White paper

Ballast water management: An overview of regulations and ballast water treatment technologies

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1. Introduction

Ballast water is essential to commercial shipping. It compensates for weight loss due to cargo operations or resource consumption, thereby providing stability, reducing stress on the hull and improving propulsion and manoeuvrability.

Vessels transport three to five billion tonnes of ballast water worldwide each year. However, the water they pump in also contains a variety of indigenous organisms, which are later released outside of their natural habitats. On any given day, this includes up to 10,000 different marine species.

While most transported species do not survive when the ballast water is discharged, some thrive in their new environment. With no natural predators, they outcompete, displace or kill native species. In such cases, they pose serious risks to local ecosystems, human health and regional economies. They can cause severe and irreversible damage, and attempts to limit further destruction are often costly.

To minimize and ultimately eliminate the transfer of harmful aquatic organisms and pathogens, various international, national and regional maritime bodies have worked for several years to establish standards for managing ballast water. In response, diverse technological solutions have emerged to help ships comply with the new requirements.

This document provides an overview of the most influential ballast water regulations and their enforcement. It offers guidance for complying with these standards, including a detailed survey of available ballast water treatment technologies. It also provides information about selecting a system and supplier to match a particular vessel's needs, and about what to consider when planning the installation.

2. Ballast water management regulations

After years of negotiations within the global maritime community, regulations for ballast water management are entering into force at the international, national, regional and local levels. The most significant regulations are those of the International Maritime Organization (IMO) and the United States Coast Guard (USCG). However, approximately 25 other nations and regional authorities have also set their own requirements.

2.1. The IMO BWM Convention

The IMO International Convention for the Control and Management of Ships' Ballast Water and Sediments, adopted in 2004 and commonly referred to as the Ballast Water Management (BWM) Convention, was ratified by a minimum of 30 member states representing at least 35% of the world's merchant shipping gross tonnage on 8 September 2016. It enters into force one year after this date, on 8 September 2017.

The BWM Convention applies to all vessels that carry ballast water and are engaged in international voyages. It establishes global ballast water management requirements and permits national, regional and local authorities to apply their own regulatory framework in their respective territorial waters. Requirements are defined for both ballast water exchange and ballast water treatment.

Ballast water exchange

Ballast water exchange is intended to kill low-salinity non-native species originating from coastal regions by exposing them to high-salinity open-ocean water. Due to its limited effectiveness and the safety risks it poses for the vessel, it is an intermediate solution to be phased out by ballast water treatment.

As of 8 September 2017, vessels must perform ballast water exchange unless using a type-approved treatment system. According to Regulations B-4 and D-1 of the BWM Convention, the procedure must be performed:

- In open ocean, at least 200 nautical miles from the nearest land
- In waters at least 200 metres in depth
- With a 95% volumetric exchange of ballast water

Ballast water treatment
Regulation B-3 of the BWM Convention requires all vessels – regardless of construction year and ballast water capacity – to be equipped with a type-approved ballast water treatment system by the date of their first IOPP renewal survey after 8 September 2017. Until this dry docking, they must comply by means of ballast water exchange.

To receive IMO type approval, treatment systems must meet the discharge criteria concerning viable organisms and concentrations of indicator microbes established in Regulation D-2 of the BWM Convention (see 3.1). The type approval procedure itself is defined in Regulation D-3 and clarified in IMO technical guidelines.

2.2. The USCG Final Rule

In March 2012, the USCG published its Standards for Living Organisms in Ship's Ballast Water Discharged in U.S. Waters. Commonly referred to as the USCG Final Rule, the legislation went into effect in June 2012.

The USCG Final Rule applies to nearly all vessels that discharge ballast into United States waters. A number of vessel types are explicitly exempted, however, including:

- Crude oil tankers engaged in coastwise service
- Vessels operating exclusively within one Captain of the Port Zone

Vessels that have ballast water tanks but do not discharge ballast into United States waters are unaffected.

The USCG Final Rule requires affected vessels to have approved ballast water treatment systems by a specific compliance date (see table). Until this time, they must perform ballast water exchange in an area 200 nautical miles from any shore prior to discharging ballast water.

