

Testing the BIO-SEA ballast water management system; Filter efficiency tests with high levels of zooplankton

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Report C033.14



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Publication date:

March 2015

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Summary

The BIO-SEA® Ballast Water Treatment System (BWTS) was tested at the IMARES land-based test facility. General goal of the tests was to compare two different brands of filter and to test the filter efficiency of finer mesh sizes of each brand. The filters were tested in combination with a 'one-shot UV-treatment' (ballasting and deballasting the same day) in order to evaluate the effect of the filters on the overall treatment efficacy.

Two test series were performed at a TRC (Treatment Rated Capacity) of 100 m³/h:

F1) using only the automatic Filtrex line and natural water:

F1.1: with 40 µm mesh + UV

F1.2: with 20 µm mesh + UV

F2) using only the manual Filtersafe line and natural water:

F2.1: with 40 µm mesh + UV

F2.2: with 25 µm mesh + UV

The tests were conducted on 4 different days in a two week period. Between F1 and F2 the challenge water in the feed tank was replenished with local surface water.

The following conclusions were drawn from the test results:

- The retention rate of the 40 µm meshes was >99% for both filters.
- This improved to approx. 99.99% for the fine meshes.
- The backwash frequency of the Filtersafe increased 2.5 times using the 25 µm filter.
- The backwash frequency of the Filtrex unit remained the same, but was high already.
- The fine meshes had only a marginal effect on water quality parameters relevant for the UV-treatment.
- For the organisms in size class ≥ 10 -<50µm, mesh size did not affect treatment efficacy.
- At the low UVt tested, a 'one-shot treatment' is not sufficient. A prolonged holding time is needed.
- Cell counts based upon vital staining overestimate the number of viable cells due to delayed mortality.

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1 Introduction

In autumn 2013, the BIO-SEA[®] Ballast Water Treatment System (BWTS) was tested at the IMARES land-based test facility in Den Helder, The Netherlands for BIO-UV. General goal of the tests was to compare two different brands of filter, to test filter efficiency of finer mesh sizes of each brand, and to test the efficacy of the BWTS at different levels of UV-t and different retention times between first and second UV-dose.

This report contains the results of the filter tests that were conducted at in September 2013. In four test series of two test-runs each, the filter efficiency and BWMS efficacy was tested in using two brands of filter and two mesh-sizes for each filter in combination with UV-treatment.

The tests with different UV-t and holding times are reported separately (Foekema *et al.*, 2014, IMARES report C038.14).

2 The IMARES test facility

The IMARES facility for land-based testing is located at Spoorhaven in Den Helder, The Netherlands. This location is less than 5 km distance from the IMARES laboratory. Location Spoorhaven is a freshwater harbour at the northern end of the 'Noord-Hollandskanaal', which connects Amsterdam to the Wadden Sea.

2.1 Facility characteristic

The test facility consists of two 250 m³ test tanks and one large 730 m³ feed tank. The feed tank can be used to create the required test water for the ballast water tests, meaning that in this tank parameters like salinity, UV-t, TSS, DOC and organic load, as well as organism density can be controlled. If necessary, components may also be injected directly in-line during the treatment, instead of adding them to the feed tank. By using barges that regularly sail through the canal with sand and gravel, also water from different origins can be collected and transported to the test facility. For instance, water from the peat area near Amsterdam, water from Lake IJssel (originating from the River Rhine) but also brackish and marine water from Den Helder harbour, Wadden Sea and North Sea. Samples can be drawn from different points in the facility according to IMO G8 guidelines and USCG ETV protocols. The basic idea is that samples can be drawn from the challenge water before and after pumping, before and after treatment through a BWTS, the test water stored in the tanks and the discharge water. Depending on the analysis connected to the sample, different types of isokinetic sample ports are available (e.g. discrete, continuous sampling).



Figure 1 The IMARES test facility where the tests were performed, with on the right the 730 m³ feed tank and on the left the two 250 m³ test tanks

2.2 Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 124296-2012-AQ-NLD-RvA). This certificate is valid until 15 December 2015. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Fish Division has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 1th of April 2017 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

3 BIO-SEA® Ballast Water Treatment System

The BIO-SEA®UV BWTS combines mechanical filtration at 40 µm and UV disinfection with medium pressure technology. The treatment system has been designed to be modular and compact, and is type approved to treat flow rates ranging from 100 to 2000 m³/h, increasing filter size and using parallel-mounted UV reactors to reach the adequate TRC (Treatment Rated Capacity, IMO G8). It operates automatically and regulates power consumption depending on water quality. The treatment process includes three steps: (1) filtration upon ballasting, (2) followed by UV treatment upon ballasting, and (3) UV treatment on discharge (filter is by-passed).



Figure 2 Example of a BIO-SEA®100 with Filtrex filter (skid configuration)

Two systems were installed at IMARES test facility in a 20" container, both with TRC = 100 m³/h:

- Filtersafe line: one BIO-SEA® system equipped with Filtersafe filter (BS-050-H) and 1 UV reactor.
- Filtrex line: one BIO-SEA® system equipped with Filtrex filter (ACB-910) and 1 UV reactor.

Two filtering baskets are available for each filter:

- The regular mesh for the approved system (40 µm)
- A lower mesh size (20 µm for the Filtrex, and 25 µm for the Filtersafe)

For technical (set-up) reasons, the Filtrex line was automatically operated, while the valves on the Filtersafe line were manual.

A technical drawing of the container set-up can be found in the Appendix.

4 Test set-up

Two test series have been performed:

F1) using only the automatic Filtrex line and natural water:

F1.1: one complete run at 100 m³/h with 40 µm mesh + UV (ballasting and deballasting the same day)

F1.2: one complete run at 100 m³/h with 20 µm mesh + UV (ballasting and deballasting the same day)

F2) using only the manual Filtersafe line and natural water:

F2.1: one complete run at 100 m³/h with 40 µm mesh + UV (ballasting and deballasting the same day)

F2.2: one complete run at 100 m³/h with 25 µm mesh + UV (ballasting and deballasting the same day)

Due to the number of analyses and the need to clean the system and replace the mesh, the four tests were conducted on four different days in a two week period. Between the F1 and F2 series, the water in the feed tank was replenished with Spoorhaven water.



Figure 3 The BIO-SEA BWMS container connected to the main piping system

Sample codes used:

CBW	Untreated Control Ballast Water, taken after the pump, before the filter during ballasting
uTBW	Treated Ballast Water taken during ballasting (Uptake) after the filter and the first UV treatment.
dTBW	Treated Ballast Water taken during deballasting after the second UV treatment

For organisms in the size class $\geq 50\mu\text{m}$, the difference between CBW and uTBW will be evaluated, as it is known that:

- the filter mainly affects larger organisms (zooplankton), and
- larger (metazoan) organisms are immediately impacted UV-treatments.

For organisms in the size class $\geq 10 - < 50\mu\text{m}$, the difference between CBW and dTBW is evaluated, in order to assess the treating potential of a "one-shot treatment" (*i.e.* ballasting and deballasting sequentially, without prolonged holding time) at the UV-transmittance (UVt) of the challenge water. This is based upon the assumptions that:

- the filter does not retain smaller organisms, and
- small organisms (protozoans) are directly affected by the UV-treatment.

5 Methods

5.1 Sampling

Samples were taken from the main line as a continuous subsample of the main stream by use of a pitot-tube. One sample point is situated after the pump before the treatment system, in order to take samples of the influent (CBW). The other sample point is situated after the treatment system in order to take samples of the treated ballast water (TBW).

