Ballast Water Treatment System with UV Filter and Advanced Oxidation Technology

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Abstract: *This article presents various methods which can be applied on a ship for treatment of ballast water and their efficiency on a variety of marine organism, ballast water treatment system with UV filter and advanced oxidation technology and about the aquatic invasive species known to have been spread by ballast water and their environmental impact. Because of shipping industry between 3 and 5 billion tonnes of ballast water are transfer internationally annually. Like a consequence of discharging untreated ballast water from ships, the risks of introducing aquatic invasive species is very high and this becomes a major threat to global biodiversity.*

Keywords: *Ballast, water, treatment, UV, ships, environment, oxidation*

1. Introduction

Ballast water means water with its suspended matter taken on board a ship to control trim, list, draught, stability or stresses of the ship.
Ballast water management means mechanical, physical, chemical and biological processes, either singularly or in combination to remove, render harmless, or avoid the uptake or discharge of harmful aquatic organisms and pathogens within ballast water and sediments.
Harmful aquatic organisms and pathogens means aquatic organisms or pathogens which, if introduced into sea, including estuaries, or into fresh water courses, may create hazards to the environment, human health property or resources, impair biological diversity or interfere with other legitimate uses of such areas [1]. When a ship does not have cargo, it fils its tanks with ballast water. Ballast water contains microorganisms, phytoplankton, zooplankton and others.
When they enter into the new marine environments, they become a threat to the local marine ecological system.
The species that survive in the new environment, may become serious pests. Estimations show that more than 3000 species are transported by ships each day and 40 recent invasions have been mediated by ballast water.

2. Ballast water quality and standards set by IMO

The regulations of discharged organism are presented in the Table 1 and the ballast water technology implementation timeline is presented in the Table 2.

Table 1: Regulations of discharged organisms according to Regulation D-2 Ballast Water Performance Standards

Organism	**Regulation of discharge ballast water**
Phytoplankton / zooplankton ≥ 50 μm	<10 viable organisms per m^3
Phytoplankton / zooplankton 10–50 μm	<10 viable organisms per mL
Toxicogenic Vibrio cholera (O1 and O139)	<1 colony forming unit per 100 mL
Escherichia coli	<250 colony forming unit per 100 mL
Intestinal enterococci	<100 colony forming unit per 100 mL

Table 2: Ballast water technology implementation timeline

	Construction year of the ship			
Ballast capacity (m^3)	**Before 2009**	**2009+**	**2009-2011**	**2012+**
<1500	Ballast water exchange or treatment until 2016	Ballast water treatment only		
	Ballast water treatment after 2016			
1500-5000	Ballast water exchange or treatment until 2014	Ballast water treatment only		
	Ballast water treatment after 2014			
>5000	Ballast water exchange or treatment until 2016		Ballast water exchange or treatment until 2016	Ballast water treatment only
	Ballast water treatment after 2016		Ballast water treatment after 2016	

Each ship will have a ballast treatment system on board that could be capable of treating the ballast water before discharging it into the marine environment (Table 3).

Table 3: List of ballast water types of treatment systems that make use of active substances and their status in the approval

Type of treatment	**Type of approval**
Filtration+Ultrasound +UV	MEPC 59 Application for Basic Approval
Filtration+Advanced electrolysis	MEPC 55 Basic Approval MEPC 59 Application for Final Approval
Coagulation+Magnetic Separation+Filtration	MEPC 57 Basic Approval
Filtration+UV	MEPC 59 Application for Final Approval MEPC 59 Application for Basic Approval
Biocide (Chlorine dioxide)	MEPC 58 Basic Approval MEPC 59 Application for Final Approval
Electrochemical oxidation+ neutralizing agent (sodiumthisulfate)	MEPC 54 Basic Approval MEPC 58 Final Approval
Filtration+UV	MEPC 57 Basic Approval MEPC 59 Application for Final Approval
Ozone	MEPC 56 Basic Approval MEPC 59 Application for Final Approval
Filtration+cavitation+ nitrogen supernaturation+ electrodialysis	MEPC 57 Basic Approval
Chemical Treatment	MEPC 54 Basic Approval
Filtration+Advanced Oxidation	MEPC 57 Basic & Final Approval

Filtration+cavitation+ ozone+sodium hypochlorite	MEPC 57 Basic Approval MEPC 59 Application for Final Approval
Hydrocyclone+ Electrolytic chlorination	MEPC 58 Basic Approval MEPC 59 Application for Final Approval
Hydrocyclone+ Filtration+Biocide (PeracleanOcean)	MEPC 57 Final Approval
Filtration+Electrolysis	MEPC 59 Application for Basic Approval
MechanicTreatment+ Ozone	MEPC 55 Basic Approval
Filtration+biocides (sodiumhypochlorite) +neutralizing agent (sodiumsulfate)	MEPC 59 Application for Final Approval MEPC 58 Basic Approval

3. Shipboard treatment of ballast water

There are more methods which can be applied on a ship for treatment of ballast water:
3.1 Filtration and cyclonic separation
3.2 Ultraviolet radiation treatment
3.3 Chemical treatment
3.4 Combined methods

3.1 Filtration and cyclonic separation

Filtration is the most frequent environmental method for the treatment of ballast water. Majority of filtration techniques are effective against sediments and many types of organisms. Cyclonic separation is accomplished using hydro cyclones.

Table 4: Summary of physical separation techniques tested

Method	Capacity	Marine organism tested	Percentage removal
Filtration	6 ton h^{-1}	Zebra mussel	> 70%
Filtration/Cyclone	199.8 m^3 h^{-1}	Phytoplankton	30%
		Macrozooplankton	30%
		Microzooplankton	95%
		Dinoflagellates	>90%
Cyclone/UV	312-350 m^3 h^{-1}	Skeletonamacostanum,Thalassiosira sp.	Not reported
		Chaetocerosgracile	Not reported
		Copepodes	Not reported
Filtration	340 m^3 h^{-1}	Phytoplankton	30–90%
		Zooplankton	
Hydro cyclone	5.7 m3 $\min^{-1}$	Zooplankton	60%
Filtration	25-75 m^3 h^{-1} m^{-2}	Phytoplankton	50–58%
	(crumb material)	Zooplankton	70-90%
Filtration	530 m^3 h^{-1}	Phytoplanktonbloom	70% (after 24h)
Filtration	2 m^3 h^{-1}	Chlorella	93%
Filtration/UV	100–3000 m^3 h^{-1}	Artemia sp.	13.7%
		Nauplius larva of Artemia	8.3%

3.2 Ultraviolet radiation treatment

Mechanical separation methods include the use of ultraviolet radiation, heat treatment and electric pulse applications.