Approved options for ballast water treatment
Two types of ballast water treatment systems can be used to comply with the USCG Final Rule:

- *Systems with USCG type approval*
  The USCG type approval process is stricter and more rigorous than that of IMO. It is defined by Title 46 of the U.S. Code of Federal Regulations Part 162 and includes land-based testing according to the Environmental Technology Verification (ETV) protocol of the U.S. Environmental Protection Agency (U.S. EPA). Existing systems with IMO type approval may fail to meet USCG type approval requirements, and will therefore require retesting or redesign.
- *Alternate Management Systems*
  Certain treatment systems with type approval from authorities outside the United States have been approved as Alternate Management Systems (AMS). These systems may be used for up to five years after the vessel's compliance date or extended compliance date.

Table: USCG Final Rule implementation schedule

	Ballast capacity	Construction date	Compliance date
New vessels	All	On or after 1 December 2013	On delivery
Existing vessels (retrofits)	< 1500 m^3	Before 1 December 2013	First scheduled dry-docking after 1 January 2016
	1500-5000 m^3		First scheduled dry-docking after 1 January 2014
	> 5000 m^3		First scheduled dry-docking after 1 January 2016

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Other compliance alternatives
Although they will not be feasible for most vessels, the USCG Final Rule provides two additional compliance alternatives:

- Exclusive use of ballast water from a public water system in the United States (includes certain tank cleanliness requirements)
- Discharge of all ballast water into an onshore facility or another vessel for treatment purposes

2.3. Other regulations

Many other countries have adopted their own policies to protect against invasive species. Georgia, Lithuania and the Ukraine, for example, have regulations dealing specifically with ballast water exchange in the Black Sea.

Various regional and local ballast water regulations are also in effect worldwide, for example in individual U.S. states. The State of California's Marine Invasive Species Program is considered the most stringent.

3. Ballast water standards and their enforcement

The regulations governing ballast water management stipulate limits for the number of organisms and the concentrations of indicator microbes that can be discharged in ballast water. Ballast water treatment systems must show that they meet these limits not only during type approval, but also throughout their operating life.

3.1. IMO and USCG discharge standards

The international discharge standards for ballast water treatment are defined in Regulation D-2 of the BWM Convention. They establish limits for discharged organisms in two different size classes, as well limits for three specific indicator microbes (see table).

The numerical discharge limits defined in the USCG Final Rule are the same as those in the BWM Convention. However, the BWM Convention requires measurement of "viable" organisms, whereas the USCG Final Rule requires measurement of "living" organisms.

Differences in measurement
The distinction between IMO and USCG measurement requirements is significant. For example, it has important implications in type approval testing.

Type approval as defined in the BWM Convention is governed in practice by the IMO G8 technical guidelines, which have been revised to create greater consistency in land-based testing. The revised G8 guidelines define "viable" organisms as those that can "successfully generate new individuals in order to reproduce the species." This can be assessed in a number of different ways.

Table: International ballast water discharge standards

Biological constituent minimum dimension	Discharge limitation
Greater than or equal to 50 µm*	Less than 10 viable organisms per cubic metre of ballast water
Less than 50 µm and greater than or equal to 10 µm	Less than 10 viable organisms per millilitre of ballast water
Indicator microbes <10 µm	**Specified concentrations**
Toxicogenic *Vibrio cholerae* (O1 and O139)	Less than 1 colony-forming unit (CFU) per 100 millilitres or less than 1 CFU per 1 gram (wet weight) zooplankton samples
Escherichia coli	Less than 250 CFU per 100 millilitres
Intestinal Enterococci	Less than 100 CFU per 100 millilitres

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The USCG type approval process, by contrast, defines organisms simply as living or dead. At present, CMFDA/FDA staining is the only approved method for determining these two states. There is, however, an ongoing discussion about the most probable number (MPN) dilution-culture method as a possible basis for USCG type approval. Already employed and accepted for IMO certification, the MPN method would also account for organisms that are rendered unable to reproduce.