The diameter of the pitot-tube is such that with a standard flow of 100 m³/h, approx. 3 m³ sample is generated during processing of 200 m³ test water (following calculations given by IMO, G2). This means that for treated water, the samples for the organism group $\geq 50 \mu\text{m}$ in minimum diameter (minimum 1 m³) are taken continuously during the course of a test run. For organisms 10-50 μm (minimum volume 10 litres) discrete samples were taken approx. half way during the filling of each m³.

For untreated influent water (CBW), three discrete samples were taken during the course of the test run. Here sample volumes were 10 L for the ≥ 10 -<50 μm and 20 L for the $\geq 50 \mu\text{m}$ size classes respectively.

5.2 Environmental parameters

Directly after taking the samples, basic water quality parameters such as temperature, conductivity, pH, dissolved oxygen concentration and turbidity were measured using handheld equipment.

At the laboratory, subsamples were processed for total suspended solids (TSS) analysis: a known volume was filtered on a pre-weighed GF/F filter. The filter was then dried at 100°C and re-weighed.

UV transmittance was analysed on a spectrophotometer at 254 nm, using milli-Q water as reference.

5.3 Operational parameters

Direct flow measurements were not yet implemented at the test facility. Therefore, the flow rate was adjusted to ca. 100 m³/h using a clamp-on flow meter provided by BIO-UV. Flow rate and power consumption were recorded in the BWTS datalog. The pressure before and after the pump was recorded during the tests.

5.4 Determination of organisms in size class ≥ 10 -<50 μm

Living cells were enumerated using fluorescence microscopy. The cells were stained with CMFDA/FDA mixture, which is actively taken up by living cells.

The size class of organisms between 10-50 μm is usually dominated by phytoplankton. Gross phytoplankton presence and the viability of the cells was analysed fluorometrically, using a Moldaencke Automated Lab Analyser (ALA). Chlorophyll-a density is given as $\mu\text{g/l}$ and viability as % activity using genty parameters. The ALA has been developed for and calibrated with freshwater algae. It measures at different wavelengths in order to obtain an indication of the presence and abundance of several main algal groups. A healthy outdoor community normally shows 40-50% activity. When something is wrong, this value may drop to 20% or even lower. When chlorophyll-a levels are close to or below the detection level, the values for activity become unreliable.

Recently, specific fluorometers have been developed for use with ballast water. The Turner BallastCheck (BC) handheld fluorometer was used for comparison with the ALA during the tests. This device only gives

a value for total chlorophyll-a and does not discriminate between algal groups. Chlorophyll-a density is given as $\mu\text{g/l}$ and viability as yield. The BC gives yield values between 0.26 and 0.55 for untreated water, 0.17-0.32 for water after uptake treatment and 0.05-0.14 after discharge treatment (this report).

Phytoplankton organisms were analysed after discharge (dTBW) as it is assumed that they are not seriously affected by filtration and the observed effects will be only due to the UV treatment. However, additional analyses done in test F1 are reported anyway. For the same reason, regrowth experiments (phytoplankton) have only been conducted for discharge samples.

5.5 Die-off/regrowth test for organisms in size class ≥ 10 - $< 50 \mu\text{m}$

To account for slower die-off, which is especially relevant after UV treatment, a 250 ml subsample of each dTBW sample was supplemented with additional nutrients and cultured under optimal growing conditions for several days. The cultures were counted regularly, using the same fluorescent staining method as described above.

The CBW samples were pooled (equal volumes) into one culture, as this only functioned as control for the culture conditions.

5.6 Number of organisms in size class $\geq 50 \mu\text{m}$

The $\geq 50 \mu\text{m}$ size class mainly consists of zooplankton, although some algal species or colonies may occur. The 20 litre CBW, and 1 m^3 TBW samples were first collected in appropriate sized containers and then concentrated into a 200 ml jar, using a standard zooplankton net with a $50 \mu\text{m}$ mesh (diagonal). These samples were stored in an isolated box and were regularly transported to the laboratory for further analysis.

At the laboratory, the CBW samples were transferred into a known volume (weight-based) for the purpose of subsampling. For dilution and cleaning, organism-free influent water from the test facility was used. From this known volume, 1 ml subsamples were taken and counted until at least 100 living organisms were found.

For the treated water, the same procedure was followed, but as the number of surviving organisms was usually very low, the full sample, representing 1 m^3 , was counted.

Organisms were considered alive, when they were moving and structurally intact. Tactile stimulation sometimes was necessary to elicit movement as some organisms may remain immobile for long periods of time.

As counting of numerous organisms takes a lot of time, the number of analyses was restricted to those that were essential for understanding the performance. A direct zooplankton count has been performed at intake before the BIO-SEA system (CBW) and during ballasting after the BIO-SEA system (uTBW), for a direct assessment of filter performance.

6 Results and Discussion

A summary of the set-up and the results of the test runs is given in Table 1. A tabulated overview of the results of the four runs is given in the appendix.

Table 1 Summary of water characteristics and test results of direct analyses

Test run	F1.1	F1.2	F2.1	F2.2
Filter Configuration	Filtrex 40 µm	Filtrex 20 µm	Filtersafe 40 µm	Filtersafe 25 µm
Date	3-9-2014	5-9-2014	10-9-2014	12-9-2014
Flow intake (m ³ /h)	106.0 (±0.0)	103.5 (±1.8)	108.0 (±0.0)	104.7 (±2.5)
Flow discharge (m ³ /h)	102.4 (±3.3)	107.9 (±3.2)	108.3 (±1.2)	104.8 (±0.8)
Pressure (bar)	1.95-2.24	1.93-2.12	1.92-2.12	1.90-2.04
Backwash frequency (min)	4-5	4-5	15-19	7
Water characteristics (CBW, mean±sd)				
UV-T (%)	39.7 (± 3.0)	43.7 (± 0.4)	48.1 (± 0.3)	46.6 (± 0.4)
Salinity (PSU)	2.25 (± 0.05)	2.27 (± 0.01)	1.85 (± 0.01)	1.67 (± 0.01)
TSS (mg/l)	8.4 (± 1.1)	4.7 (± 0.2)	4.8 (± 0.3)	8.5 (± 0.6)
Turbidity (ntu)	4.7 (± 0.2)	2.4 (± 0.1)	3.2 (± 0.1)	5.2 (± 0.1)
Temperature (°C)	22.4 (± 1.5)	20.4 (± 0.3)	18.6 (± 0.2)	17.6 (± 0.2)
Dissolved oxygen (%)	93.6 (± 4.6)	85.7 (± 2.6)	83.5 (± 0.7)	92.4 (± 1.4)
pH	8.31 (± 0.48)	8.72 (± 0.02)	8.41 (± 0.10)	8.74 (± 0.03)
Biology: organisms ≥50µm (n/m³, mean±sd)				
CBW (intake)	317436 (±115578)	606407 (±97000)	261030 (±87296)	230654 (±88376)
uTBW (1 treatment)	13199 (±4309)	179 (±69)	1768 (±1583)	20 (±30)
dTBW (2 treatments)	2509 (±1857)	36 (±19)	308 (±255)	13 (±6)
Retention rate 1 (%)	95.842	99.970	99.323	99.991
Retention rate 2 (%)	99.210	99.994	99.882	99.995
Biology: organisms ≥10 - <50µm (n/ml, mean±sd)				
CBW (intake)	662 (±34)	547 (±90)	4379 (±995)	9134 (±747)
dTBW (2 treatments)	316 (±36)	310 (±20)	868 (±115)	1502 (±225)
Retention rate (%)	52.2	43.3	80.2	83.6

6.1 Sampling

Individual values for each replicate sample (A, B and C) are given as well as the average value for all replicates together. During the 40 µm mesh tests (F1.1 and F2.1), a fourth replicate sample (D) was collected at discharge. Due to water shortage the volumes of these final replicate samples were 625 L and 540 L respectively. Results of the regrowth experiments of these samples deviated markedly from the other samples and were, therefore, excluded from the summary data (Table 1).