Table 5: Summary of mechanical separation techniques

Method	**Capacity**	**Marine organism tested**	**Percentage removal**
UV	Not reported	Gymnodinium sp.	<6%
		Alexandrium sp	
		Chattonella sp	<40%
UV	2 m^3 h^{-1}	Chlorella	87%
UV	0.2–1.6 m^3 h^{-1}	Various	78–100%
UV	Not reported	Phytoplankton	40–99%
		Zooplankton	
		Bacteria	
UV/hydrocyclone	312–350 m^3 h^{-1}	Phytoplankton	>85%
		Zooplankton	
		Bacteria	
UV	100–3000 m^3 h^{-1}	Artemia salina	99.5%
		Dinoflagellate Prorocentrum	84.7%
		Tetraselmis sp.	87.6%
UV/Filtration	Not reported	Phytoplankton	>70%
		Zooplankton	
		Bacteria	
Heat	50,000 of ballast water	Phytoplankton	>98%
		Zooplankton	
		Bacteria	
Heat	Various tests	Phytoplankton	>99%
		Zooplankton	
		Bacteria	
Heat	85 L $\min^{-1}$	Zooplankton	90%
		Bacteria	95%
Heat Microwave	1–2 L $\min^{-1}$	Microalgae (Nannochloropsis oculata)	Complete in activation
		Zooplankton (Artemia)	
		Oyster larvae(Crassostrea virginica)	
Heat Microwave	1–2 L $\min^{-1}$	Artemia cysts	100%
Heat Ultrasound		Artemia salina	
		Larvae stage	100%

		adults	85%
		cysts	60%
		Dunaliella tertiolecta	40%

3.3 Chemical treatment

Table 6: Summary of chemical treatment technique

Method	Capacity	Marine organism tested	Percentage removal
Biocides	Not reported	Three fresh water organisms	>95%
Biocides	Lab scale	Bacteria	Effective
Biocides	Lab scale	Marine organisms	Effective
Biocides	Lab scale	Microalgae	Effective
		Dinoflagellates cysts bacteria	
Biocides (Naphthoquinones)	Lab scale	Dinoflagellates cysts	>95%
Biocides	Lab scale	Living biomass	>99%
Chlorine	Not reported	Gymnodinium catenatum cysts	100%
Sodium hypochlorite	5 mgL^{-1}	Bacteria	85.2–100%
		Phytoplankton	Effective
	2 mgL^{-1}	Zooplankton (Artemiasalina)	15-100%
Chlorine	Not reported	Zooplankton,Phytoplankton,	>99%
		Bacteria	
Chlorine dioxide	Not reported	Alexandrium catenella and Gymnodinium catenatum	>97%
Chlorine dioxide	Not reported	Gymnodinium catenatum cysts	75–98%
NaOCl	Not reported	Cysts	>89%
Ozone	400 Lh^{-1}	Bacillussubtilisspores	Not effective
Ozone	400 Lh^{-1}	Dinoflagellate alga Amphidinium sp.	>98%
Ozone	Not reported	Zooplankton,Phytoplankton	99%
		Bacteria	
Ozone	Not reported	Zooplankton, Phytoplankton	90–99%
		Bacteria	
Ozone	Not reported	5 species marine organisms	>95%
Ozone		Zooplankton, Phytoplankton,	>96%
	(1.3–3.11)∗ 103 m^3	Bacteria	
Electrolytic	1200 m^3h^{-1}	Phytoplankton	>99.99%
		Mesozooplankton	>99%
Electrolysis	2.5 m^3h^{-1}	Artemia	>95%
Magnetic separator	100 m^3day^{-1}	Red phytoplankton	>92%

3.4 Combined methods

Combined methods are used for ballast water treatment.

Table 7: Summary of combined treatment techniques [2]

Method	Capacity	Marine organism tested	Comments
Filtration+UV	5.7 m^3h^{-1}	Zooplankton	Effective (undetectable level)
Filtration+UV		Zooplankton	Effective
		Phytoplankton	
		Bacteria	
Filtration+UV	304 m^3h^{-1}	Zooplankton	60%
		Phytoplankton	60%
Cyclonic separation+UV	200 m^3h^{-1}		30%
		Zooplankton	60%
		Phytoplankton	
Filtration+UV	2 m^3h^{-1}	Chlorella	>93%
Filtration+UV	312–350 m^3h^{-1}	Zooplankton	effective
Hydrocyclone+chemi caldisinfectant	530 m^3h^{-1}	Zooplankton	effective
		Phytoplankton	
		Bacteria	
UV+US	200–1600 Lh^{-1}	Artemiasalina	97–100%
UV+H2O2			94–100%

4. Ballast water treatment system with UV and advanced oxidation technology (AOT)

4.1 Description of the system

This is an integral part of the vessel's ballast water system, on the discharge side of the vessel's ballast water pumps. During ballast operation, the water is led through the filter, which removes larger particles and organisms, and then to the advanced oxidation technology reactor, where the water is treated with UV light and advanced oxidation technology. During deballast, the water is led the same way, but the filter is bypassed. The UV lamps are powered by the LDC (via LPSs, lamp power supplies). The AOT reactor has one dedicated LDC. Flow is monitored by the flow meter and regulated by the control valve. The control valve also regulates pressure during back flushing of the filter.

