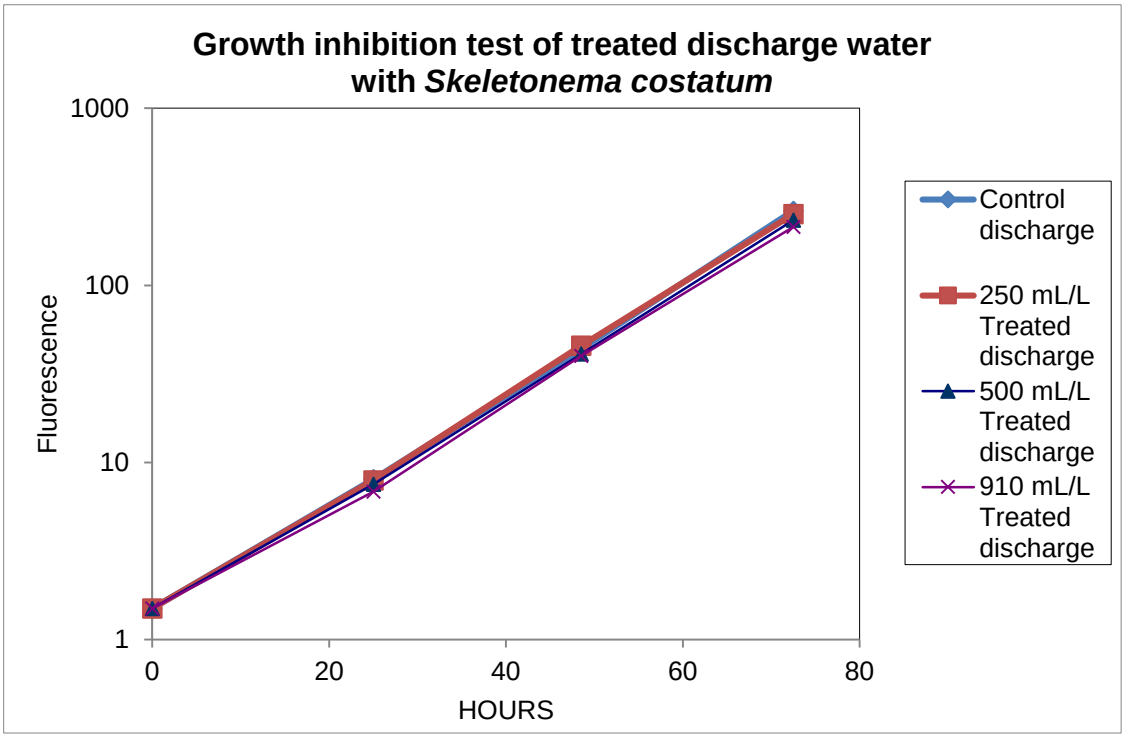
Treated discharge concentration in mL/L	Growth per hour	Inhibition in per cent
250	0.071	0
250	0.072	0
250	0.070	1
500	0.071	0
500	0.068	4
500	0.070	1
910	0.071	0
910	0.068	4
910	0.068	4

Dunnett's procedure

NOEC: ≥910 mL/L
LOEC: >910 mL/L

Data did allow any statistical calculation of the EC values

EC10: >910 mL/L
EC25: >910 mL/L
EC50: >910 mL/L


Growth inhibition test of treated discharge water with *Skeletonema costatum*
1000
100
10
1
Fluorescence
0
20
40
60
80
HOURS
Control discharge
250 mL/L Treated discharge
500 mL/L Treated discharge
910 mL/L Treated discharge

A.2 Inhibition of the growth of *Skeletonema costatum* with control discharge water compaired to laboratory control

Statistical parameters calculated from continuous responses based on continuous mean
Test type: Growth inhibition test

Control values

Laboratory control	Growth per hour	Inhibition in per cent
Control 1	0.068	-
Control 2	0.073	-
Control 3	0.069	-
Control 4	0.071	-
Control 5	0.069	-
Control 6	0.071	-
Control mean	0.070	0

Control values

Control discharge	Growth per hour	Inhibition in per cent
Control 1	0.073	0
Control 2	0.072	0
Control 3	0.071	0
Control 4	0.071	0
Control 5	0.069	2
Control 6	0.070	0
Control mean	0.073	0

Dunnett's procedure showed no significant difference between the growth of the control discharge water compaired to the laboratory control.

A.3 Inhibition of the growth of *Skeletonema costatum* with 3,5-DCP

Statistical parameters calculated from continuous responses based on continuous mean
Test type: Growth inhibition test

Control values

Control discharge	Growth per hour	Inhibition in per cent
Control 1	0.069	-
Control 2	0.071	-
Control 3	0.072	-
Control 4	0.073	-
Control 5	0.074	-
Control 6	0.070	-
Control mean	0.072	0

Experimental data

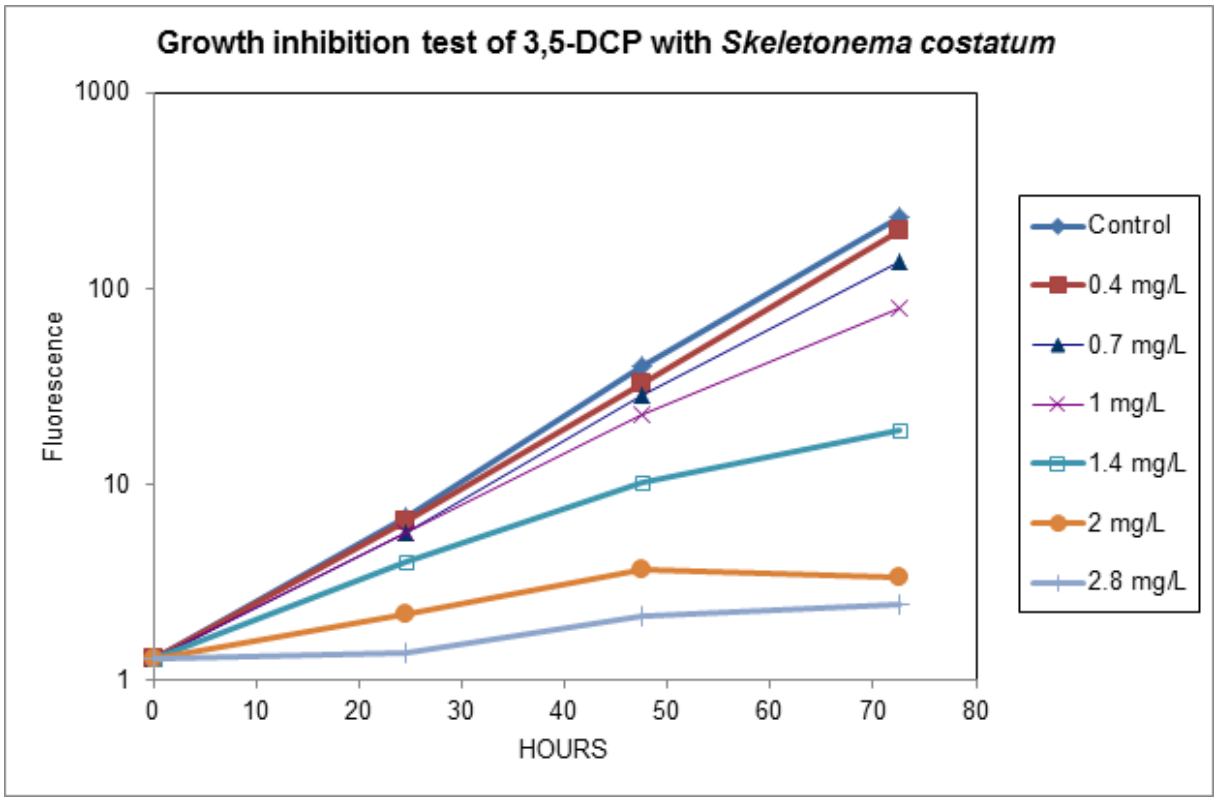
Treated discharge concentration in mg/L	Growth per hour	Inhibition in per cent
0.40	0.069	3
0.40	0.070	2
0.70	0.064	10
0.70	0.066	8
1.00	0.059	17
1.00	0.054	24
1.40	0.038	47
1.40	0.036	50
2.00	0.019	73
2.00	0.006	92
2.80	0.013	82
2.80	0.003	96