For the discharge samples in tests F1.2 and F2.2 less than 3 m³ of water was available for sampling, resulting in dTBW-C samples of 460 L and 900 L respectively.

6.2 Environmental parameters

From test series F1 to series F2, the water in the feed tank was replenished with surface water from the local canal. At the same time it started to rain. From the end of test 1.2 on September 5th, to the start of test F2.1 on September 10th, 8:00 AM, 348 mm rainfall was registered at the nearby meteorological station at Den Helder Airport, followed by another 316 mm until September 12th at 8:00 AM (Source:

KNMI). Consequently, the water characteristics changed slightly between series F1 and F2 (Table 5 to Table 8 in the Appendix), as in total 125 m³ rainwater was added to the feed tank. Due to the rainfall, salinity and temperature were lower in the second test series, while UVt slightly increased.

Turbidity and TSS in the test water were low. For freshwater tests, IMO guidelines (G8) indicate a minimum of 50 mg/l, which is 5-10 times higher than was observed in the current test. Turbidity and TSS were not affected by the mesh size of the filtration unit. Although a slight improvement was seen in most cases, for the Filtrex the effect of the 40µm mesh appeared stronger than the 20µm mesh (Table 2). The UVt% increased approx. 1% in all cases, except for the Filtrex 40µm mesh (F1.1), where the difference was larger. This test also showed a relative large difference between sequential samples.

The above results suggest incomplete mixing in the feed tank, resulting in a relative high density of 'large' material during the first run (F1.1) compared to the second (F1.2). Prior to the third run (F2.1) the feed tank was refilled and this well mixed, but due to enhanced settling out, the levels of material (TSS) were again higher in the fourth (F2.2).

Table 2 Overview of water quality parameters that may interfere with UV-treatment

Test run - mesh	UVt (%)		TSS (mg/l)		Turbidity (ntu)	
	CBW	uTBW	CBW	uTBW	CBW	uTBW
F1.1 Filtrex 40µm	39.7	44.7	8.4	6.0	4.7	4.5
F1.2 Filtrex 20µm	43.7	44.5	4.7	4.0	2.4	2.4
F2.1 Filtersafe 40µm	48.1	49.0	4.8	4.2	3.2	3.0
F2.2 Filtersafe 25µm	46.6	47.5	8.5	6.7	5.2	4.7

6.3 Organisms ≥50 µm

The density of living zooplankton (dominating size group ≥50 µm), was slightly reduced after water replenishment between tests F1 and F2. Especially during test F1.2 the density of zooplankton was very high with 500,000 to 700,000 individuals per m³. Detailed results are given in Table 9 to Table 12 in the appendix. The effect of the filter shows clearly in Figure 4 (note log-scaling). The number of living organisms in the uTBW samples is strongly reduced compared to the CBW samples (95% to 99% reduction). This is more strongly the case for the finer mesh sizes (>99% reduction).

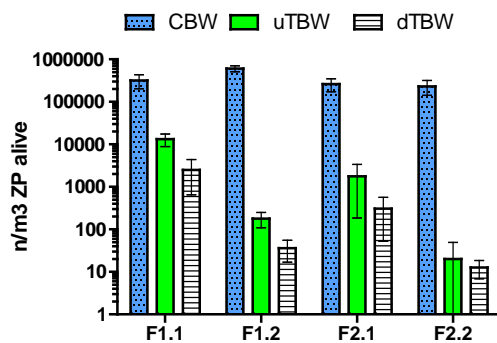


Figure 4 Living organisms ≥50 µm (zooplankton; ZP). Average of three samples (four samples in dTBW F1.1 and F2.1).

During analysis of the samples of the first tests (F1.1 and F1.2), high numbers of dead copepod nauplii were observed in the samples, but these were not counted as it was considered to be an effect of the pump. Later it was realised that they were still relevant for filter performance and the dead organisms were counted in the samples of the F2 tests. The analysis of the total number of nauplii could not be completed for all replicate samples and these results should, therefore, be considered indicative.

The analyses are most complete for the second test series with the Filtersafe line. Here the 40µm mesh removed only 30% of the total nauplii, whereas the 25µm mesh removed nearly 97% (Figure 5, note that y-axis has logarithmic scaling). The actual numbers are given in *Table 11* and *Table 12* in the appendix. A further reduction was realised by the second (UV) treatment, but not as efficient as filtration. The pattern for the Filtrex line, although incomplete, is similar.

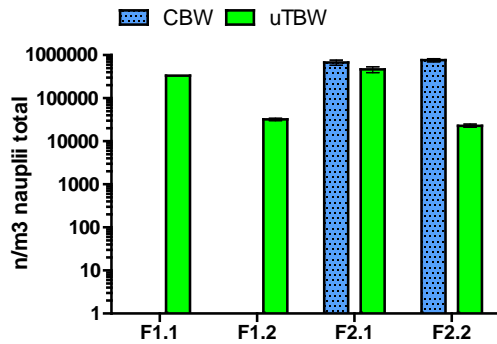


Figure 5 Total copepod nauplii counted in 1 ml subsample

6.4 Organisms ≥ 10 - < 50 µm

With the replenishment of water between the F1 and F2 tests, the abundance of phytoplankton (the main constituent of the group ≥ 10 - < 50 µm) increased. This was notable in the cell counts (Figure 6), as well as in chlorophyll-a concentrations (Figure 7). The direct effect of the treatments on cell counts and total chlorophyll-a was limited (Figure 6 and Figure 7), but viability directly decreased (Figure 8) showing the impact of UV on the algae. The mesh size had no apparent influence, as is witnessed by the results of uTBW samples (not fully assessed with cell counts for this size class, but with comparable results using ALA). Detailed results are given in *Table 9* to *Table 12* in the appendix.

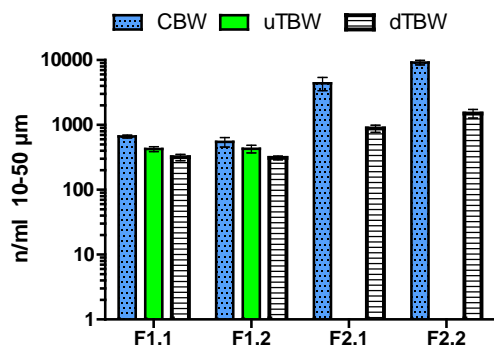


Figure 6 Counts of living cells

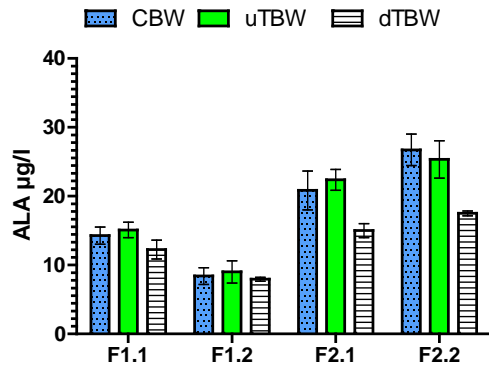


Figure 7 Concentration Chlorophyll-a (ALA)

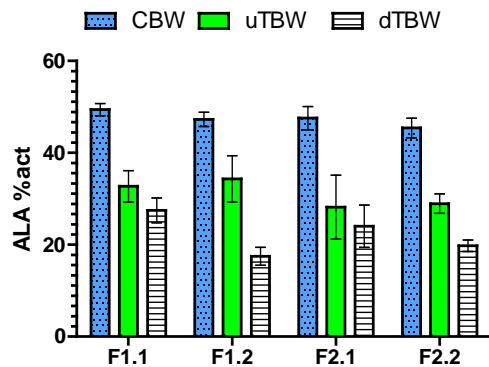


Figure 8 Viability (measured as % activity)

The Moldaencke ALA has been developed for biological research of freshwater and not to analyse the effect of ballast water treatment with its accompanying extreme low levels of living algae. The ALA measures chlorophyll-a using fluorescence and the activity of the photosynthetic system using the genty method. The limit of detection of the ALA is 3-5 µg/l chl-a. The % activity in a healthy outdoor phytoplankton community is usually between 40% and 50%, dropping to 20% or lower when something is wrong. Usually, the activity does not fall below 10% as long as chlorophyll-a is above detection levels, indicating that the genty parameter is not an absolute measure of death.