The advanced oxidation technology reactors are cleaned using the CIP (*cleaning-in-place*) module, which first rinse the AOT reactor with fresh water, and then circulates CIP liquid through the AOT. At the end of the process the AOT reactor and the filter (filter preservation) is filled with fresh water from the CIP. The complete system and ongoing processes are controlled and monitored from the control cabinet. Control can also be performed from remote control panels and the ship's ISCS, via the remote interface. The by-pass valve makes it possible to bypass the entire system, for example to secure ballast operation if the system is not functioning. The valve is controlled from the ISCS (integrated ship control system).

4.2 The key components of the system

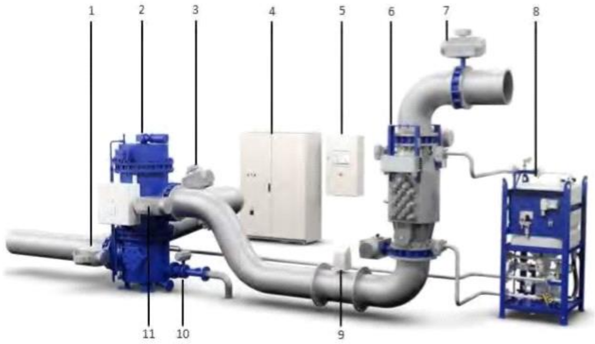

Fig. 1. Advanced oxidation technology system

Components:
1. Filter inlet valve
2. Filter
3. Filter bypass valve
4. Lamp drive cabinet (LDC)
5. Control cabinet with main control panel
6. AOT reactor
7. Control valve
8. CIP (cleaning-in-place) module
9. Flow meter
10. Backflush valve
11. Filter outlet valve

Not in illustration:
• System bypass valve
• Sampling devices, before and after treatment
• Pressure monitoring device

4.3 The main processes performed by this water ballast treatment system

4.3.1. Start-up

Ballasting and deballasting begins with a start-up phase. There must be available power for the system. If power management is integrated, this will be confirmed automatically. If power management is not integrated, this is confirmed manually.
During start-up, the UV lamps are warmed up for 90 seconds. Cooling water is pumped through the AOT reactor to secure that the UV lamps are not overheated. The flow is monitored by the flow meter to secure that there is enough flow to cool the UV lamps. If flow deviates from parameter set values, an alarm is issued and the system is shut down.

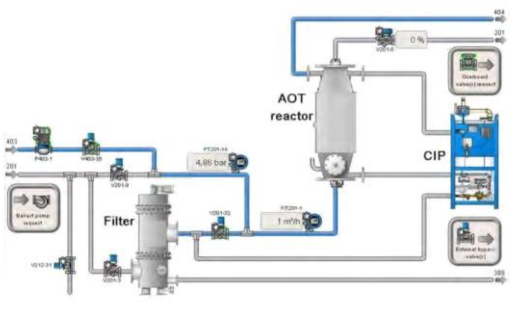

Fig. 2. Ballast and deballast start-up

4.3.2. Ballasting

After the start-up, when the lamps are ready, the operator is requested to start the ballast pump. The ballast water is pumped from the sea chest to the filter, that removes larger particles and organisms. This also reduces the amount of sediment build-up in the ballast water tanks. The organisms and sediments caught in the filter are flushed overboard via regular filter backflush operations. The water is finally led to the AOT reactor, which produces radicals and UV light that breaks down and neutralize the organisms.

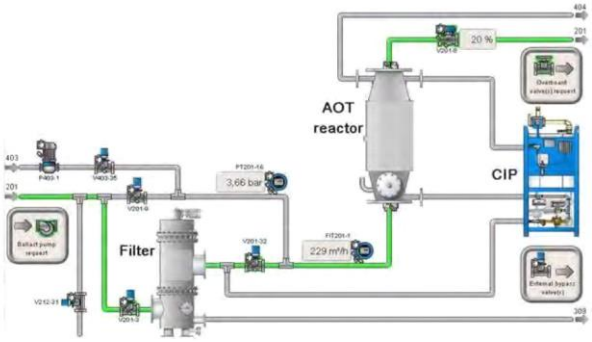

Fig. 3. Ballasting

4.3.2.1. Power optimization

It is possible to activate power optimization (parameter p237). During ballast and deballast, the lamp power is adjusted according to the value from the UV intensity sensor, which constantly measure the water transmittance. In clear water with good transmittance, the lamps are automatically dimmed, to lower the power consumption. This means that the lamps are lit to the degree needed for full treatment, but not more. The purpose is to save power by dimming the lamps to minimum power required to fully treat the water. The UV lamps are regulated individual on all AOT reactors between 50 % and 100 % of full effect.

Power optimization during special conditions.

• During start-up and the first two minutes of ballast/deballast, the UV lamps are lit to 100 % to ensure treatment before values from the UV sensor are stable.

• Pause: UV lamps are dimmed to 50 % during pause and lit to 100 % for 2 minutes when process is resumed.

• Stop: UV lamps are lit to 100 % for 10 seconds before they are stopped. This will prolong the life of the lamps.

• Low UV intensity: See Actions at low UV intensity below.

• Broken UV lamps: See Operation with broken UV lamp below.

➢ *Actions at low UV intensity*

If the UV intensity falls below minimum (defined in parameter p221) for one AOT reactor, a warning is issued, but process continues. When UV intensity falls below limit defined in the type certificate, a new warning is issued and a log is written to the event log. The operation continues but does not fulfill the type approval certificate. However, the flow is decreased so that the treatment shall correspond to the type approval requirements. The operator will have do decide to continue or stop the operation.

➢ *Operation with broken UV lamp*

If a UV lamp breaks a warning is issued and a log is written to the event log. The operation continues but does not full fill the type approval certificate. However, the flow is decreased to 80 % of current flow for all AOT reactors and the UV lamps are lit to 100 %. These actions are taken so that the treatment shall correspond to the type approval requirements.

The operator will have to choose one alternative:

• Stop the operation.

• Continue operation and not comply with type approval certificate.

4.3.2.2. Backflush

To keep the filter clean, it is automatically backflushed. The backflush is performed during ongoing process without interrupting the ballasting process. When a ballast operation is stopped, a backflush is performed before the system comes to a full stop. The water used for backflushing is returned to the sea directly at the ballasting site.