Vessel General Permit (VGP) limits
Vessels sailing in United States waters must adhere not only to the ballast water discharge standards of the USCG Final Rule, but also to the specific limitations of the U.S. EPA Vessel General Permit (VGP). More information on VGP requirements can be found at *https://www.epa.gov/npdes/vessels-vgp*

3.2. Demonstrating compliance

Documentation and inspections of the ballast water treatment system, as well as sampling of the ballast water discharge, are necessary to verify compliance. Specific procedures exist for both the BWM Convention and the USCG Final Rule.

Reporting and inspection worldwide
According to the BWM Convention, all vessels with a gross tonnage of 400 or greater are subject to regular surveys and inspections. To ensure that ballast water management is carried out according to regulated procedures and standards, all ships must have on board:

- An approved, ship-specific Ballast Water and Sediments Management Plan
- A Ballast Water Record Book
- A valid international Ballast Water Management Certificate

Ships are required to enter any accidental non-compliant discharge into the Ballast Water Record Book. This information should be signed by the officer in charge and immediately reported to the concerned Port State Authority.

Port State Control guidelines provide recommendations for inspections and sampling to verify compliance with the BWM Convention. These do not, however, remove the right of port states to carry out more rigorous testing of ballast water discharge.

Reporting and inspection in United States waters
The USCG Final Rule requires ballast water reporting and recordkeeping via one of two means: the Ballast Water Management Report (BWMR) form or the Equivalent Reporting Program.

A BWMR form must be submitted in conjunction with arrival in United States waters. This must be done no later than 6 hours after arrival, or at least 24 hours before arrival for vessels travelling to the Great Lakes or the Hudson River from outside the U.S. Exclusive Economic Zone (EEZ). Signed reports must be retained for at least two years. Further information and instructions on using the BWMR form can be found at *http://invasions.si.edu/nbic/submit.html*

To take part in the Equivalent Reporting Program, the applicant vessel must be non-seagoing and operate solely within the U.S. EEZ or Canadian equivalent. Additional requirements, restrictions and information for this programme are available at *http://invasions.si.edu/nbic/equivalentprogram.html*

In accordance with VGP legislation, vessels must also perform the following routine procedures for the ballast water treatment system:

- System functionality monitoring to verify operation according to the manufacturer's specifications
- Biological organism monitoring for three listed indicator organisms: total heterotrophic bacteria, E. coli and enterococci
- Residual biocide and derivative monitoring for active ingredients used in the treatment system

4. Ballast water treatment systems

There are many ballast water treatment systems on the market that have received type approval to meet international discharge standards. However, no single system is suitable for all vessel types, sizes and operating conditions.

It is therefore important to understand the strengths and weaknesses of each technology, so as to choose a system whose capabilities match the vessel and its sailing profile. This section provides an overview of the different technologies, as well as an in-depth look at the most common alternatives.

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4.1. Water quality and ballast water treatment

Before considering any treatment technology, it is necessary to understand key factors of water quality. The water pumped into a vessel's ballast tanks can vary considerably, and it will affect different ballast water treatment systems in different ways. Specific water characteristics may limit a system's ability to comply in a given situation, for example, or cause it to consume more power.

Three water characteristics are especially important: salinity, temperature and ultraviolet transmittance.

Salinity
Salinity is the total concentration of salts dissolved in the water. It can be impacted by temperature, climate, season and other factors. For example, most ports are exposed to river run-off, which means their average salinity levels are generally lower than that of ocean water.

Temperature
Surface water is warmed by solar radiation, which decreases with distance from the equator. The warmest water is located closest to the equator, while the coldest water is found at the poles.

Ultraviolet (UV) transmittance
UV transmittance is the measurement of how much UV light is able to pass through a sample of water. Dissolved matter in the water causes light intensity to decrease exponentially with distance from the source. While UV transmittance in seawater is generally high, it tends to be lower in coastal waters. In harbours it usually ranges from 90% down to 60%, but can sometimes fall to 50% or below.