For reasons of comparison, the Turner Ballast Check was used in parallel. The BC has been developed especially for the assessment of ballast water and uses PAM-measurements to assess the activity of the photosynthetic system (expressed as yield). The yield seems unstable <0.05, indicating that is probably close to the detection limit. Overall, ALA and BC showed similar results, with activity/yield as viability indicators decreasing after each UV-treatment. The BC measurements showed larger differences between each step from CBW, via uTBW to dTBW. Neither of the assessments indicated full mortality.

Table 3 Overview of bulk phytoplankton assessments

Test run - mesh	ALA act%			BC yld		
	CBW	uTBW	dTBW	CBW	uTBW	dTBW
F1.1 Filtrex 40µm	49.4	32.7	27.5	0.41	0.24	0.11
F1.2 Filtrex 20µm	47.3	34.5	17.5	0.41	0.20	0.10
F2.1 Filtersafe 40µm	47.6	28.2	23.9	0.51	0.27	0.09
F2.2 Filtersafe 25µm	45.4	28.9	19.8	0.53	0.27	0.09

6.5 Additional comments

The UV-treatment did not reduce the cell number to levels below the D-2 standard (10 living cells/ml). During the die-off/regrowth experiments with the dTBW samples, a further reduction in cell numbers was observed until 3-4 days after the treatment, due to delayed mortality. The resulting numbers of living cells remained higher than 10 cells/ml (Figure 9).

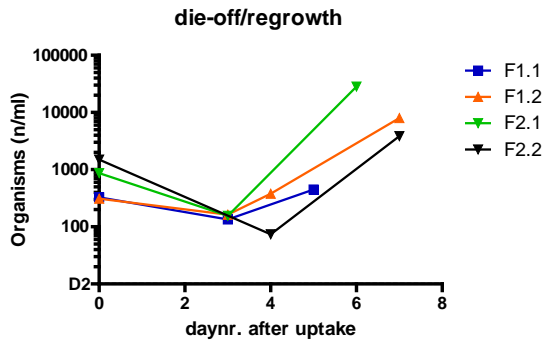


Figure 9 Counts of living cells in die off/regrowth cultures

A remarkable observation was the rapid regrowth of phytoplankton in the dTBW-D samples taken during tests F1.1 and F2.1. This was not indicated by the first analyses on the test days (see Table 9 and Table 11 in the appendix). It is probable that these samples, taken at the end of the uptake period, were somehow contaminated with untreated phytoplankton. Therefore, these samples were excluded from the analyses.

Table 4 Overview of regrowth results.

Test run	F1.1	F1.2	F2.1	F2.2
Filter Configuration	Filtrex 40 μ m	Filtrex 20 μ m	Filtersafe 40 μ m	Filtersafe 25 μ m
Regrowth dTBW ¹	134 (\pm 21)	162 (\pm 45)	155 (\pm 31)	74 (\pm 46)
Retention rate regrowth (%)	79.7	70.35	96.5	99.2

¹ Minimum cell counts after 3 days (F2.2 4 days) for 3 replicates (F1.1 and F2.1 sample D excluded)

Probably due to rainfall, the UV-t increased slightly between the first and second test series (from 40% to 48%). This resulted in a slightly improved performance in the second test series, although this was partially masked by the higher organism densities. Nevertheless, D-2 standards were not met, neither in direct counts for phytoplankton, nor in the die-off/regrowth experiments. During pre-tests in August, however, cell numbers did drop below the D-2 standards in the die-off/regrowth experiments, even though UV-t levels were only 35-40% (Figure 10). The most obvious difference between the august tests and the filter tests in September was the retention time of the water between the first UV treatment during uptake and the second treatment during discharge. In August the water was retained overnight, whereas in September it was only retained for a few hours. This suggests that there is a minimum retention time between 1st and 2nd treatment for UV to be fully effective. Tests during November indicated that retention time between the treatment steps is especially important for the organism group ≥ 10 - $< 50\mu$ m, whereas for larger organisms the actual dose (as was influenced by UV-t) is important (Foekema *et al.*, 2014).

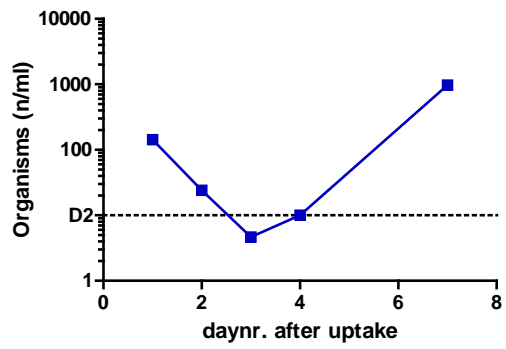


Figure 10 *Phytoplankton die-off/regrowth in August pre-test*

7 Conclusions

The main purpose of filters in a BWMS is to remove larger organisms that are less susceptible to the definitive UV treatment, as well as suspended material that may interfere with the UV transmission. The mesh size of the screen determines the size of the particles removed.

Using a finer filter mesh had a marked effect on the retention of zooplankton (the main constituent of the size class $\geq 50 \mu\text{m}$). As percentage the additional retention of the 20 μm and 25 μm mesh was small, because the retention of the 40 μm meshes was already $>99\%$. However, in absolute terms it means the difference between thousands per m^3 and a few dozen.

The Filtersafe showed a 2.5-fold increase in backwash frequency between the 40 and 25 μm meshes. The Filtrex showed the same backwash frequency for both meshes (40 and 20 μm), but this frequency was higher than with the Filtersafe. It is possible that the high backwash frequency of the Filtrex with 40 μm mesh was caused by a relative high load of large particles in the water.

Finer meshes did remove slightly more suspended solids and other material that may interfere with the UV-treatment. The effect was, however, marginal. Apart from the first test run with the Filtrex 40 μm mesh, the UVt increased only 1%. No effect of filter type on the efficacy of the UV-treatment was observed.

Phytoplankton (the main constituent of the size class ≥ 10 - $<50\mu\text{m}$) was not affected by the mesh sizes used. In the analyses directly after the treatments using vital staining still high numbers of viable cells were observed. Regrowth cultures with these samples showed a continuing decline in living cells during 2-3 days following the treatments, due to delayed mortality, but not enough to meet the D-2 standards. The low UVt of the challenge water undoubtedly plays a role here, but pre-tests indicated that D-2 standards can be met at even lower UVt values. In the current tests, the treated water was directly deballasted after the ballasting process was completed, with only some time to clean the piping and change settings in between. This represents a 'one-shot treatment', *i.e.* a complete treatment with ballasting followed by immediate deballasting. This suggests that a minimum retention time is needed for the UV-treatment to obtain optimal effect.