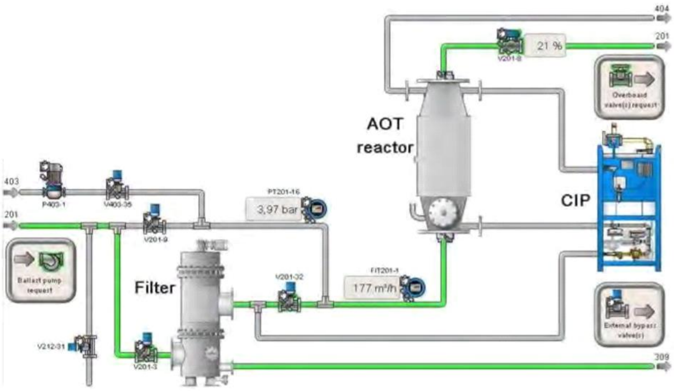

Fig. 4. Filter backflush

4.3.2.3. Ballast after-treatment (CIP)

After a ballast operation, a cleaning-in-place (CIP) process is performed to clean the AOT reactor. This process can either be performed immediately after a ballast operation or within 30 hours after. Note, that it is possible to perform new processes during these 30 hours. A CIP process takes about 25 minutes per AOT reactor, if default parameters are used.

The AOT reactors are cleaned one at a time. First, the AOT reactor is rinsed with fresh water. Then the cleaning-in-place (CIP) module circulates a biodegradable solution through the AOT reactor to remove seawater scaling. After the cleaning is finished, the AOT reactor is filled with fresh water to preserve the filter and prevent scaling, algae growth etc. Then the system continues with the same procedure for the next AOT reactor. Finally, the filter is filled with fresh water to prevent scaling and algae growth. The cleaning liquid is reused between the cleaning operations.

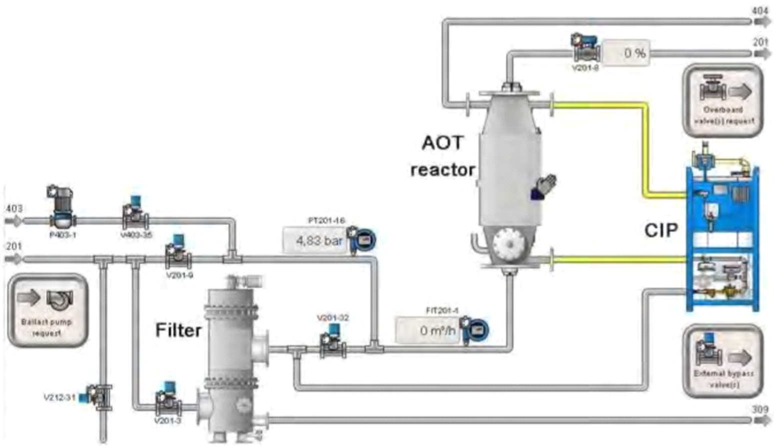

Fig. 5. CIP process

4.3.3. Deballasting

After the start-up, when the lamps are ready, the operator is requested to start the ballast pump. The water passes through the AOT reactor, but the filter is bypassed since the water has already been filtered during ballasting. The reason for treating the water a second time during deballasting is to secure that the treatment is fully effective. The minor part of the organisms, which were only injured during ballast, will be rendered totally harmless during the deballast.

The process flow and power optimization are controlled in the same way as during ballasting.

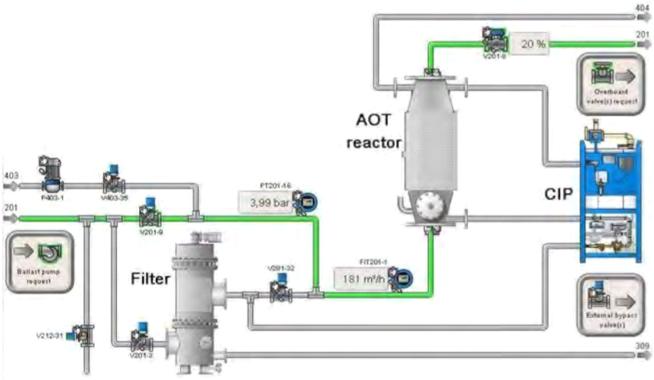

Fig. 6. Full debalastting

4.3.3.1. Deballast after-treatment (CIP)

After deballast operation, a cleaning cycle is performed to clean the AOT reactor. It is performed in the same way as described for the ballasting process. If only deballast operations has been performed since the last CIP process, the filter does not need to be filled with fresh water at the end of the cycle, since the filter has not been used.

4.3.4. Stripping with eductor

Stripping can be performed to achieve total emptying of the ballast tanks via a stripping eductor. To use ballast water treatment system during a stripping process an eductor must be installed before the system.
The water used in the stripping process, must be filtered from particles larger than approximately 5 mm. The water passes through the water ballast treatment system as a regular deballasting process (with the filter bypassed). The water is finally pumped into the sea.
Note the following:
- The eductor is not part of Alfa Laval’s scope of supply.
- Procedures to dispose of sediments from the sieve must be included in the vessel’s ballast water management plan.

4.3.5. Ballast water handling in the event of malfunction

The system is equipped with a bypass valve. The valve can be used in case of emergency to secure the ship, by allowing ballast water operations (ballast, deballast and internal transfers) without involving the ballast water treatment system. The valve is controlled by the ISCS, but all bypass valve activities are logged in the event log. Such valve is required by the International Convention for the Control and Management of Ship’s Ballast Water and Sediments 2004.
If the system malfunction in connection with general cargo operation, ballast and deballast operations should be avoided. In case untreated water is pumped to a ballast tank, this water shall be discharged on open sea (according to regulations) and exchanged for treated water. Note that full treatment requires treatment both during ballast and deballast.
The procedures concerning emergency and malfunction of the ballast water treatment system should be implemented in the ships Ballast water management plan.

4.4. System components

4.4.1. AOT reactor

The main part of this ballast water treatment system is the AOT reactor in combination with a lamp drive cabinet (LDC) giving power to the UV lamps in the AOT reactor. The LDC does not need to be placed in close relation to the AOT reactor.