Dunnett's procedure

NOEC: 0.70 mg/L
LOEC: 1.00 mg/L

EC values and limits of the 95% confidence interval

y(EC)	LCL	EC(yo)	UCL
10	0.62	0.76	0.87
50	1.28	1.40	1.53
90	2.24	2.57	>2.80


Growth inhibition test of 3,5-DCP with *Skeletonema costatum*
1000
100
10
1
Fluorescence
0
10
20
30
40
50
60
70
80
HOURS
Control
0.4 mg/L
0.7 mg/L
1 mg/L
1.4 mg/L
2 mg/L
2.8 mg/L

APPENDIX B

Primary data on larval development ratio tests with the crustacean *Acartia tonsa*

B.1 Larval development and growth test (F0 generation)

Concentration		Start			End of exposure						
		Eggs added (+ nauplii added)		Number of eggs and nauplii added	Eggs	Nauplii N	Cope-podites C	LDR C/ (N+C)	Hatching success	ELS mortality	ELS survival
		Eggs	N	Number	Number			%			
Control discharge water	A	59	1	60	13	14	19	57.6	78.0	29.8	70.2
	B	73	1	74	7	15	31	67.4	90.4	31.3	68.7
	C	84	1	85	9	12	34	73.9	89.3	39.5	60.5
	D	65	1	66	10	13	26	66.7	84.6	30.4	69.6
	E	80	3	83	9	14	33	70.2	88.8	36.5	63.5
	F	76	1	77	20	21	22	51.2	73.7	24.6	75.4
	G	83	3	86	17	20	28	58.3	79.5	30.4	69.6
	H	80	0	80	17	20	20	50.0	78.8	36.5	63.5
	I	81	6	87	7	15	35	70.0	91.4	37.5	62.5
	J	71	2	73	16	14	33	70.2	77.5	17.5	82.5
	K	72	1	73	19	13	26	66.7	73.6	27.8	72.2
	L	68	3	71	11	13	28	68.3	83.8	31.7	68.3
Laboratory control	A	74	2	76	14	15	33	68.8	81.1	22.6	77.4
	B	67	4	71	13	10	27	73.0	80.6	36.2	63.8
	C	73	1	74	15	10	24	70.6	79.5	42.4	57.6
	D	71	0	71	10	10	25	71.4	85.9	42.6	57.4
	E	77	4	81	11	20	32	61.5	85.7	25.7	74.3
	F	77	1	78	16	13	19	59.4	79.2	48.4	51.6
Hatching control	A	83	1	84	16	66	-	-	80.7	2.9	97.1
	B	74	3	77	19	52	-	-	74.3	10.3	89.7
	C	63	3	66	13	46	-	-	79.4	13.2	86.8
	D	81	1	82	20	57	-	-	75.3	8.1	91.9
Treated discharge water 250 mL/L	A	87	3	90	19	10	35	77.8	78.2	36.6	63.4
	B	84	4	88	21	15	32	68.1	75.0	29.9	70.1
	C	80	1	81	19	15	28	65.1	76.5	30.6	69.4
	D	75	2	77	15	15	24	61.5	80.5	37.1	62.9
	E	69	4	73	15	15	30	66.7	79.5	22.4	77.6
	F	80	1	81	14	16	35	68.6	82.7	23.9	76.1
	G	74	6	80	17	17	29	63.0	78.8	27.0	73.0
	H	71	1	72	14	17	32	65.3	80.6	15.5	84.5
	I	74	5	79	19	20	25	55.6	75.9	25.0	75.0
	J	71	2	73	18	16	24	60.0	75.3	27.3	72.7
Treated discharge water 500 mL/L	A	63	2	65	9	10	22	68.8	86.2	42.9	57.1
	B	65	3	68	9	16	27	62.8	86.8	27.1	72.9
	C	63	2	65	7	13	26	66.7	89.2	32.8	67.2
	D	58	2	60	17	10	29	74.4	71.7	9.3	90.7
	E	79	1	80	11	19	34	64.2	86.3	23.2	76.8
	F	86	4	90	15	13	31	70.5	83.3	41.3	58.7
	G	71	2	73	7	20	18	47.4	90.4	42.4	57.6
	H	71	2	73	14	11	26	70.3	80.8	37.3	62.7
	I	80	1	81	20	9	37	80.4	75.3	24.6	75.4
	J	70	3	73	12	8	36	81.8	83.6	27.9	72.1
Treated discharge water 1,000 mL/L	A	85	2	87	14	15	39	72.2	83.9	26.0	74.0
	B	80	0	80	12	15	36	70.6	85.0	25.0	75.0
	C	70	0	70	20	13	26	66.7	71.4	22.0	78.0
	D	83	1	84	19	19	29	60.4	77.4	26.2	73.8
	E	70	0	70	11	18	20	52.6	84.3	35.6	64.4
	F	75	1	76	12	14	21	60.0	84.2	45.3	54.7
	G	89	1	90	22	18	31	63.3	75.6	27.9	72.1
	H	89	1	90	13	9	36	80.0	85.6	41.6	58.4
	I	88	1	89	11	18	32	64.0	87.6	35.9	64.1
	J	76	3	79	7	14	27	65.9	91.1	43.1	56.9

B.2 Larval development ratio

Replicate No.	Control discharge water	Treated discharge water 250 mL/L	Treated discharge water 500 mL/L	Treated discharge water 1,000 mL/L	Laboratory control
	Larval development ratio %				
1	58	78	69	72	69
2	67	68	63	71	73
3	74	65	67	67	71
4	67	62	74	60	71
5	70	67	64	53	62
6	51	69	71	60	59
7	58	63	47	63	-
8	50	65	70	80	-
9	70	56	80	64	-
10	70	60	82	66	-
11	67	-	-	-	-
12	68	-	-	-	-
Count	12	10	10	10	6
Mean	64	65	69	66	67
P-value	-	0.38	0.12	0.34	0.19
Significantly lower ratio	-	NO	NO	NO	NO
Significantly higher ratio	-	NO	NO	NO	NO

B.3 Hatching succes

Replicate No.	Control discharge water	Treated discharge water 250 mL/L	Treated discharge water 500 mL/L	Treated discharge water 1,000 mL/L	Laboratory control
	hatching succes %				
1	78	78	86	84	81
2	90	75	87	85	81
3	89	77	89	71	80
4	85	81	72	77	86
5	89	80	86	84	86
6	74	83	83	84	79
7	80	79	90	76	-
8	79	81	81	86	-
9	91	76	75	88	-
10	78	75	84	91	-
11	74	-	-	-	-
12	84	-	-	-	-
Count	12	10	10	10	6
Mean	82	78	83	83	82
P-value		0.04	0.37	0.47	0.44
Significantly lower hatching		YES	NO	NO	NO
Significantly higher hatching		NO	NO	NO	NO

B.4 ELS survival

Replicate No.	Control discharge water	Treated discharge water 250 mL/L	Treated discharge water 500 mL/L	Treated discharge water 1,000 mL/L	Laboratory control
	ELS survival %				
1	70	63	57	74	77
2	69	70	73	75	64
3	61	69	67	78	58
4	70	63	91	74	57
5	64	78	77	64	74
6	75	76	59	55	52
7	70	73	58	72	-
8	64	85	63	58	-
9	63	75	75	64	-
10	83	73	72	57	-
11	72	-	-	-	-
12	68	-	-	-	-
Count	12	10	10	10	6
Mean	69	72	69	67	64
P-value		0.10	0.47	0.29	0.10
Significantly lower survival		NO	NO	NO	NO
Significantly higher survival		NO	NO	NO	NO