8 References

ETV (2010): Generic protocol for the verification of ballast water treatment technology. EPA/600/R-10/146.

Foekema E.M., G. Hoornsman, C. Sonneveld & F. Arenoe-Ghita (2014): Testing the BIO-SEA ballast water management system; Efficacy tests with 80 and 60% UV-t. IMARES report C038.14.

IMO (2008): Revised guidelines for approval of ballast water management systems (G8). MEPC 174(58) Annex 4.

Justification

Report number : C033.14

Project number : 430.51111.01

The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of IMARES.

Approved: Dr. E.M. Foekema
Researcher

Signature:



Date: March 2015

Approved: Drs. F.C. Groenendijk
Head of Department

Signature:



Date: March 2015

Appendix

Table 5 Environmental parameters of Test F1.1, Filtrex 40 µm, Sept 3, 2013

3-9-13	Salinity (psu)	Temperature (°C)	DO (%)	pH	Turbidity (ntu)	TSS (mg/l)	UV-t (%)
CBW-A	2.30	21.5	89.8	7.77	4.5	8.5	36.3
CBW-B	2.25	21.6	92.3	8.47	4.9	9.5	41.2
CBW-C	2.21	24.1	98.7	8.69	4.9	7.3	41.6
Average	2.25	22.4	93.6	8.31	4.7	8.4	39.7
uTBW-A	2.27	21.0	91.9	8.41	4.3	5.5	44.3
uTBW-B	2.23	21.4	89.5	8.60	4.4	6.3	44.8
uTBW-C	2.27	21.0	96.9	8.79	4.7	6.2	44.9
Average	2.26	21.1	92.8	8.60	4.5	6.0	44.7
dTBW-A	2.27	21.0	93.2	8.77	4.3	6.0	44.3
dTBW-B	2.29	20.5	92.1	8.75	5.0	5.7	44.8
dTBW-C	2.28	20.6	92.2	8.75	4.3	6.8	44.6
dTBW-D	2.28	20.8	93.1	8.74	4.0	7.3	44.5
Average	2.28	20.7	92.7	8.75	4.4	6.5	44.6

Table 6 Environmental parameters of Test F1.2, Filtrex 20 µm, Sept 5, 2013

5-9-13	Salinity (psu)	Temperature (°C)	DO (%)	pH	Turbidity (ntu)	TSS (mg/l)	UV-t (%)
CBW-A	2.28	20.1	82.8	8.75	2.3	4.8	44.0
CBW-B	2.27	20.4	87.8	8.71	2.4	4.5	43.8
CBW-C	2.26	20.6	86.5	8.71	2.4	4.8	43.2
Average	2.27	20.4	85.7	8.72	2.4	4.7	43.7
uTBW-A	2.80	19.9	86.7	8.76	2.6	3.4	44.6
uTBW-B	2.27	20.4	82.2	8.75	2.2	4.3	44.6
uTBW-C	2.25	20.8	84.8	8.52	2.5	4.3	44.3
Average	2.44	20.4	84.6	8.68	2.4	4.0	44.5
dTBW-A	2.23	22.3	90.9	8.60	2.2	3.8	43.2
dTBW-B	2.25	22.3	91.0	8.60	1.9	4.9	45.0
dTBW-C	2.19	23.0	91.4	8.73	2.4	5.4	45.0
Average	2.22	22.5	91.1	8.64	2.2	4.7	44.4

Table 7 Environmental parameters of Test F2.1, Filtersave 40 µm, Sept 10, 2013

10-9-13	Salinity (psu)	Temperature (°C)	DO (%)	pH	Turbidity (ntu)	TSS (mg/l)	UV-t (%)
CBW-A	1.85	18.4	82.9	8.50	3.6	4.6	48.0
CBW-B	1.85	18.6	83.3	8.43	3.2	5.1	48.5
CBW-C	1.84	18.7	84.2	8.31	2.7	4.6	47.9
Average	1.85	18.6	83.5	8.41	3.2	4.8	48.1
uTBW-A	1.85	18.2	82.9	8.48	3.0	4.1	49.2
uTBW-B	1.85	18.8	83.4	8.52	3.2	4.0	48.9
uTBW-C	1.87	18.1	83.8	8.41	2.8	4.4	49.0
Average	1.86	18.4	83.4	8.47	3.0	4.2	49.0
dTBW-A	1.84	19.5	90.5	8.53	2.8	4.2	47.1
dTBW-B	1.84	19.6	89.9	8.49	2.8	3.8	48.0
dTBW-C	1.84	19.5	89.9	8.48	2.7	3.8	48.5
dTBW-D	1.84	19.0	89.3	8.55	2.6	4.0	47.7
Average	1.84	19.4	89.9	8.51	2.7	4.0	47.8

Table 8 Environmental parameters of Test F2.2, Filtersave 25 µm, Sept 12, 2013

12-9-13	Salinity (psu)	Temperature (°C)	DO (%)	pH	Turbidity (ntu)	TSS (mg/l)	UV-t (%)
CBW-A	1.67	17.8	91.2	8.76	5.2	9.2	46.2
CBW-B	1.68	17.5	92.0	8.75	5.3	8.2	46.8
CBW-C	1.67	17.6	94.0	8.70	5.1	8.1	46.9
Average	1.67	17.6	92.4	8.74	5.2	8.5	46.6
uTBW-A	1.68	17.5	91.1	8.75	4.7	7.1	47.8
uTBW-B	1.68	17.7	92.3	8.78	4.8	6.3	47.3
uTBW-C	1.68	17.8	94.2	8.73	4.6	6.6	47.3
Average	1.68	17.7	92.5	8.75	4.7	6.7	47.5
dTBW-A	1.67	18.6	92.4	8.27	4.4	7.7	47.5
dTBW-B	1.67	18.2	93.1	8.32	4.3	6.4	47.8
dTBW-C	1.67	18.2	93.2	6.21	4.6	7.4	46.8
Average	1.67	18.3	92.9	7.60	4.4	7.2	47.4

Table 9 Biological results for Test F1.1 Filtrex 40 µm screen, Sept 3, 2013

	Living 10-50 µm/ml	BC Chl-a (µg/l)	BC Yield	ALA Chl-a (µg/l)	ALA Act %	die-off 10-50 µm/ml	BC yld	Vol (L)	Living >50µm /m3	Total nauplii /m3	Living nauplii /m3
CBW-A	635	25.3	0.29	13.1	49.31			20	292972	n.a.	n.a.
CBW-B	650	25.4	0.48	14.1	50.78			20	443287	n.a.	5507
CBW-C	700	24.6	0.46	15.6	48.12			20	216048	n.a.	n.a.
average	662	25.1	0.41	14.3	49.40	5050	0.58		317436	-	5507
uTBW-A	395	21.5	0.23	13.8	36.60			1000	12703	n.a.	n.a.
uTBW-B	465	22.2	0.23	15.7	30.07			1000	17735	n.a.	n.a.
uTBW-C	415	25.8	0.27	15.8	31.46			1000	9160	332731	8830
average	425	23.1	0.24	15.1	32.71				13199	332731	8830
dTBW-A	315	25.3	0.09	14.1	27.72	156	0.12	1000	1593	n.a.	971
dTBW-B	365	21.2	0.13	10.8	30.16	114	0.10	1000	4736	n.a.	n.a.
dTBW-C	305	24.8	0.11	11.9	23.77	133	0.09	1000	497	n.a.	40
dTBW-D	280	20.3	0.13	12.2	28.25	2613	0.56	625	3210	n.a.	n.a.
average	316	22.9	0.11	12.3	27.48	134.3			2509	-	506