4.4.1.1. AOT reactor working principle

The main treatment process take place inside the AOT reactor, where the UV light inactivates the cell DNA to prevent regrowth of organisms. The UV light also generates radicals. The radicals are extremely reactive and react instantaneously with micro organisms and other organic contaminants destructing their membranes. The radicals are extremely short-lived and exist only for some milliseconds. This means that they will only exist inside the AOT reactor. The quantity of radicals produced in the reactor is sufficient to treat the water as it passes through the reactor.

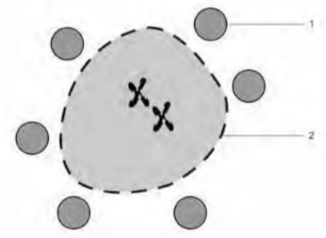

Fig. 7. AOT

Destruction of cell membranes
1. Radical
2. Cell membrane

There are no chemical substances added to the process, and there are no toxic residuals created. Since the water is not affected chemically there are no environmental impact, and the process does not influence corrosion in any way.

4.4.1.2. AOT reactor description

The AOT reactor consist of the reactor, sensors and valves for ballast water, fresh water and CIP liquid, as shown in the illustration below. The AOT reactor accommodates 16 medium-pressure UV lamps (6 kW each) powered from the lamp drive cabinet (LDC). The UV lamps are enclosed in individual quartz-glass sleeves.
The UV lamps get very warm, so they must be cooled whenever they are lit. To secure that there is water in the reactor when the lamps are lit, each reactor is equipped with a level switch. The level switch also secures that enough CIP liquid is pumped into the reactor during the CIP process. To secure that the lamps are adequately cooled by the ballast water, each AOT reactor is equipped with one temperature transmitter that shut down the reactor at 60 °C, completed with a temperature switch that automatically shuts down the reactor if the temperature reaches 65 °C.
A UV sensor monitors the UV lamp efficiency in relation to the water transmittance inside the AOT reactor. Based on this input, the power to the UV lamps are regulated between 50 and 100 % of full capacity. The UV lamps will be dimmed to lowest possible level, where they are still effective.
Note, that the lamps are always lit with full effect during start-up and the first two minutes of full ballast to secure full efficiency independent of transmittance. The lamps are also turned up to full effect for 10 seconds before stop and normal shut down. This method will prolong the UV lamp life time.
The illustration below shows the main components for the AOT reactor (Fig. 8).

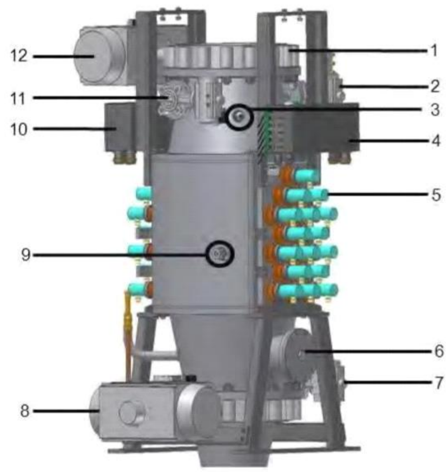

Fig. 8. AOT reactor

AOT reactor components:
1. Ballast water outlet valve
2. CIP liquid outlet valve (actuator indicated)
3. Level switch
4. Junction box
5. UV lamp cap (UV lamp and quartz sleeve inside)
6. Access hatch
7. CIP liquid / fresh water inlet valve and reactor drain valve (actuator indicated)
8. Ballast water inlet valve (actuator indicated)
9. UV sensor
10. Junction box
11. Cooling water outlet valve
12. Ballast water outlet valve actuator (actuator indicated)

4.4.2. Lamp drive cabinet (LDC)

The lamp drive cabinet gives power to the AOT.

4.4.2.1. LDC working principle

The AOT reactor is connected to a lamp drive cabinet (LDC) containing 16 lamp power supplies (LPS), each feeding one lamp with power. The LPS also monitors the function of each UV lamp and takes action if a fault occurs. Lamps on the cabinet indicates if power is on, UV lamps are lit and if the cabinet needs to be reset after a shutdown or power off.

4.4.2.2. LDC description

The LDC is equipped with a cooling system to maintain correct operating temperature in the LDC, using low-temperature cooling water. The cooling water flow is constant, but the fan is regulated based on heat inside the cabinet. When lamps are lit, the fan starts at 15 % of full effect. When the temperature reaches 40°, the fan starts to regulated between 15 % and 100 %, according to parameter settings based on input from the temperature transmitter in the LDC.
The humidity in the cabinet is monitored by a liquid sensor. If a leakage from the heat exchanger is detected, a warning is issued, the reactor is shut down and the cooling water inlet valve to the LDC is shut.
The LDC can be placed up to 150 meters (cable length) from the AOT reactor. The main breaker cut the power to the LDC and the AOT reactor.

Fig. 9. LDC

LDC components:
1. Fan
2. Heat exchanger
3. Lamp power supplies (LPS)
4. Fuses
5. Cooling water inlet and outlet
6. Main breaker
7. Status lights and reset button

4.4.3. Filter

4.4.3.1. Filter working principle

The filter is a fully automatic self-rinsing component, equipped with filter elements to remove particles and organisms from the ballast water flow. The ballast water is lead through the filter, and filtered particles are trapped in the filter. The filter control cabinet is only used for connections. The filter is entirely controlled from the ballast water control system.

4.4.3.2. Filter description

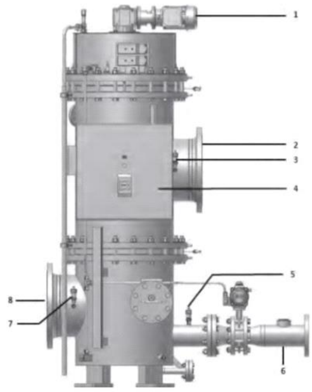

Fig. 10. Filter

Filter components:
1. Geared motor
2. Water outlet
3. Pressure transmitter, outlet
4. Filter control cabinet.
5. Pressure transmitter, backflush line
6. Backflush outlet
7. Pressure transmitter, inlet
8. Water inlet

To secure efficient filtration, the filter performs a self-rinsing backflush operation at time set intervals or when triggered by indication of dirt in the filter. Pressure drop over the filter is monitored by pressure transmitters on the filter inlet and outlet. Dirt is detected by an increased differential pressure drop caused by particles in the filter. When the differential pressure reaches a parameter set value, an automatic backflush operation starts.