B.5 Inhibition of the hatching success of Acartia tonsa

Control values

Control discharge	Hatching (%)	Inhibition (%)
Control 1	78.0	-
Control 2	90.4	-
Control 3	89.3	-
Control 4	84.6	-
Control 5	88.8	-
Control 6	73.7	-
Control 7	79.5	-
Control 8	78.8	-
Control 9	91.4	-
Control 10	77.5	-
Control 11	73.6	-
Control 12	83.8	-
Control mean	82.4	0

Experimental data

Treated discharge Concentration (mL/L)	Larval development ratio (%)	Inhibition (%)
250	78.2	5
250	75.0	9
250	76.5	7
250	80.5	2
250	79.5	4
250	82.7	0
250	78.8	4
250	80.6	2
250	75.9	8
250	75.3	9
500	86.2	0
500	86.8	0
500	89.2	0
500	71.7	13
500	86.3	0
500	83.3	0
500	90.4	0
500	80.8	2
500	75.3	9
500	83.6	0
1000	83.9	0
1000	85.0	0
1000	71.4	13
1000	77.4	6
1000	84.3	0
1000	84.2	0
1000	75.6	8
1000	85.6	0
1000	87.6	0
1000	91.1	0

Data did not allow statistical calculation of the 95% confidence limits

EC10: >1000 mL/L
EC25: >1000 mL/L
EC50: >1000 mL/L

B.6 Measurements of pH, oxygen and salinity

Date	2013.10.02			2013.10.04			2013.10.04			2013.10.07		
Concentration (mL/L)	Day 0			Day 2 (before addition)			Day 2 (after addition)			Day 5		
	pH	O_2 (%)	Sal. (PSU)	pH	O_2 (%)	Sal. (PSU)	pH	O_2 (%)	Sal. (PSU)	pH	O_2 (%)	Sal. (PSU)
Control discharge water	8.1	97	18.0	8.1	96	18.0	8.1	100	17.9	8.2	96	18.0
Treated discharge water 250 mL/L	8.0	97	18.0	8.1	96	18.0	8.1	100	17.9	8.3	95	17.9
Treated discharge water 500 mL/L	8.0	97	18.0	8.1	97	18.0	8.1	100	18.0	8.2	93	18.0
Treated discharge water 1,000 mL/L	8.1	97	18.0	8.2	97	18.0	8.2	100	18.0	8.2	94	18.0
Laboratory control	7.9	98	17.9	8.2	99	17.8	8.2	100	17.8	8.4	100	17.9

APPENDIX C

Primary data on short-term toxicity tests on embryo and sac-fry stages with the marine fish *Cyprinodon variegatus*

C.1 Hatching and survival of *Cyprinodon variegatus*

DATE		2013.11.07 - Day 0											
Concentration (mL/L)	Total number of eggs	Malformed larvae			Dead larvae			Total hatched larvae			Total live larvae		
		A	B	C	A	B	C	A	B	C	A	B	C
Control discharge water	30	-	-	-	-	-	-	0	0	0	0	0	0
Treated discharge water 250 mL/L	30	-	-	-	-	-	-	0	0	0	0	0	0
Treated discharge water 500 mL/L	30	-	-	-	-	-	-	0	0	0	0	0	0
Treated discharge water 1,000 mL/L	30	-	-	-	-	-	-	0	0	0	0	0	0
Laboratory control	30	-	-	-	-	-	-	0	0	0	0	0	0

DATE		2013.11.08 - Day 1											
Concentration (mL/L)	Total number of eggs	Malformed larvae			Dead larvae			Total hatched larvae			Total live larvae		
		A	B	C	A	B	C	A	B	C	A	B	C
Control discharge water	30	-	-	-	-	-	-	0	0	0	0	0	0
Treated discharge water 250 mL/L	30	-	-	-	-	-	-	0	0	0	0	0	0
Treated discharge water 500 mL/L	30	-	-	-	-	-	-	0	0	0	0	0	0
Treated discharge water 1,000 mL/L	30	-	-	-	-	-	-	0	0	0	0	0	0
Laboratory control	30	-	-	-	-	-	-	0	0	0	0	0	0

DATE		2013.11.09 - Day 2											
Concentration (mL/L)	Total number of eggs	Malformed larvae			Dead larvae			Total hatched larvae			Total live larvae		
		A	B	C	A	B	C	A	B	C	A	B	C
Control discharge water	30	-	-	-	-	-	-	0	0	0	0	0	0
Treated discharge water 250 mL/L	30	-	-	-	-	-	-	0	0	0	0	0	0
Treated discharge water 500 mL/L	30	-	-	-	-	-	-	0	0	0	0	0	0
Treated discharge water 1,000 mL/L	30	-	-	-	-	-	-	0	0	0	0	0	0
Laboratory control	30	-	-	-	-	-	-	0	0	0	0	0	0

DATE		2013.11.10 - Day 3											
Concentration (mL/L)	Total number of eggs	Malformed larvae			Dead larvae			Total hatched larvae			Total live larvae		
		A	B	C	A	B	C	A	B	C	A	B	C
Control discharge water	30	0	0	0	0	0	0	2	3	3	2	3	3
Treated discharge water 250 mL/L	30	0	0	0	0	0	0	4	3	3	4	3	3
Treated discharge water 500 mL/L	30	0	0	0	0	0	0	4	2	3	4	2	3
Treated discharge water 1,000 mL/L	30	0	0	0	0	0	0	3	4	1	3	4	1
Laboratory control	30	-	0	0	-	0	0	0	3	1	0	3	1

DATE		2013.11.11 - Day 4											
Concentration (mL/L)	Total number of eggs	Malformed larvae			Dead larvae			Total hatched larvae			Total live larvae		
		A	B	C	A	B	C	A	B	C	A	B	C
Control discharge water	30	0	0	0	0	0	0	5	10	8	5	10	8
Treated discharge water 250 mL/L	30	0	0	0	0	0	0	6	8	4	6	8	4
Treated discharge water 500 mL	30	0	0	0	0	0	0	8	6	8	8	6	8
Treated discharge water 1,000 mL/L	30	0	0	0	0	0	0	8	8	5	8	8	5
Laboratory control	30	0	0	0	0	0	0	2	8	8	2	8	8

DATE		2013.11.12 - Day 5											
Concentration (mL/L)	Total number of eggs	Malformed larvae			Dead larvae			Total hatched larvae			Total live larvae		
		A	B	C	A	B	C	A	B	C	A	B	C
Control discharge water	30	0	0	0	0	0	0	10	10	10	10	10	10
Treated discharge water 250 mL/L	30	0	0	0	0	0	0	10	10	10	10	10	10
Treated discharge water 500 mL/L	30	0	0	0	0	0	0	10	10	10	10	10	10
Treated discharge water 1,000 mL/L	30	0	0	0	0	0	0	10	10	10	10	10	10
Laboratory control	30	0	0	0	0	0	0	10	10	10	10	10	10

DATE		2013.11.13 - Day 6											
Concentration (mL/L)	Total number of eggs	Malformed larvae			Dead larvae			Total hatched larvae			Total live larvae		
		A	B	C	A	B	C	A	B	C	A	B	C
Control discharge water	30	0	0	0	0	0	0	10	10	10	10	10	10
Treated discharge water 250 mL/L	30	0	0	0	0	0	0	10	10	10	10	10	10
Treated discharge water 500 mL/L	30	0	0	0	0	0	0	10	10	10	10	10	10
Treated discharge water 1,000 mL/L	30	0	0	0	0	0	0	10	10	10	10	10	10
Laboratory control	30	0	0	0	0	0	0	10	10	10	10	10	10