Table 10 Biological results for Test F1.2 Filtrex 20 µm screen, Sept 5, 2013

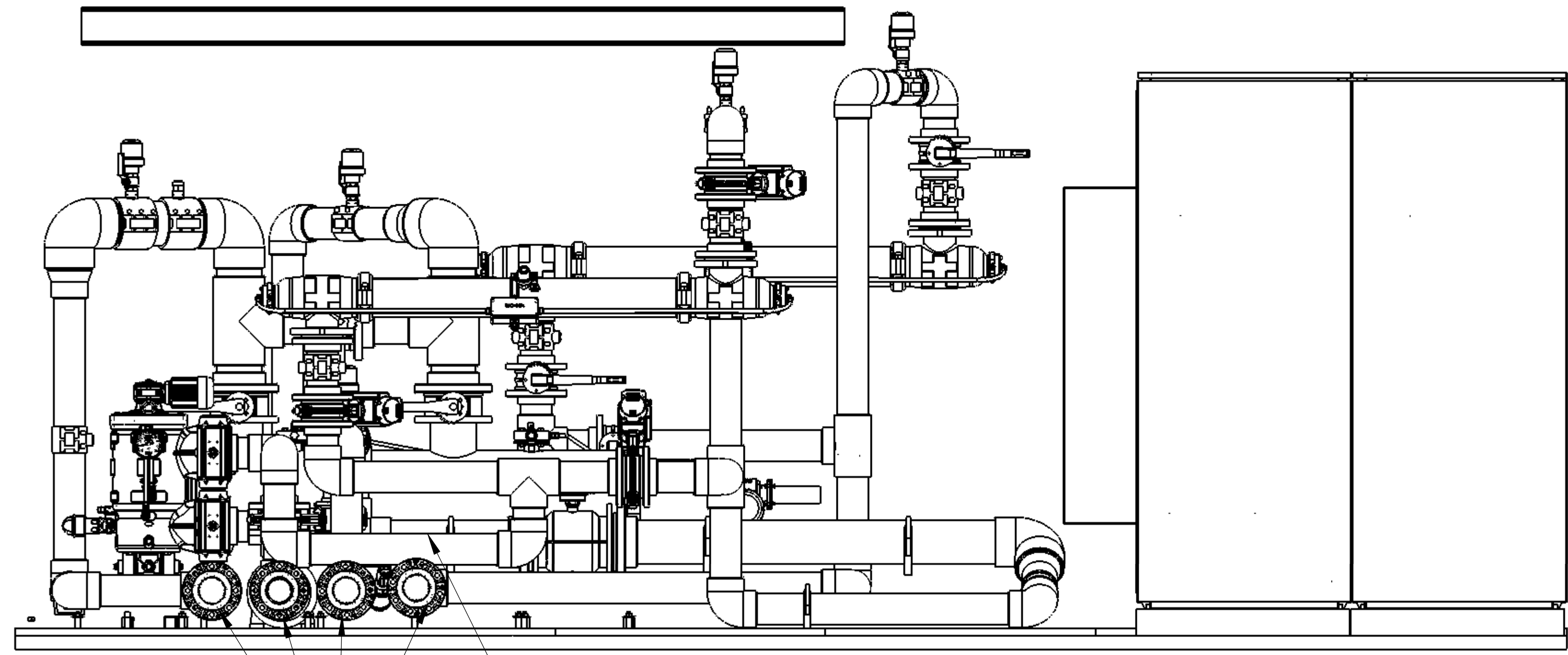
	Living 10-50 µm/ml	BC Chl-a (µg/l)	BC Yield	ALA Chl-a (µg/l)	ALA Act %	die-off 10-50 µm/ml	BC yld	Vol (L)	Living >50µm /m3	Total nauplii /m3	Living nauplii /m3
CBW-A	490	16.6	0.39	7.0	45.70			20	700438	n.a.	204128
CBW-B	500	17.3	0.42	8.9	48.79			20	612096	n.a.	148023
CBW-C	650	10.2	0.42	9.3	47.35			20	506688	n.a.	75375
average	547	14.7	0.41	8.4	47.28	2730	0.55		606407	-	142509
uTBW-A	410	16.1	0.19	7.4	29.34			1000	121	29846	30
uTBW-B	380	17.6	0.21	9.0	39.42			1000	256	32351	110
uTBW-C	490	18.0	0.22	10.6	34.28			1000	160	34100	70
average	427	17.2	0.20	9.0	34.35				179	32099	70
dTBW-A	290	14.9	0.12	7.6	16.18	191	0.13	1000	48	n.a.	7
dTBW-B	310	15.7	0.10	8.1	19.73	186	0.13	1000	46	n.a.	21
dTBW-C	330	16.1	0.10	8.1	16.49	110	0.07	460	14	n.a.	0
average	310	15.6	0.10	7.9	17.47	162.3			36	-	9