The backflushing does not interrupt the filtration process, since all filter candles are not cleaned at the same time. The not cleaned filter candles continue the filtration of the ballast water. It is also possible to start backflush manually from the control system.

The filter candles are backflushed in two steps:

- **Step 1:**

The flushing arm is positioned under the first filter candle to be backflushed. The purpose of the flushing arm is to collect the backflush water and lead it, with the flushed particles, to the backflush line. From this point, this filter candle is not used for filtering. A valve on top of the filter candle is opened to lead water through the filter candle from the top downwards. The water flow through the filter candle down to the flushing arm, flushes particles from the filter candle walls and lead them to the backflush line.

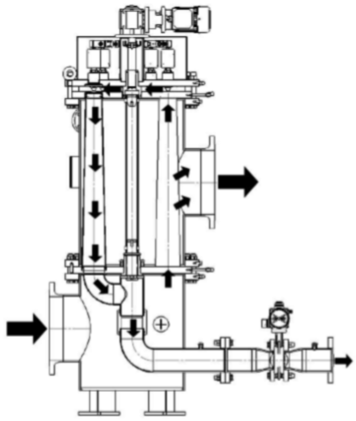

Fig. 11. Step 1

- **Step 2:**

The valve on top of the filter candle is closed to stop the axial flow to the filter element. The existing water pillar inside the candle continues the flow downwards, which creates an under pressure. This under pressure forces water to flow radial through the filter candle from the outside (filtered side) to the inside (unfiltered side), which pulls remaining particles from the mesh and downwards to the backflush line.
When the first candle is backflushed, the flushing arm change position and the process is repeated until all filter candles are rinsed.

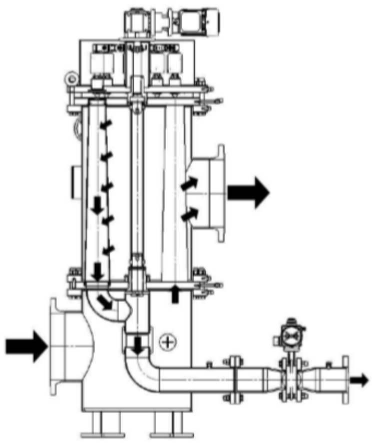

Fig. 12. Step 2

4.4.3.3. Backflushing for different dirt loads
Below, the filter pressure drop over time (pfilter) is illustrated for different dirt load situations in the filter. Different dirtload depends on the water condition, which means that "normal" condition regarding filter backflush depends on the water conditions.

- **Low dirt load**

In water with low dirt load, the backflush cycle is started by the time trigger (default: every 30 minutes). As long as the pressure is below 0.85 (0.085 MPa) bar, there is no need for the pressure triggered backflush. See examples below.

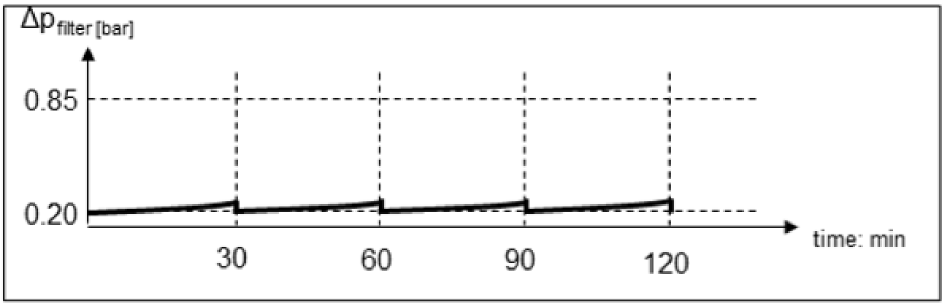

Fig. 13. Low dirt load 1

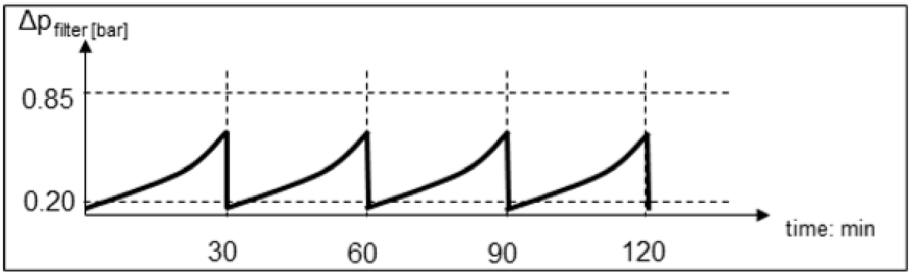

Fig. 14. Low dirt load 2

➢ **Medium dirt load**

In more dirty waters the backflush cycle will be triggered when pfilter reaches 0.85 bar, which indicates dirt in the filter candles.
After each backflush, the backflush timer is reset. The filter will be backflushed again after 30 minutes or when Δpfilter reaches 0.85 bar, whichever comes first.
In the example below, three backflushes are triggered due to high differential pressure over the filter. After that, there is not so much dirt build-up, so the next backflush is performed after 30 minutes.