DATE		2013.11.14 – Day 7											
Concentration (mL/L)	Total number of eggs	Malformed larvae			Dead larvae			Total hatched larvae			Total live larvae		
		A	B	C	A	B	C	A	B	C	A	B	C
Control discharge water	30	0	0	0	0	0	0	10	10	10	10	10	10
Treated discharge water 250 mL/L	30	0	0	0	0	0	0	10	10	10	10	10	10
Treated discharge water 500 mL/L	30	0	0	0	0	0	0	10	10	10	10	10	10
Treated discharge water 1,000 mL/L	30	0	0	0	0	0	0	10	10	10	10	10	10
Laboratory control	30	0	0	0	0	0	0	10	10	10	10	10	10

DATE		2013.11.13 - Day 8											
Concentration (mL/L)	Total number of eggs	Malformed larvae			Dead larvae			Total hatched larvae			Total live larvae		
		A	B	C	A	B	C	A	B	C	A	B	C
Control discharge water	30	0	0	0	0	0	0	10	10	10	10	10	10
Treated discharge water 250 mL/L	30	0	0	0	0	0	0	10	10	10	10	10	10
Treated discharge water 500 mL/L	30	0	0	0	0	0	0	10	10	10	10	10	10
Treated discharge water 1,000 mL/L	30	0	0	0	0	0	0	10	10	10	10	10	10
Laboratory control	30	0	0	0	0	0	0	10	10	10	10	10	10

DATE		2013.11.16 - Day 9											
Concentration (mL/L)	Total number of eggs	Malformed larvae			Dead larvae			Total hatched larvae			Total live larvae		
		A	B	C	A	B	C	A	B	C	A	B	C
Control discharge water	30	0	0	0	0	0	0	10	10	10	10	10	10
Treated discharge water 250 mL/L	30	0	0	0	0	0	0	10	10	10	10	10	10
Treated discharge water 500 mL/L	30	0	0	0	0	0	0	10	10	10	10	10	10
Treated discharge water 1,000 mL/L	30	0	0	0	0	0	0	10	10	10	10	10	10
Laboratory control	30	0	0	0	0	0	0	10	10	10	10	10	10

DATE		2013.11.17 - Day 10											
Concentration (mL/L)	Total number of eggs	Malformed larvae			Dead larvae			Total hatched larvae			Total live larvae		
		A	B	C	A	B	C	A	B	C	A	B	C
Control discharge water	30	0	0	0	0	0	0	10	10	10	10	10	10
Treated discharge water 250 mL/L	30	0	0	0	0	0	0	10	10	10	10	10	10
Treated discharge water 500 mL/L	30	0	0	0	0	0	0	10	10	10	10	10	10
Treated discharge water 1,000 mL/L	30	0	0	0	0	0	0	10	10	10	10	10	10
Laboratory control	30	0	0	0	0	0	0	10	10	10	10	10	10

DATE		2013.11.18 - Day 11											
Concentration (mL/L)	Total number of eggs	Malformed larvae			Dead larvae			Total hatched larvae			Total live larvae		
		A	B	C	A	B	C	A	B	C	A	B	C
Control discharge water	30	0	0	0	0	0	0	10	10	10	10	10	10
Treated discharge water 250 mL/L	30	0	0	0	0	0	0	10	10	10	10	10	10
Treated discharge water 500 mL/L	30	0	0	0	0	0	0	10	10	10	10	10	10
Treated discharge water 1,000 mL/L	30	0	0	0	0	0	0	10	10	10	10	10	10
Laboratory control	30	0	0	0	0	0	0	10	10	10	10	10	10

DATE		2013.11.19 - Day 12											
Concentration (mL/L)	Total number of eggs	Malformed larvae			Dead larvae			Total hatched larvae			Total live larvae		
		A	B	C	A	B	C	A	B	C	A	B	C
Control discharge water	30	0	0	0	0	0	0	10	10	10	10	10	10
Treated discharge water 250 mL/L	30	0	0	0	0	0	0	10	10	10	10	10	10
Treated discharge water 500 mL/L	30	0	0	0	0	0	0	10	10	10	10	10	10
Treated discharge water 1,000 mL/L	30	0	0	0	0	0	0	10	10	10	10	10	10
Laboratory control	30	0	0	0	0	0	0	10	10	10	10	10	10

C.2 Measurements of pH, oxygen and salinity

DATE	2013.11.07 - Day 0											
Concentration (mL/L)	Temp. (°C)			Oxygen (% saturation)			Salinity (PSU)			pH		
	A	B	C	A	B	C	A	B	C	A	B	C
Control discharge water	24.1	24.1	24.1	95	95	95	17.8	17.8	17.8	7.9	7.9	7.9
Treated discharge water 250 mL/L	24.3	24.3	24.3	95	95	95	17.9	17.9	17.9	7.9	7.9	7.9
Treated discharge water 500 mL/L	24.3	24.3	24.3	95	95	95	17.9	17.9	17.9	7.9	7.9	7.9
Treated discharge water 1,000 mL/L	24.2	24.2	24.2	95	95	95	17.8	17.8	17.8	8.0	8.0	8.0
Laboratory control	24.9	24.9	24.9	100	100	100	18.2	18.2	18.2	7.9	7.9	7.9

DATE	2013.11.11 - Day 4 (before renewal)											
Concentration (mL/L)	Temp. (°C)			Oxygen (% saturation)			Salinity (PSU)			pH		
	A	B	C	A	B	C	A	B	C	A	B	C
Control discharge water	24.6	24.2	24.2	97	97	97	18.4	18.3	18.3	8.2	8.2	8.2
Treated discharge water 250 mL/L	26.0	25.7	25.4	96	93	97	18.6	18.4	18.4	8.1	8.1	8.1
Treated discharge water 500 mL/L	24.6	24.9	24.8	96	96	96	18.3	18.3	18.2	8.2	8.2	8.2
Treated discharge water 1,000 mL/L	24.4	24.7	24.8	94	95	97	18.3	18.2	18.4	8.2	8.2	8.2
Laboratory control	24.3	24.3	24.0	97	98	98	18.7	18.7	18.7	8.1	8.1	8.1

DATE	2013.11.11 - Day 4 (after renewal)											
Concentration (mL/L)	Temp. (°C)			Oxygen (% saturation)			Salinity (PSU)			pH		
	A	B	C	A	B	C	A	B	C	A	B	C
Control discharge water	26.8	26.8	26.8	100	100	100	17.9	17.9	17.9	8.1	8.1	8.1
Treated discharge water 250 mL/L	26.3	26.3	26.3	100	100	100	18.1	18.1	18.1	8.0	8.0	8.0
Treated discharge water 500 mL/L	26.3	26.3	26.3	100	100	100	17.9	17.9	17.9	8.0	8.0	8.0
Treated discharge water 1,000 mL/L	26.8	26.8	26.8	100	100	100	17.9	17.9	17.9	7.9	7.9	7.9
Laboratory control	24.9	24.9	24.9	100	100	100	18.2	18.2	18.2	7.9	7.9	7.9

DATE	2013.11.13 - Day 6 (before renewal)											
Concentration (mL/L)	Temp. (°C)			Oxygen (% saturation)			Salinity (PSU)			pH		
	A	B	C	A	B	C	A	B	C	A	B	C
Control discharge water	25.1	25.4	25.3	93	92	94	18.1	18.0	18.0	8.1	8.1	8.1
Treated discharge water 250 mL/L	25.3	25.4	25.4	93	93	93	18.3	18.1	18.1	8.0	8.1	8.1
Treated discharge water 500 mL/L	25.4	25.4	25.4	93	92	94	18.1	18.0	18.0	8.1	8.1	8.1
Treated discharge water 1,000 mL/L	25.4	25.4	25.3	92	93	91	18.1	18.1	18.2	8.1	8.1	8.1
Laboratory control	25.0	25.5	25.4	93	93	94	18.6	18.5	18.4	8.0	8.0	8.0