Table 11 Biological results for Test F2.1 Filtersafe 40 µm screen, Sept 10, 2013

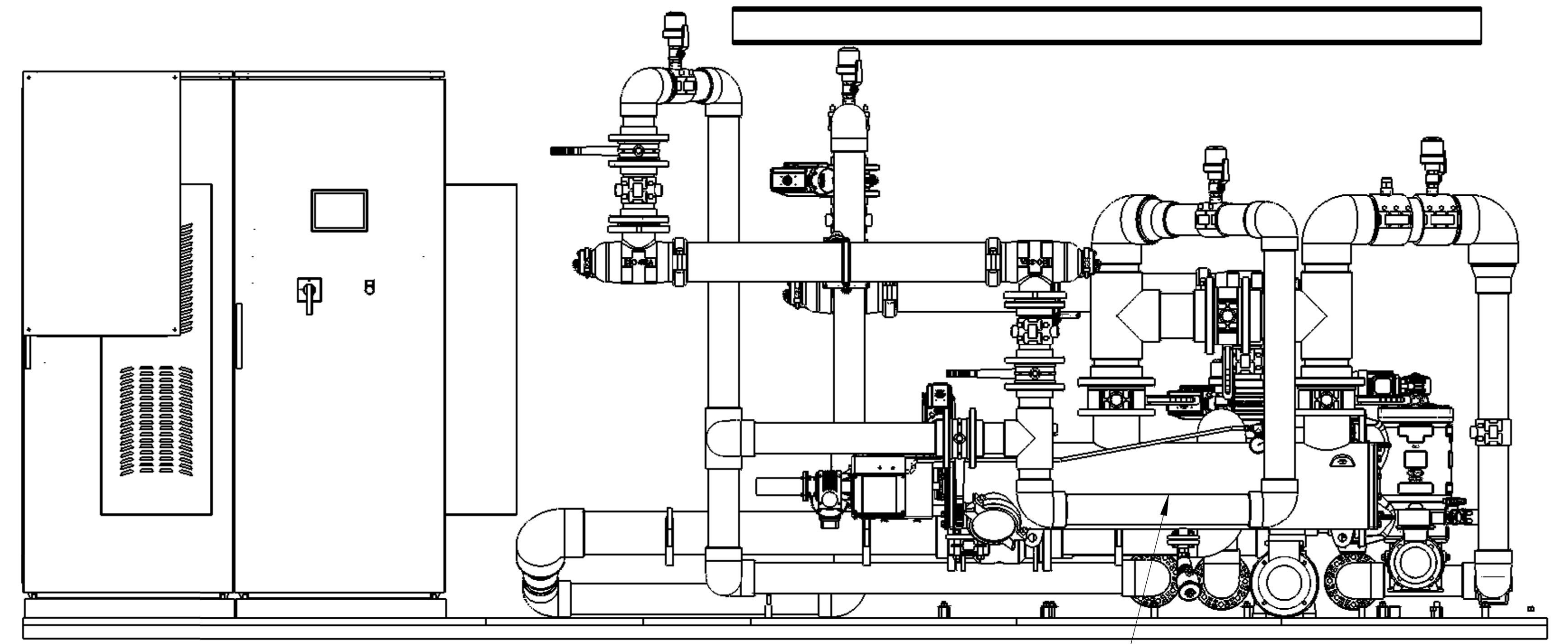
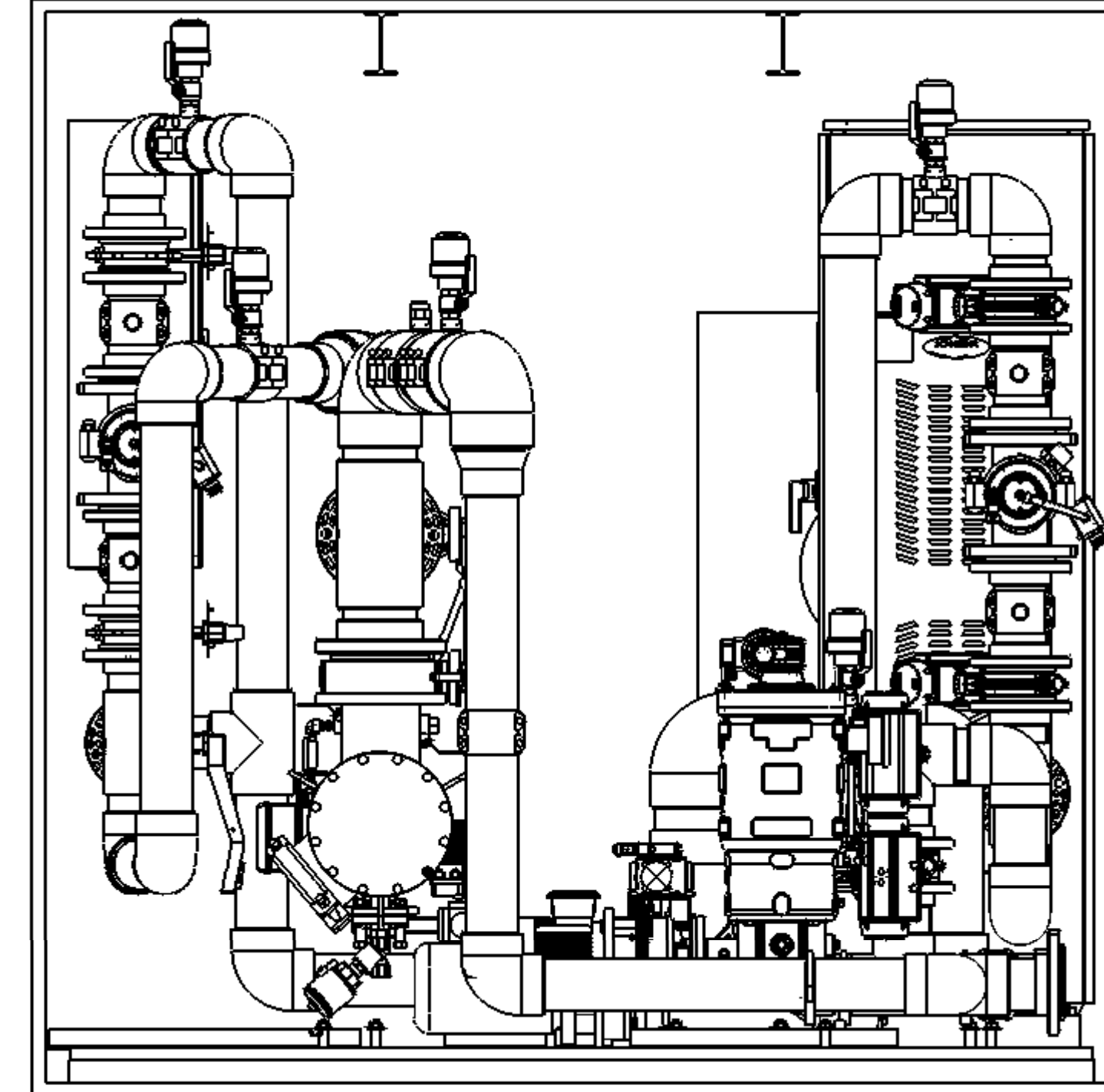
	Living 10-50 µm/ml	BC Chl-a (µg/l)	BC Yield	ALA Chl-a (µg/l)	ALA Act %	die-off 10-50 µm/ml	BC yld	Vol (L)	Living >50µm /m3	Total nauplii /m3	Living nauplii /m3
CBW-A	3250	32.9	0.53	17.9	48.25			20	361125	607500	244688
CBW-B	4763	33.6	0.51	21.1	49.68			20	221299	n.a.	118073
CBW-C	5125	35.5	0.49	23.5	44.76			20	200667	735000	132563
average	4379	34.0	0.51	20.8	47.56	101000	0.60		261030	671250	165108
uTBW-A	n.a.	31.3	0.31	21.2	35.95			1000	2191	n.a.	1400
uTBW-B	n.a.	28.3	0.27	21.8	22.64			1000	3097	515310	2786
uTBW-C	n.a.	31.7	0.23	24.1	25.94			1000	17	412034	1
average	-	30.4	0.27	22.4	28.18				1768	463672	1396
dTBW-A	785	22.8	0.11	14.4	27.86	162	0.16	1000	206	n.a.	144
dTBW-B	820	25.3	0.10	16.1	22.02	182	0.12	1000	669	n.a.	625
dTBW-C	1000	20.9	0.09	13.9	27.29	121	0.16	1000	75	n.a.	14
dTBW-D	n.a.	22.3	0.075	15.6	18.45	631	0.26	540	281	n.a.	259
average	868	22.8	0.09	15.0	23.91	155.0			308	-	261

Table 12 Biological results for Test F2.1 Filtersafe 25 µm screen, Sept 12, 2013

	Living 10-50 µm/ml	BC Chl-a (µg/l)	BC Yield	ALA Chl-a (µg/l)	ALA Act %	die-off 10-50 µm/ml	BC yld	Vol (L)	Living >50µm /m3	Total nauplii /m3	Living nauplii /m3
CBW-A	9213	47.2	0.53	24.7	46.66			20	178508	809575	100860
CBW-B	9838	46.0	0.52	26.3	46.62			20	180761	712800	106128
CBW-C	8350	48.0	0.54	29.2	42.94			20	332693	n.a.	230689
average	9134	47.1	0.53	26.7	45.41	194500	0.36		230654	761188	145892
uTBW-A	n.a.	36.3	0.24	25.2	28.80			1000	5	21508	0
uTBW-B	n.a.	32.9	0.29	22.7	31.12			1000	54	24304	30
uTBW-C	n.a.	38.3	0.29	28.1	26.90			1000	1	n.a.	0
average	-	35.8	0.27	25.3	28.94				20	22906	10
dTBW-A	1735	24.9	0.08	17.4	18.36	64	0.18	1000	16	n.a.	0
dTBW-B	1285	24.9	0.07	17.2	20.21	33	0.14	1000	16	n.a.	0
dTBW-C	1485	24.4	0.13	17.9	20.73	124	0.05	900	6	n.a.	0
average	1502	24.7	0.09	17.5	19.77	73.7			13	-	0