4.2. Pre-treatment alternatives

Most ballast water treatment systems utilize a two-step process, in which disinfection (main treatment) by chemical or physical means is preceded by a pre-treatment step. Pre-treatment removes solid material, such as suspended particles and larger microorganisms.

Three technologies are commonly used for pre-treatment: hydrocyclones, coagulation/flocculation and filtration.

Hydrocyclones
Hydrocyclones remove particles by rotating the ballast water at high velocity, but their efficiency is limited by the fact that many microorganisms have about the same density as the water. Hydrocyclones must often be installed in parallel to treat higher flows, creating a high pressure drop across them. As a result, the available pressure from the ballast pump may be a limitation.

Coagulation/flocculation
Coagulation/flocculation uses chemicals to trigger the formation of larger masses, which can then easily be filtered from the ballast water. This process is time-consuming and requires a large tank, and is therefore less common than the other separation technologies.

Filtration
Filtration is the most widely used method of pre-treatment. It involves passing ballast water through fixed screens, generally with a mesh size of less than 50 µm. Candle, basket and disc filter types are the most common.

Different manufacturers have different ways of manufacturing the filter weave and measuring the mesh size. It is therefore impossible to judge the performance of a filter by comparing the mesh size alone. Its performance must be determined through biological tests. If too many organisms are able to pass the pre-treatment step, the dose provided by main treatment step may be insufficient to ensure compliance.

4.3. Main treatment alternatives: chemical disinfection

Chemical disinfection technologies for main treatment use active substances that may be added or produced in situ. These active substances must be evaluated during system certification.

The effectiveness of the chemical processes themselves varies according to the water characteristics discussed previously (see 4.1), as well as the type of organisms that are present. During long voyages, there is a risk of regrowth if all active substances are consumed, which may result in non-compliance at discharge.

The use of chemicals can also present physical challenges, such as increased corrosion risk or changes in tank coatings. In addition, both holding time and total residual oxidants should be considered.

Holding time
Holding time is the necessary interval between ballasting and deballasting to ensure effective treatment, which must be specified during type approval. Normally around 24 hours, the holding time of some chemical systems can be as much as five days. Such systems may be unsuitable for vessels that ballast and deballast frequently.

Total residual oxidants
Total residual oxidants (TRO) are the active substances left by ballast water treatment systems that make use of oxidants, such as electrochlorination systems. TRO levels decrease with holding time as oxidants are consumed, but must be not greater than 0.1 mg/L at discharge according to legislation. If they exceed this limit prior to deballasting, additional post-treatment is needed to neutralize the remaining TRO.

Table: Overview of chemical disinfection technologies

Disinfection technology	Method	Considerations
Chlorination	Uses approximately 1-10 ppm (mg/L) of the chlorine-based germicide sodium hypochlorite (NaOCl), added to the ballast tank to kill organisms and pathogens that have bypassed the separation step. Prior to discharge, it is important to neutralize total residual oxidants (TRO) in the ballast tank, i.e. any residual sodium hypochlorite that may be present. This is usually done through the use of sodium meta-bisulphite or sodium thiosulfate.	Creates undesirable by-products, including chlorinated hydrocarbons and trihalomethanes (chloroform), and may therefore require additional post-treatment, depending upon the chlorine concentration and holding time in the tank. Requires consumables as well as special ventilated storage rooms.
Electrochlorination	Passes seawater through an electrolytic cell, where direct current produces chlorine and hydrogen gases. The chlorine gas is immediately dissolved in the water to produce the germicides sodium hypochlorite (NaOCl) and bromine hypochlorite (BrOCl), which neutralize microorganisms. Prior to discharge, it is important to neutralize total residual oxidants (TRO) in the ballast tank, i.e. any residual hypochlorites that may be present. This is usually done through the use of sodium meta-bisulphite or sodium thiosulfate.	Requires the addition of salt or high-salinity water, which must be stored on board, in order to be effective in brackish or fresh water. Low water temperature also impacts effectiveness. These factors result in significant power consumption when operating in low-salinity or colder water. Because hydrogen gas is deemed potentially hazardous, the equipment needs hydrogen traps, flame arrestors or other methods to safely handle the gas produced. Cleaning of the electrodes requires acid wash or other external electrode cleaning methods. Requires both consumables and special ventilation.
Ozonation	Generates ozone by means of either UV light or high-voltage electricity (corona discharge). Ballast water passes through a Venturi throat, which creates a vacuum that pulls the ozone gas into the water.	Requires the use of auxiliary equipment, such as compressors, dryers and air chillers. Has greater disinfection effectiveness against bacteria and viruses than chlorination, but can also produce harmful by-products, most notably bromate and insoluble metal oxides. Requires consumables.