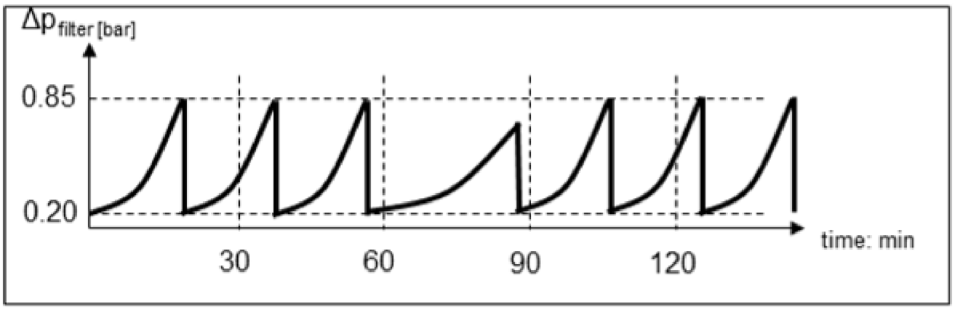

Fig. 15. Medium dirt load

➢ **Heavy dirt load**

In conditions with heavy dirtload, the system will perform more frequent backflushes to keep the filter clean.
Also, the 0.85 limit might be exceeded. In this case the self-rinsing cycle will run continuously until the problem is solved and the pressure has returned below 0.85 bar. It is OK that the flow momentarily fluctuates in an irregular curve, but it is important that the curve stabilizes.
In the example below, a series of backflushes are performed (approx. every 4 minute). After that the pressure rises above 0.85 where the filter is backflushed constantly. After that, the normal control is resumed, where the filter backflush is triggered by pressure (2 times) or by time (last backflush in the example.

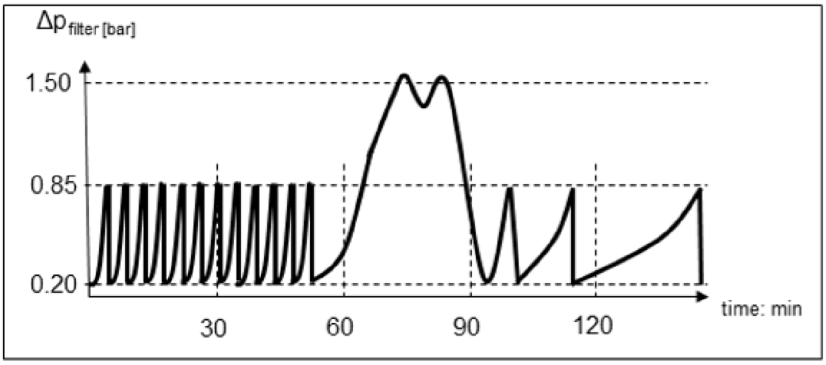

Fig. 16. Heavy dirt load

➢ Long term dirt build-up

Over time, the filter candles will undergo a long-term build-up of particles that are not removed by backflushing. One effect of this is that "normal" pressure will increase over time. Therefore, the maintenance schedule state that the candles shall be inspected and manually cleaned once a year.
The extent of the long-term dirt build-up is dependent on the water conditions. In the great majority of cases this will not cause any problems – cleaning once a year is enough. But in exceptional cases (vessels trading very muddy waters) it might be necessary to clean the filter candles more often. If the pressure triggered backflushing is performed with short intervals, we suggest that the filter candles are manually cleaned more often than once a year.

4.4.4. CIP (cleaning-in-place) module

4.4.4.1. CIP working principle

To ensure full performance in ballast water treatment system, an automatic cleaning cycle is performed after ballast and deballast operation. The purpose is to keep the quartz sleeves covering the UV lamps and the UV sensor clean, to maximize the effect of the UV lamps, and thereby treatment efficiency.
During a cleaning cycle, the CIP module rinse the reactor with fresh water and circulates a CIP liquid through the AOT reactor. The low-pH CIP liquid removes scaling, calcium chlorides, metal ion build-up and chemical fouling on the lamps' quartz glass sleeves. After finished cycle, the liquid is returned to the CIP module tank; the CIP liquid is reusable for a great number of cycles. The sequence is finalized by filling the AOT reactor with fresh water. A backflow preventer secures that no CIP liquid is mixed with the fresh water.

4.4.4.2. CIP module description

The CIP module consists of a tank where the CIP liquid is stored between usage. The pumps and valves integrated in the CIP module are controlled by the valve block.
To secure that there is enough CIP liquid for the process, the level switch in the reactor indicates when it is filled with CIP liquid. To prevent intrusion of water in the fresh water system, a backflow preventer is used in the CIP module.
The CIP module is equipped with two membrane pumps:
• Pump 1 (4) circulates the CIP liquid in the AOT reactor and fills it with fresh water.
• Pump 2 (6) drains water (sea and fresh water) overboard from the reactor, via the drain line.

Fig. 17. CIP module

CIP module components:
1. Deaeration valve
2. Valve block
3. Regulator
4. Pump (CIP liquid)
5. Backflow preventer
6. Pump (reactor drain)
7. Tank for CIP liquid

4.4.5. Control cabinet and control system

The control cabinet is used to control and monitor the entire system, via the built-in main control panel (Fig. 18). It is also used to communicate with the vessel's systems and components, if integrated. The control cabinet functions as a single point of contact for signal cables to and from the vessel. Examples of integration: Remote interface integration and power management system (PMS). Remote interface will allow control of ballast water treatment system from the vessel's ISCS and PMS integration will allow automatic verification that there is enough power to run an operation. If not integrated, the operator must verify this manually. Also, integration with other external components (not part of Alfa Laval's scope of supply), such as GPS or booster pumps, are done to the control cabinet.

Fig. 18. Control cabinet with main control panel

4.4.5.1. Control system

The control system is used to set parameters, operate and monitor the ballast water treatment system. The control system continuously monitors ballast water treatment (sensors, communication and PLC status), both during operation and in standby mode. Any deviation is either communicated to the operator or handled automatically, based on parameter settings. Safety risks are always handled automatically. The control system stores all alarms and relevant events for at least 24 months. The memory has a vast safety margin but when it is full, data will be deleted starting with the oldest logs. Logged information can be exported to a USB memory stick.

There are three alternative ways to monitor and control the system: main panel, remote control panel (optional) and remote interface (optional). If two ballast water treatment systems are installed on a vessel, two control systems are needed.

4.4.5.2. Main control panel

The main control panel in mounted in the control cabinet, and it is included in the standard installation of the system (Fig. 19). It is installed in the engine room. The main control panel handles every aspect of the control system. It allows the operator to monitor the system, to operate it manually and automatically, and to set parameters. Please note that some of the operations are password-protected.

Fig. 19. Main control panel

4.4.5.3. Remote control panel (optional)

As an option, it is possible to install one or two additional panels to be placed in locations from where ballast operations are performed. A remote control panel looks and functions in the same way as the main control panel, and it allows same operations (Fig. 20).