DATE	2013.11.13 - Day 6 (after renewal)											
Concentration (mL/L)	Temp. (°C)			Oxygen (% saturation)			Salinity (PSU)			pH		
	A	B	C	A	B	C	A	B	C	A	B	C
Control discharge water	24.0	24.0	24.0	95	95	95	17.9	17.9	17.9	8.1	8.1	8.1
Treated discharge water 250 mL/L	24.1	24.1	24.1	95	95	95	17.9	17.9	17.9	8.0	8.0	8.0
Treated discharge water 500 mL/L	24.2	24.2	24.2	95	95	95	17.9	17.9	17.9	8.0	8.0	8.0
Treated discharge water 1,000 mL/L	24.1	24.1	24.1	94	94	94	17.9	17.9	17.9	7.8	7.8	7.8
Laboratory control	24.3	24.3	24.3	96	96	96	18.3	18.3	18.3	7.8	7.8	7.8

DATE	2013.11.15 - Day 8 (before renewal)											
Concentration (mL/L)	Temp. (°C)			Oxygen (% saturation)			Salinity (PSU)			pH		
	A	B	C	A	B	C	A	B	C	A	B	C
Control discharge water	25.4	25.4	25.3	97	96	96	18.3	18.2	18.1	8.1	8.1	8.1
Treated discharge water 250 mL/L	25.3	25.1	25.3	92	96	96	18.4	18.2	18.2	8.0	8.0	8.1
Treated discharge water 500 mL/L	25.4	25.4	25.4	96	95	96	18.1	18.1	18.1	8.1	8.1	8.1
Treated discharge water 1,000 mL/L	25.5	25.4	25.4	92	92	92	18.2	18.1	18.2	8.1	8.1	8.1
Laboratory control	25.2	25.3	25.4	97	96	96	18.6	18.5	18.5	7.9	8.0	8.0

DATE	2013.11.15 - Day 8 (after renewal)											
Concentration (mL/L)	Temp. (°C)			Oxygen (% saturation)			Salinity (PSU)			pH		
	A	B	C	A	B	C	A	B	C	A	B	C
Control discharge water	24.1	24.1	24.1	95	95	95	17.9	17.9	17.9	8.1	8.1	8.1
Treated discharge water 250 mL/L	24.4	24.4	24.4	97	97	97	17.9	17.9	17.9	8.1	8.1	8.1
Treated discharge water 500 mL/L	24.2	24.2	24.2	97	97	97	17.9	17.9	17.9	8.1	8.1	8.1
Treated discharge water 1,000 mL/L	24.2	24.2	24.2	95	95	95	17.9	17.9	17.9	8.1	8.1	8.1
Laboratory control	25.1	25.1	25.1	97	97	97	18.3	18.3	18.3	7.8	7.8	7.8

DATE	2013.11.18 - Day 11 (before renewal)											
Concentration (mL/L)	Temp. (°C)			Oxygen (% saturation)			Salinity (PSU)			pH		
	A	B	C	A	B	C	A	B	C	A	B	C
Control discharge water	25.5	25.4	25.4	100	99	98	18.2	18.2	18.1	8.1	8.1	8.1
Treated discharge Water 250 mL/L	26.6	26.1	25.9	98	99	99	17.8	18.0	18.1	7.8	8.0	8.0
Treated discharge water 500 mL/L	25.8	25.7	25.6	98	98	98	18.1	18.2	18.1	8.1	8.1	8.1
Treated discharge water 1,000 mL/L	25.5	25.6	25.4	97	96	97	18.2	18.1	18.2	8.1	8.1	8.1
Laboratory control	25.4	25.4	25.4	100	99	100	18.6	18.5	18.5	8.1	8.0	8.0

DATE	2013.11.18 - Day 11 (after renewal)											
Concentration (mL/L)	Temp. (°C)			Oxygen (% saturation)			Salinity (PSU)			pH		
	A	B	C	A	B	C	A	B	C	A	B	C
Control discharge water	24.6	24.6	24.6	98	98	98	17.9	17.9	17.9	7.8	7.8	7.8
Treated discharge Water 250 mL/L	24.7	24.7	24.7	96	96	96	18.0	18.0	18.0	7.9	7.9	7.9
Treated discharge water 500 mL/L	25.0	25.0	25.0	97	97	97	17.9	17.9	17.9	7.8	7.8	7.8
Treated discharge water 1,000 mL/L	25.9	25.9	25.9	100	100	100	17.9	17.9	17.9	7.7	7.7	7.7
Laboratory control	25.1	25.1	25.1	99	99	99	18.2	18.2	18.2	7.8	7.8	7.8

DATE	2013.11.19 - Day 12											
Concentration (mL/L)	Temp. (°C)			Oxygen (% saturation)			Salinity (PSU)			pH		
	A	B	C	A	B	C	A	B	C	A	B	C
Control discharge water	25.5	25.5	25.5	100	100	100	18.0	18.0	18.1	8.1	8.1	8.1
Treated discharge Water 250mL/L	25.6	25.6	25.5	99	99	99	18.2	18.1	18.1	7.9	8.0	8.0
Treated discharge water 500 mL/L	25.5	25.5	25.5	98	97	97	18.0	18.0	18.0	8.0	8.1	8.1
Treated discharge water 1,000 mL/L	25.5	25.5	25.5	90	91	92	18.1	18.0	18.1	8.1	8.1	8.1
Laboratory control	25.5	25.5	25.5	100	100	100	18.4	18.4	18.4	8.1	8.1	8.0

C.3 Larval growth test

T-test on lengths (mm)

Replicate No.	Control discharge water	Treated discharge water 250 mL/L	Treated discharge water 500 mL/L	Treated discharge water 1,000 mL/L	Laboratory control
	Lengths (mm)				
1	4.0	4.0	4.0	4.0	4.0
2	4.0	3.9	4.0	4.0	3.9
3	4.0	3.9	3.9	3.9	3.9
4	4.0	3.9	4.0	3.9	4.0
5	4.1	4.0	3.9	4.0	4.0
6	4.0	4.0	4.0	4.0	4.1
7	4.0	4.0	4.0	4.0	4.0
8	3.9	4.1	3.9	4.0	3.9
9	4.0	4.0	3.8	4.0	4.0
10	4.1	4.0	4.0	4.0	3.9
11	4.0	4.0	4.0	3.9	4.0
12	3.9	4.0	4.0	4.0	3.9
13	4.0	4.1	4.0	4.0	3.9
14	4.0	4.0	4.1	3.9	4.1
15	4.2	4.1	3.9	3.8	3.9
16	4.1	4.1	4.0	4.0	3.9
17	4.0	4.2	4.0	4.0	4.1
18	3.9	4.0	3.9	4.0	4.1
19	3.9	3.9	3.9	4.0	4.0
20	3.9	4.0	3.9	4.0	4.1
21	3.9	4.0	4.0	4.0	4.0
22	3.9	4.0	4.0	4.0	3.9
23	4.0	4.0	4.0	4.0	4.1
24	3.9	4.0	4.0	4.0	3.9
25	4.0	3.9	4.1	4.0	4.0
26	4.0	4.0	4.0	4.0	4.0
27	4.0	4.0	3.9	3.9	4.0
28	4.0	4.0	4.0	4.0	4.0
29	3.9	4.0	4.0	4.0	3.9
30	4.0	3.9	4.0	4.0	4.1
Count	30	30	30	30	30
Mean	4.0	4.0	4.0	4.0	4.0
P-value		0.24	0.23	0.27	0.50
Significantly smaller than control discharge		NO	NO	NO	NO

APPENDIX D

Certificate of compliance, ISO 9001 certificate, accreditation and GLP authorization

COPY

Certificate no: **DS/I093222-A**
Page 1 of 1

Lloyd's Register Certificate of Compliance

Office: **Lloyd's Register EMEA**
Copenhagen Design Support Centre, Statutory Section
Strandvejen 104A, 2nd floor
DK-2900 Hellerup
Denmark

Date: **09 May 2012**

This certificate is issued to **DHI Ballast Water Centre, Denmark**

DHI Ballast Water Centre, Denmark

The Document(s) listed in paragraph 1 of the appendix have been examined for compliance with:

- Resolution MEPC.174(58), Annex part 2

and are found to comply from quality assurance and quality control aspects subject to the following:

1.1. It is required to maintain full and accurate log files in order to demonstrate correct quality measures

1.2. The Quality Assurance Project Plan is a project specific document and should as such be subject to review and commenting prior to each project start-up.