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Table: Overview of chemical disinfection technologies

Disinfection technology	Method	Considerations
Peracetic acid and hydrogen peroxide	Disinfects through the use of this chemical blend with few known harmful by-products.	The chemicals are relatively expensive and require high mixing concentrations as well as considerable storage space. Requires consumables.
Chlorine dioxide	Disinfects quickly when added to ballast water as an aqueous solution in order to avoid problems with handling gases (accumulations of chlorine dioxide gas are known to spontaneously detonate).	Requires safe storage and handling on board. Rarely used despite its fast-acting disinfection capabilities, due to excessive amounts of toxic chlorite that are produced in some circumstances. Requires consumables.
Gas super-saturation (combination of chemical and physical disinfection)	Depletes the oxygen supply available to marine microorganisms by injecting nitrogen gas into the ballast water in sealed ballast tanks. This causes asphyxiation or suffocation of the microorganisms.	A treatment time of several days in the ballast tanks is needed for the method to be effective. A nitrogen generator must also be installed on board, which is a complicated installation with a large footprint.

Electrochlorination technology in depth
Electrochlorination, or electrolytic chlorination, is the most common chemical disinfection technology used in ballast water treatment systems. Electrochlorination systems usually employ pre-treatment filtration and treat the water once during ballasting.

The electrochlorination process uses electricity to produce a disinfecting hypochlorite solution from a common salt solution, which produces hydrogen gas as a by-product. The process is sensitive to:

- *Water salinity*
  Low salinity makes it difficult to generate the hypochlorite disinfectant, which results in lower efficiency and greater power consumption. Salt must be added to compensate, either directly or by means of a separate high-salinity water source. If the system is not fully automatic, this increases the complexity of both installation and operation.
- *Water temperature*
  Lower water temperatures exponentially increase the amount of energy needed to produce the hypochlorite disinfectant. Optimal water temperature is above 15°C, with normal low-end temperatures in the range between 10°C and 17°C. Water below 10°C significantly reduces the formation of chlorine, which means preheating is needed to ensure compliance in colder seawater.

Electrochlorination systems involve a large footprint and complex installation, with numerous components, pipes and safety arrangements. Further physical considerations include:

- *Ventilation*
  Electrochlorination generates hydrogen and chlorine gases, which are both explosive and toxic. Any dangerous gases must be managed and classification society requirements for system ventilation should be observed.
- *Chemical storage*
  Safety measures may also be needed when storing necessary chemicals, such as separate, explosion-proof compartments with ventilation. Additional safety equipment and training for the crew may also be required.

Finally, it is important to note that disinfection by-products (DBPs) can be formed when using electrochlorination. DBPs result from reactions with organic content in the water, which means more can be expected where organic content is higher, e.g. in brackish water. Because toxic DBPs can bioaccumulate in marine organisms, a number of studies have raised questions regarding their long-term environmental impact.*

**For one example, see: "Emerging risks from ballast water treatment: The run-up to the International Ballast Water Management Convention", Chemosphere, 112 (2014), 256-266.*

4.4. Main treatment alternatives: physical disinfection

Physical disinfection technologies for main treatment are an alternative to chemical disinfection. In contrast to chemical disinfection processes, physical disinfection processes do not involve active substances or the resulting residuals. Most are used during both ballasting and deballasting, without any significant holding time.

As with chemical disinfection technologies, however, there are both benefits and limitations to any physical disinfection technology. The effectiveness of treatment is similarly dependent upon the water's characteristics (see 4.1) and the type of organisms that are present.