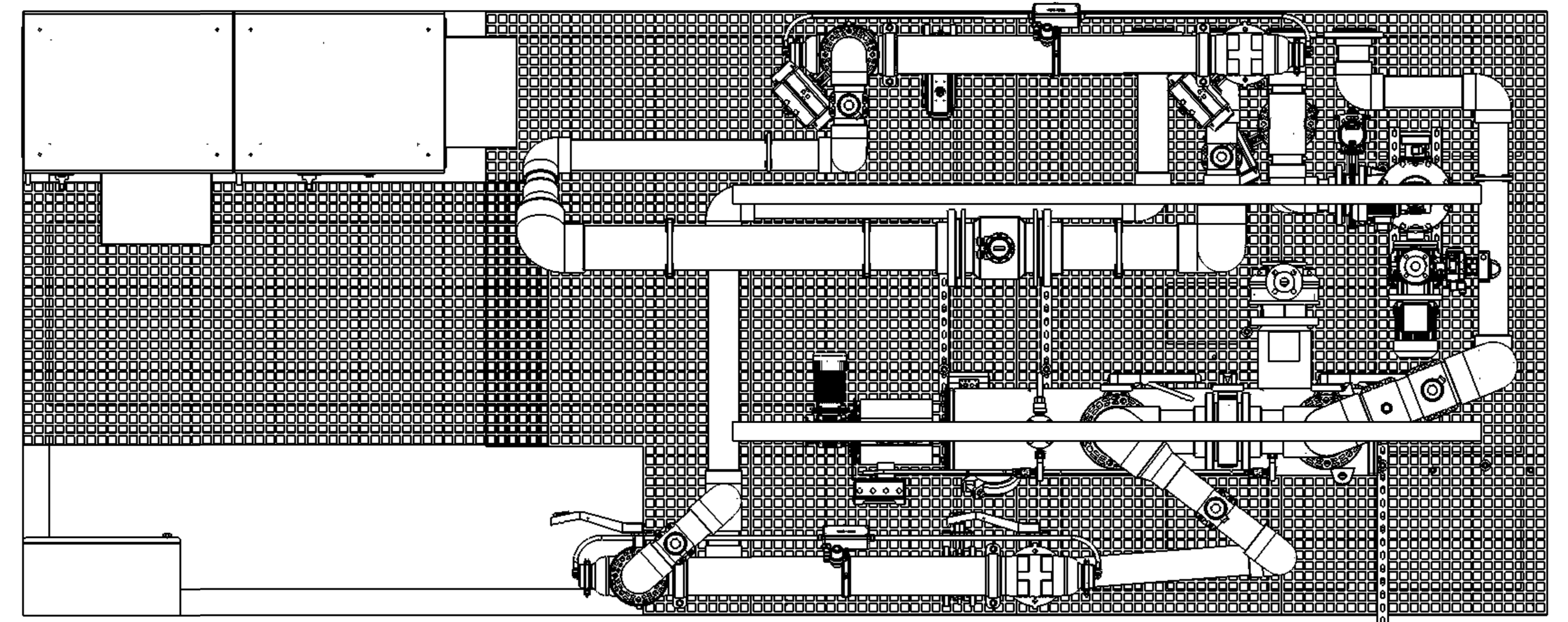
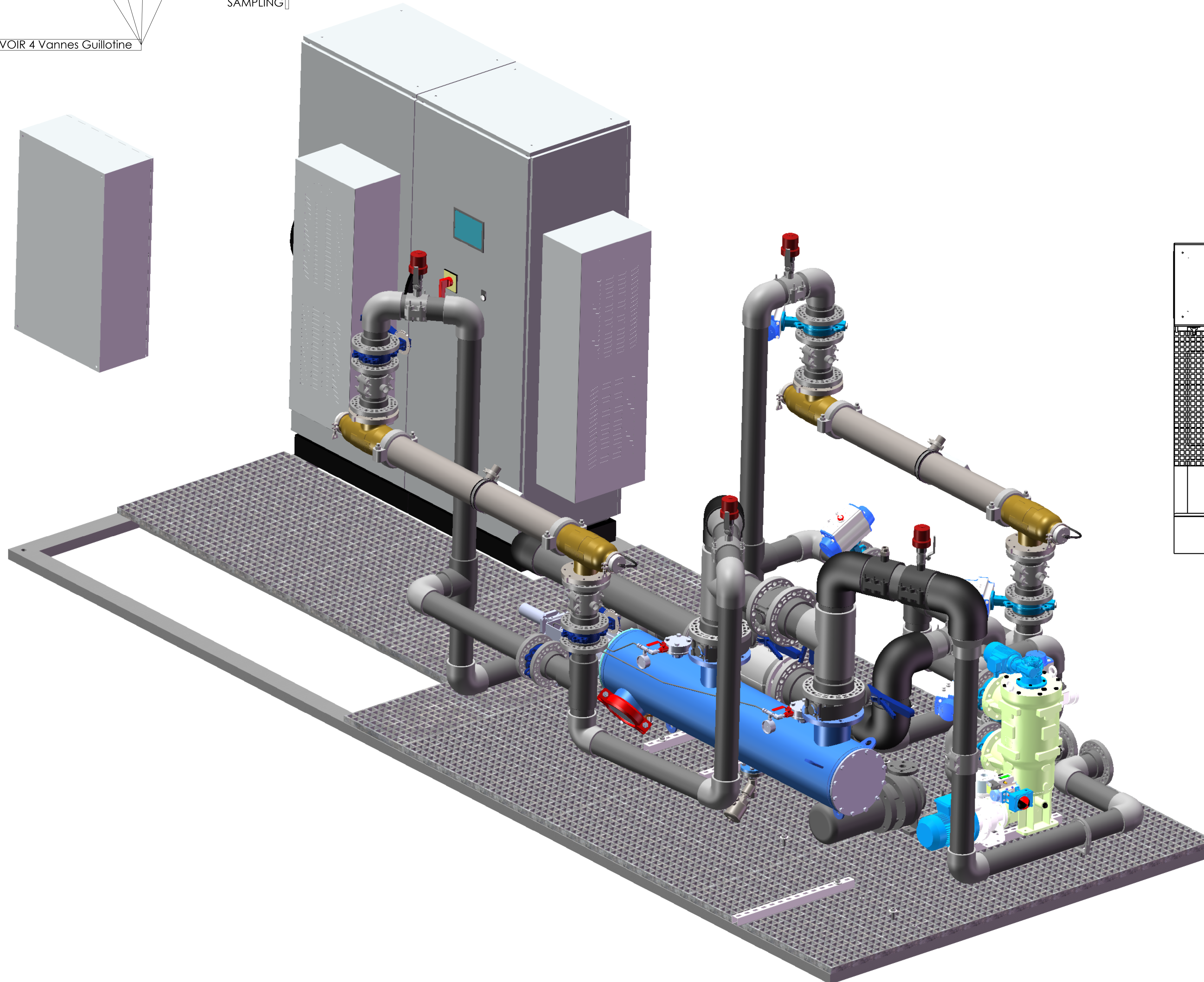


GARDER LONGUEUR POUR SAMPLING[]



GARDER LONGUEUR POUR SAMPLING[]

PREVOIR 4 Vannes Guillotine



Ind.	Description	Date	Créer Par	Vérifié Par
Ind. 2104	Désignation : Skid_Bio-Sea_(MARES)			Réf PMI :
CN : 2104	N° de Plan : A0404			Créer Par : Vion, Patrick
Date : 11-02-10	Configuration : Configuration_100m3-h			Masse : 524318.23
Echelle : 1:13	Bio UV Zac de la petite camargue, 34400 Lunel, France Tél: 04.99.133.911 / Fax: 04.99.133.919 www.bio-uv.com			Matière :
Format : A0	Ce plan est la propriété de BIO-UV. Reproduction et communication interdite. Loi du 11/03/1957			Ind. C