1.3. This design appraisal document is to be kept together with quality management plan.

1.4. Subject certificate is valid until 15 June 2015.

1. The documents listed below have been examined

Drawing No.	Rev.	Title	Status	Date
Date: 07 Sep 2011	**2.3**	**Quality Management Plan**	**B**	**09 May 2012**

2. The documents listed below have been considered together with the submitted documents in the appraisal

Drawing No.	Rev.	Title
11810704	**02**	**Quality Assurance Project Plan**

Appraisal Status Key

B Examined and found to comply with §2.2, Part 2 of the annex of IMO Resolution MEPC 174 (58)

Martin Schabert
Statutory Department
Copenhagen Design Support Centre
Surveyor to Lloyd's Register EMEA

LLOYD'S REGISTER EMEA
Lloyd's Register
M. Schabert
COPENHAGEN DESIGN SUPPORT CENTRE

A member of the Lloyd's Register Group

Lloyd's Register, its affiliates and subsidiaries and their respective officers, employees or agents are, individually and collectively, referred to in this clause as the 'Lloyd's Register Group'. The Lloyd's Register Group assumes no responsibility and shall not be liable to any person for any loss, damage or expense caused by reliance on the information or advice in this document or howsoever provided, unless that person has signed a contract with the relevant Lloyd's Register Group entity for the provision of this information or advice and in that case any responsibility or liability is exclusively on the terms and conditions set out in that contract.

Form 1124 (2005.02)

This is a copy of an electronic document. In the event of any conflict or ambiguity between the copy and the electronic document, which is retained and published by Lloyd's Register, the original electronic and certified version shall always prevail.

DNV BUSINESS ASSURANCE

MANAGEMENT SYSTEM CERTIFICATE

Certificate No. 109333-2012-AQ-DEN-DANAK

This is to certify that

DHI Group

has been found to conform to the management system standard:

DS/EN ISO 9001:2008

This certificate is valid for the following product or service ranges:

Consulting, software, research & development and laboratory testing, analysis & products within the area of water, environment & health

Locations included in the certification will appear in the appendix.

Place and date:

Hellerup, 2014-01-14

DET NORSKE VERITAS,
BUSINESS ASSURANCE, DANMARK A/S

This certificate is valid until:

2015-01-10

DANAK
SYSTEM Reg.nr. 5001

The audit has been performed under the supervision of:

Henrik Bjørnstrup
Lead Auditor

Lars Appel
Managing Director

Lack of fulfilment of conditions as set out in the Certification Agreement may render this certificate invalid.

DNV BUSINESS ASSURANCE

APPENDIX TO CERTIFICATE

This appendix refers to certificate no. 109333-2012-AQ-DEN-DANAK

DHI Group

Locations included in the certification are as follows:

Site Address	Scope:
Agern Allé 5 2970 Hørsholm, Denmark	Consulting, MIKE by DHI Software Development, MIKE by DHI & MIKE by DHI Customised software sales, MIKE by DHI & MIKE by DHI Customised software support, Solutions Software development, Research, Development & Innovation, Laboratory Analysis, Testing & Products
INCUBA Science Park**,** Gustav Wieds Vej 10 8000 Århus, Denmark	Consulting, Solutions Software Development and Research, Development & Innovation
c/o Department of Geography and Geology, University of Copenhagen, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark	Consulting
Drakegatan 6, S-412 50 Göteborg, Sweden	Consulting, MIKE by DHI & MIKE by DHI Customised Software Support, Research, Development & Innovation
Södra Tullgatan 4, S-211 41 Malmö, Sweden	Consulting, MIKE by DHI & MIKE by DHI Customised Software Sales, MIKE by DHI & MIKE by DHI Customised Software Support, Research, Development & Innovation
Svartmangatan 18, S-111 29 Stockholm, Sweden	Consulting, MIKE by DHI & MIKE by DHI Customised Software Support, Research, Development & Innovation

Lack of fulfilment of conditions as set out in the Certification Agreement may render this certificate invalid.

Honnörsgatan 16, Box 3289, S-350 53 Växjö, Sweden	Consulting, MIKE by DHI & MIKE by DHI Customised Software Sales, MIKE by DHI & MIKE by DHI Customised Software Support, Research, Development & Innovation
1 CleanTech Loop, #03-05 CleanTech One Singapore 637141, Singapore	Consulting, MIKE by DHI & MIKE by DHI Customised Software Sales MIKE by DHI & MIKE by DHI Customised Software Support, Solutions Software Development, Research, Development & Innovation, Laboratory Analysis & Testing, Health & Safety, Environment
3A01-02, Block G, Pusat Dagangan Phileo Damansara I, No. 9, Jalan 16/11, Off Jalan Damansara, 46350 Petaling Jaya, Selangor, Malaysia	Consulting, MIKE by DHI Software Sales & Solutions Software Development, Research, Development & Innovation
11th Floor, Wisma Perindustrian, Jalan Istiadat, Likas, 88400 Kota Kinabalu, Sabah, Malaysia	Consulting, MIKE by DHI Software Sales and Solutions Software Development, Research, Development & Innovation
IIIrd Floor, NSIC – STP Complex, NSIC Bhawan, Okhla Industrial Estate, New Delhi – 110020, India	Consulting, MIKE by DHI Software Sales & Support and Solutions Software Development, Research, Development & Innovation
Level 5, 67 Astor Terrace, Spring Hill Brisbane QLD 4000, Australia	Consulting, Solutions Software Development
Level 2, 12 Short Street Southport QLD 4215, Gold Coast, Australia	Consulting, MIKE by DHI & MIKE by DHI Customised Software Sales MIKE by DHI & MIKE by DHI Customised Software Support
Suite 8.01, Level 8, 50 Clarence Street, Sydney NSW 2001, Australia	Consulting
Suite 146, Equus Center 580 Hay Street, Perth WA 6000, Australia	Consulting
101 E Centre, Oaklands Rd, Albany 0752, Auckland, New Zealand	Consulting, MIKE© by DHI Software Sales & Support and Solutions Software Development
First Floor, 192 Papanui Road Merivale, Christchurch 8141, New Zealand	Consulting, MIKE© by DHI Software Sales & Support and Solutions Software Development
2/4 rue Edouard Nignon, CS 47202, 44372 Nantes Cedex 3	Consulting, MIKE by DHI & MIKE by DHI Customised software sales, MIKE by DHI & MIKE by DHI Customised software support
Waltersdorfer Straße 105, 12526 Berlin-Bohnsdorf	Consulting, MIKE© by DHI Software Development, Sales & Support
Comeniusstraße 109, 01309 Dresden	Consulting, Solutions Software development