Fig. 20. Main control panel with four integrated remote control panels

4.4.5.4. Remote interface (optional)

As an option, the control system can be integrated with the vessel's ISCS via modbus. This allows monitoring and operation of system from the ISCS's graphical user interface (Fig. 21).

Note that Alfa Laval does not supply the graphical user interface to handle the system in the ISCS, only the means to enable the integration.

Fig. 21. Remote interface

4.4.6. Main valves
The main valves in the system are:
• Inlet valves:
The inlet valves direct the water flow from the vessel's ballast water system into the system. Different valves are used during ballast and deballast.
- System and filter inlet valve - inlet valve to ballast water treatment system during ballast. The valve directs the water flow through the system filter.
- Filter outlet valve - the valve directs the water flow from the filter to the AOT reactor during ballast.
- Inlet valve -inlet valve to the system during deballast. The valve directs the water to the ballast water treatment system, but bypass the filter, since the water was filtered during ballasting.
• Control valve - the valve has the following functions:
- automatic regulation to maintain flow during operation so it does not exceed selected certified maximum flow. Regulation is based on input from the flow meter.
- automatic regulation to maintain pressure needed to perform backflush of the filter. Regulation is based on input from the pressure transmitter.
- outlet valve from the system to the vessel's ballast water system after treatment.
• System bypass valve - makes it possible to completely bypass the system. The valve is solely operated from the ISCS, but the valve positioning is (and must be) indicated in the control system. When ballast water treatment system is bypassed, an event is written to the event log. The component is optional to be included in Alfa Laval's scope of supply.
• Cooling water inlet valve - supplies cooling water to the reactor to secure cooling of the lamps and prevent overheating during start-up.
• Check valve - ensures that there is water in the reactor at all times.

4.4.7. Flow meter
The flow meter monitors the process-flow during operation. It has two main functions:
• It monitors that the flow within the ballast water treatment system does not exceed its certified flow. If the certified flow is exceeded a warning is issued.
• Via the flow transmitter, mounted on the flow meter, it sends valuable data to the control system, where it is displayed. Example of information: Current flow and data about total amount of treated ballast water. The flow meter consists of two main parts: a flow sensor, which is a pipe with four electrodes detecting the flow. On top of the pipe, there is a terminal box, where the flow transmitter is mounted. The flow transmitter monitors the flow and transmits the information to the ballast water treatment control system.

4.4.8. Pressure monitoring device
The pressure monitoring device is a manifold that includes the following components to monitor and handle pressure in the system:
• Pressure transmitter - send current pressure information to the control system. The control system uses the information to take actions accordingly, for example issue warnings, shut down the system or adjusting the control valve to obtain optimal pressure during filter backflush.

• Pressure gauge - analogue displayed of current pressure.
• Needle valve - enables connection of external instruments for calibration.
• Safety valve - relief of over pressure.

4.4.9. Sampling devices

The two sampling devices make it possible to take water samples to test the water. One sampling device is installed before the water is treated and one after the water is treated. This enables comparative tests of treated and untreated water. The component is optional to be included in Alfa Laval's scope of supply [3].

5. Conclusion

Because of regulations and for protection of the environment, ship owners must comply with Ballast water management convention.
Here there are some criteria's for choosing the best technology for ballast water treatment system:

- safety of the crew and passengers;
- effectiveness in removing target organisms;
- ease to operate treatment equipment;
- amount of interference with normal ship operations and travel time;
- structural integrity of the ship;
- size and expense of treatment equipment;
- mount of potential damage of the environment;
- ease of port authorities to monitor for compliance with regulations.

While several ballast water treatment technologies have been certified according to the IMO guidelines, further evaluation is necessary with regards to new marine organisms with emphasis on higher organisms, development of new processes at lab, pilot and full scale, as well as studying the environmental implications of these technologies. One of the most common methods of treating ballast water is mid-ocean water exchange. By exchanging of port ballast water in the open ocean is thought to eliminate species residing in the ballast by exposing them to different salinity and causing mortality due to osmosis [9]. This has an efficiency of 97% to 99%. The probability of organisms surviving ballast water exchange depends on waters of origin and location. In the absence of large salinity differences between receiving waters and discharge waters, organisms may be able to survive (Table 8) [10].

Table 8: Aquatic Invasive Species Known to Have Been Spread by Ballast Water [4],[5]

Species Name	Native from	Introduced to	Environmental Impact
European green crab *Carcinus Maenus*	➢ European Atlantic coast	➢ S Australia ➢ South Africa ➢ United States ➢ Japan	Resistant to predation due to hard shell. Competes with and displaces native crabs and becomes a dominant species in invaded areas. Consumes and depletes wide range of prey species. Alters inter-tidal rocky shore ecosystem.
Zebra mussel Dreissena polymorpha	➢ E of Europe ➢ Black Sea	➢ W and N Europe ➢ Ireland ➢ Baltic Sea ➢ E of North America	Fouls all available hard surfaces in mass numbers. Displaces native aquatic life. Alters habitat, ecosystem and food web. Causes severe fouling problems on infrastructure and vessels.

			Blocks water intake pipes, sluices, and irrigation ditches.
Chinese mitten crab Eiocheir sinensis	➢ N of Asia	➢ W Europe ➢ Baltic Sea ➢ W coast North America	Burrows into river banks and dykes causing erosion and siltation. Preys on native fish and invertebrate species, causing local extinctions during population outbreaks. Interferes with fishing activities.

Table 9: Probability of organism to survive and reproduce in freshwater (FW), brackish water (BW), and saline water (SW)

Receiving Waters	**Discharged Ballast**		
	FW	**BW**	**SW**
FW	High	Medium	Low
BW	Medium	High	High
SW	Low	High	High

The article shows that one of the most efficient and modern ballast water treatment system is with UV and advanced oxidation technology (AOT.), because it has a large spectrum of species that he is eliminating and is not harmful to the environment [6], [7], [8].
Because of the amount of ships in the world, management of ballast water requires significant attention globally, as it becomes more susceptible to invasive species [9], [10].

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