Max-Planck-Straße 6, 28857 Syke, Germany	Consulting, MIKE by DHI & MIKE by DHI Customised software sales, MIKE by DHI & MIKE by DHI Customised software support
Volmerstraße 8, 12489 Berlin, Germany	Consulting MIKE by DHI Software Development, MIKE by DHI & MIKE by DHI Customised software sales, MIKE by DHI & MIKE by DHI Customised software support, Solutions Software development
Via Pomba 23, 10123 Torino, Italy	Consulting, MIKE by DHI & MIKE by DHI Customised software sales, MIKE by DHI & MIKE by DHI Customised software support
Via Operai, 40/19, 16149 Genova, Italy	Consulting, MIKE by DHI & MIKE by DHI Customised software sales, MIKE by DHI & MIKE by DHI Customised software support
Gaustadalléen 21, 0349 Oslo, Norway	Consulting, MIKE by DHI & MIKE by DHI Customised software sales, MIKE by DHI & MIKE by DHI Customised software support
Abels gate 5, 7030 Trondheim, Norway	Consulting, MIKE by DHI & MIKE by DHI Customised software sales, MIKE by DHI & MIKE by DHI Customised software support

Place and date:

Hellerup, 2014-01-14

DET NORSKE VERITAS,
BUSINESS ASSURANCE, DANMARK A/S

This certificate is valid until:

2015-01-10

DANAK
SYSTEM Reg.nr. 5001

The audit has been performed under the supervision of:

Henrik Bjørnstrup
Lead Auditor

Lars Appel
Managing Director

Lack of fulfilment of conditions as set out in the Certification Agreement may render this certificate invalid.

Accreditation to testing

COPY

DANAK

Company:	**DHI**
	Agern Allé 5 **DK-2970 Hørsholm**
Registration number:	**26**
Valid:	**24-10-2012 to 31-07-2015**

Scope:

Testing

Product

- **Biological items**
- **Chemicals and chemical products**
- **Construction products**
- **Environmental samples**

Test Type

- **Biological and biochemical testing**
- **Chemical testing**
- **Microbiological testing**
- **Ionising radiation and radiochemistry**
- **Sampling**

Testing is performed according to the current list of test methods approved by DANAK.

The company complies with the criteria in EN ISO/IEC 17025:2005 – General requirements for the competence of testing and calibration laboratories and demonstrates technical competence for the defined scope and the operation of a quality management system (refer joint ISO-ILAC-IAF Communiqué dated January 2009, www.danak.dk).

Issued the 24 October 2012

Jesper Høy / **Kirsten Jebjerg Andersen**

In case of any disputes, the Document in Danish language shall have priority.

COPY

DANAK

GOOD LABORATORY PRACTICE

STATEMENT OF COMPLIANCE

Laboratory inspection and study audits for compliance with the OECD Principles for Good Laboratory Practice were carried out at

Laboratory: DHI

on

Dates: 21st and 22nd October 2011

The laboratory inspection and study audits have been carried out in accordance with the regulation settled in Order No. 906 of 14th September 2009 from the Danish Ministry of Environment. The laboratory has been monitored for GLP Compliance within the following scope:

Type of products:

- *Industrial chemicals*
- *Pesticides*
- *Biocides*

Type of tests:

- *Environmental toxicity studies on aquatic and terrestrial organisms.*
- *Studies of behaviour in water, soil and air, bioaccumulation*

The laboratory was found to be operating in compliance with the OECD Principles of Good Laboratory Practice.

Date: 08 August 2012

Jesper Høy
Managing director, DANAK

Kirsten Jebjerg Andersen
GLP inspector, DANAK

APPENDIX 6

Quality control and quality assurance for performance evaluation in land-based test facility with the BAWAT BWMS

Quality control and quality assurance	Description	Overall responsible
Quality control, data from laboratory analyses and database entries	All results related to samples and laboratory analyses are stored in relevant databases. All data entries in databases have been quality controlled. Laboratory records are filed in the DHI archives.	Last data entry 25 April 2014 Camilla Hedberg
Quality control, onsite data from the DHI Maritime Technology Evaluation Facility, Hundested	Logging of data related to the activities at the test facility was conducted for each individual test cycle. Operational data and extracts from the DHI online monitoring system were quality controlled as part of the reporting process. Onsite data records are filed in the DHI archives.	Quality control last data set 26 June 2014 Camilla Hedberg
Quality control, draft final report	Data and data interpretation related to the present performance evaluation have been quality controlled, and all data are truly and accurately presented in the final report.	Quality control final report 7 July 2014 Torben Madsen
Quality control, final report	Data and data interpretation related to the present performance evaluation have been quality controlled, and all data are truly and accurately presented in the final report.	Quality control final report 17 September 2014 Torben Madsen
Quality assurance (final report)	The performance evaluation in land-based test facility for the BAWAT BWMS complies with the conditions outlined in the QMP, QAPP and SOPs. The performance evaluation was conducted in compliance with the IMO G8 guidelines. The guidance requirements for biological efficacy test cycles were consistently fulfilled except for minor deviations, which were considered negligible and were appropriately addressed in the final report	Quality assurance of project 15 September 2014 Louise Schlüter

APPENDIX 7

Certificate of compliance, ISO 9001 certificate, accreditation and GLP authorisation

COPY

Certificate no: **DS/I093222-A**
Page 1 of 1

Lloyd's Register Certificate of Compliance

Office: **Lloyd's Register EMEA**
Copenhagen Design Support Centre, Statutory Section
Strandvejen 104A, 2nd floor
DK-2900 Hellerup
Denmark

Date: **09 May 2012**

This certificate is issued to **DHI Ballast Water Centre, Denmark**

DHI Ballast Water Centre, Denmark

The Document(s) listed in paragraph 1 of the appendix have been examined for compliance with:

- Resolution MEPC.174(58), Annex part 2

and are found to comply from quality assurance and quality control aspects subject to the following:

1.1. It is required to maintain full and accurate log files in order to demonstrate correct quality measures

1.2. The Quality Assurance Project Plan is a project specific document and should as such be subject to review and commenting prior to each project start-up.

1.3. This design appraisal document is to be kept together with quality management plan.

1.4. Subject certificate is valid until 15 June 2015.

1. The documents listed below have been examined

Drawing No.	Rev.	Title	Status	Date
Date: 07 Sep 2011	**2.3**	**Quality Management Plan**	**B**	**09 May 2012**

2. The documents listed below have been considered together with the submitted documents in the appraisal

Drawing No.	Rev.	Title
11810704	**02**	**Quality Assurance Project Plan**

Appraisal Status Key

B Examined and found to comply with §2.2, Part 2 of the annex of IMO Resolution MEPC 174 (58)

Martin Schabert
Statutory Department
Copenhagen Design Support Centre
Surveyor to Lloyd's Register EMEA

LLOYD'S REGISTER EMEA
Lloyd's Register
M. Schabert
COPENHAGEN DESIGN SUPPORT CENTRE

A member of the Lloyd's Register Group

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Form 1124 (2005.02)

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DNV BUSINESS ASSURANCE

MANAGEMENT SYSTEM CERTIFICATE

Certificate No. 109333-2012-AQ-DEN-DANAK

This is to certify that

DHI Group

has been found to conform to the management system standard:

DS/EN ISO 9001:2008

This certificate is valid for the following product or service ranges:

Consulting, software, research & development and laboratory testing, analysis & products within the area of water, environment & health

Locations included in the certification will appear in the appendix.

Place and date:

Hellerup, 2014-01-14

DET NORSKE VERITAS,
BUSINESS ASSURANCE, DANMARK A/S

This certificate is valid until:

2015-01-10

DANAK
SYSTEM Reg.nr. 5001

The audit has been performed under the supervision of:

Henrik Bjørnstrup
Lead Auditor

Lars Appel
Managing Director

Lack of fulfilment of conditions as set out in the Certification Agreement may render this certificate invalid.

DNV BUSINESS ASSURANCE

APPENDIX TO CERTIFICATE

This appendix refers to certificate no. 109333-2012-AQ-DEN-DANAK

DHI Group

Locations included in the certification are as follows:

Site Address	Scope:
Agern Allé 5 2970 Hørsholm, Denmark	Consulting, MIKE by DHI Software Development, MIKE by DHI & MIKE by DHI Customised software sales, MIKE by DHI & MIKE by DHI Customised software support, Solutions Software development, Research, Development & Innovation, Laboratory Analysis, Testing & Products
INCUBA Science Park**,** Gustav Wieds Vej 10 8000 Århus, Denmark	Consulting, Solutions Software Development and Research, Development & Innovation
c/o Department of Geography and Geology, University of Copenhagen, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark	Consulting
Drakegatan 6, S-412 50 Göteborg, Sweden	Consulting, MIKE by DHI & MIKE by DHI Customised Software Support, Research, Development & Innovation
Södra Tullgatan 4, S-211 41 Malmö, Sweden	Consulting, MIKE by DHI & MIKE by DHI Customised Software Sales, MIKE by DHI & MIKE by DHI Customised Software Support, Research, Development & Innovation
Svartmangatan 18, S-111 29 Stockholm, Sweden	Consulting, MIKE by DHI & MIKE by DHI Customised Software Support, Research, Development & Innovation

Lack of fulfilment of conditions as set out in the Certification Agreement may render this certificate invalid.

Honnörsgatan 16, Box 3289, S-350 53 Växjö, Sweden	Consulting, MIKE by DHI & MIKE by DHI Customised Software Sales, MIKE by DHI & MIKE by DHI Customised Software Support, Research, Development & Innovation
1 CleanTech Loop, #03-05 CleanTech One Singapore 637141, Singapore	Consulting, MIKE by DHI & MIKE by DHI Customised Software Sales MIKE by DHI & MIKE by DHI Customised Software Support, Solutions Software Development, Research, Development & Innovation, Laboratory Analysis & Testing, Health & Safety, Environment
3A01-02, Block G, Pusat Dagangan Phileo Damansara I, No. 9, Jalan 16/11, Off Jalan Damansara, 46350 Petaling Jaya, Selangor, Malaysia	Consulting, MIKE by DHI Software Sales & Solutions Software Development, Research, Development & Innovation
11th Floor, Wisma Perindustrian, Jalan Istiadat, Likas, 88400 Kota Kinabalu, Sabah, Malaysia	Consulting, MIKE by DHI Software Sales and Solutions Software Development, Research, Development & Innovation
IIIrd Floor, NSIC – STP Complex, NSIC Bhawan, Okhla Industrial Estate, New Delhi – 110020, India	Consulting, MIKE by DHI Software Sales & Support and Solutions Software Development, Research, Development & Innovation
Level 5, 67 Astor Terrace, Spring Hill Brisbane QLD 4000, Australia	Consulting, Solutions Software Development
Level 2, 12 Short Street Southport QLD 4215, Gold Coast, Australia	Consulting, MIKE by DHI & MIKE by DHI Customised Software Sales MIKE by DHI & MIKE by DHI Customised Software Support
Suite 8.01, Level 8, 50 Clarence Street, Sydney NSW 2001, Australia	Consulting
Suite 146, Equus Center 580 Hay Street, Perth WA 6000, Australia	Consulting
101 E Centre, Oaklands Rd, Albany 0752, Auckland, New Zealand	Consulting, MIKE© by DHI Software Sales & Support and Solutions Software Development
First Floor, 192 Papanui Road Merivale, Christchurch 8141, New Zealand	Consulting, MIKE© by DHI Software Sales & Support and Solutions Software Development
2/4 rue Edouard Nignon, CS 47202, 44372 Nantes Cedex 3	Consulting, MIKE by DHI & MIKE by DHI Customised software sales, MIKE by DHI & MIKE by DHI Customised software support
Waltersdorfer Straße 105, 12526 Berlin-Bohnsdorf	Consulting, MIKE© by DHI Software Development, Sales & Support
Comeniusstraße 109, 01309 Dresden	Consulting, Solutions Software development

Max-Planck-Straße 6, 28857 Syke, Germany	Consulting, MIKE by DHI & MIKE by DHI Customised software sales, MIKE by DHI & MIKE by DHI Customised software support
Volmerstraße 8, 12489 Berlin, Germany	Consulting MIKE by DHI Software Development, MIKE by DHI & MIKE by DHI Customised software sales, MIKE by DHI & MIKE by DHI Customised software support, Solutions Software development
Via Pomba 23, 10123 Torino, Italy	Consulting, MIKE by DHI & MIKE by DHI Customised software sales, MIKE by DHI & MIKE by DHI Customised software support
Via Operai, 40/19, 16149 Genova, Italy	Consulting, MIKE by DHI & MIKE by DHI Customised software sales, MIKE by DHI & MIKE by DHI Customised software support
Gaustadalléen 21, 0349 Oslo, Norway	Consulting, MIKE by DHI & MIKE by DHI Customised software sales, MIKE by DHI & MIKE by DHI Customised software support
Abels gate 5, 7030 Trondheim, Norway	Consulting, MIKE by DHI & MIKE by DHI Customised software sales, MIKE by DHI & MIKE by DHI Customised software support

Place and date:

Hellerup, 2014-01-14

DET NORSKE VERITAS,
BUSINESS ASSURANCE, DANMARK A/S

This certificate is valid until:

2015-01-10

DANAK
SYSTEM Reg.nr. 5001

The audit has been performed under the supervision of:

Henrik Bjørnstrup
Lead Auditor

Lars Appel
Managing Director

Lack of fulfilment of conditions as set out in the Certification Agreement may render this certificate invalid.

Accreditation to testing

COPY

DANAK

Company:	**DHI**
	Agern Allé 5 **DK-2970 Hørsholm**
Registration number:	**26**
Valid:	**24-10-2012 to 31-07-2015**

Scope:

Testing

Product

- **Biological items**
- **Chemicals and chemical products**
- **Construction products**
- **Environmental samples**

Test Type

- **Biological and biochemical testing**
- **Chemical testing**
- **Microbiological testing**
- **Ionising radiation and radiochemistry**
- **Sampling**

Testing is performed according to the current list of test methods approved by DANAK.

The company complies with the criteria in EN ISO/IEC 17025:2005 – General requirements for the competence of testing and calibration laboratories and demonstrates technical competence for the defined scope and the operation of a quality management system (refer joint ISO-ILAC-IAF Communiqué dated January 2009, www.danak.dk).

Issued the 24 October 2012

Jesper Høy / **Kirsten Jebjerg Andersen**

In case of any disputes, the Document in Danish language shall have priority.

COPY

DANAK

GOOD LABORATORY PRACTICE

STATEMENT OF COMPLIANCE

Laboratory inspection and study audits for compliance with the OECD Principles for Good Laboratory Practice were carried out at

Laboratory: DHI

on

Dates: 21st and 22nd October 2011

The laboratory inspection and study audits have been carried out in accordance with the regulation settled in Order No. 906 of 14th September 2009 from the Danish Ministry of Environment. The laboratory has been monitored for GLP Compliance within the following scope:

Type of products:

- *Industrial chemicals*
- *Pesticides*
- *Biocides*

Type of tests:

- *Environmental toxicity studies on aquatic and terrestrial organisms.*
- *Studies of behaviour in water, soil and air, bioaccumulation*

The laboratory was found to be operating in compliance with the OECD Principles of Good Laboratory Practice.

Date: 08 August 2012

Jesper Høy
Managing director, DANAK

Kirsten Jebjerg Andersen
GLP inspector, DANAK