Ultraviolet (UV) technologies in depth
Most ballast water treatment systems for physical disinfection make use of UV light, which has been used to disinfect drinking water for 100 years. UV systems have little or no impact on the environment and do not contribute to the corrosion of ballast tanks over time.

After filtration during ballasting to remove particles and larger organisms, UV systems direct ballast water into a disinfection chamber, or "reactor", where the remaining organisms are neutralized through exposure to UV light. During deballasting, the water passes through the reactor again to eliminate any regrowth during transit.

Table: Overview of physical disinfection technologies

Disinfection technology	Method	Considerations
Ultraviolet (UV) irradiation	Uses low-pressure amalgam or mercury lamps or medium-pressure mercury lamps surrounded by natural quartz sleeves to produce UV light that disrupts the DNA of marine organisms, preventing them from reproducing.	Requires large amounts of energy. Low-pressure lamps use less power, but have a larger footprint than medium-pressure lamps due to a longer lamp length and the need for up to 10 times as many lamps.
Advanced oxidation technology (AOT) using UV and titanium dioxide	Combines direct UV treatment with a titanium dioxide (TiO_2) catalyst and synthetic quartz glass sleeves to generate radicals that react with microorganisms and other organic contaminants. This destroys cell membranes and prevents organism reproduction or regrowth.	Has a higher UV optical efficiency than standard UV lamps, due to the use of synthetic quartz sleeves. The drawbacks are cost and the partial shadowing of the light by the catalyst.
Enhanced UV treatment	Uses medium-pressure mercury lamps to produce UV light that passes directly through synthetic quartz glass sleeves, thus generating radicals that react with microorganisms and other organic contaminants. This destroys cell membranes and prevents organism reproduction or regrowth.	Has a higher UV optical efficiency than standard UV lamps, due to use of synthetic quartz sleeves. This increases the biological performance without affecting the power consumption.
Deoxygenation	Depletes the oxygen supply in ballast water by injecting nitrogen, carbon dioxide or other inert gas into the space above deaerated water in sealed ballast tanks. This causes the asphyxiation or suffocation of marine organisms.	Requires holding time of 1-4 days to effectively kill the organisms and is therefore not suitable for ships with short transit times. Significantly reduces tank corrosion due to the lack of oxygen. Equipment is needed to produce the inert gas.
Cavitation	Uses high-power ultrasound waves to generate cavitation bubbles in the ballast water. The generation and collapse of the bubbles result in intense shear forces and high stress that kill organisms by effectively breaking their cell walls.	Is not known or anticipated to pose any environmental concerns. System capacity is highly energy dependent, and the process may have an adverse effect on ship coatings, tank coatings and/or ship structure.

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The effectiveness of this process is closely tied to the configuration of the UV lamps and the quartz sleeves that protect them from the surrounding water. Differentiating factors include:

- *Low-pressure vs. medium-pressure lamps*
  Low-pressure UV lamps are the most effective at converting electricity into UV light and have lower operating temperatures that create a somewhat longer operating life. However, medium-pressure lamps have a broader emission spectrum that gives them a much higher output per unit of lamp length, as well as a higher intensity that shocks microorganisms and impairs their ability to self-repair. In water with low UV transmittance, such as the low-clarity water often encountered in ballast water treatment, medium-pressure lamps penetrate further and provide better biological disinfection.
- *Natural vs. synthetic quartz*
  Natural or synthetic quartz can be used in both UV lamps and the sleeves that protect them. While synthetic quartz is more expensive than natural quartz, it emits additional UV light at a shorter wavelength. This increases UV output by around 15% and produces radicals close to the sleeve, which enhances biological performance through photoionization.

Depending on the factors above, biological disinfection performance can vary greatly from one UV system to another. In particular, system limitations differ with regard to water quality factors:

- *UV transmittance*
  Many UV systems are tested in clear water with high UV transmittance, where differences in light intensity are less apparent. In natural waters with low UV transmittance, these systems may have difficulty complying. A system with a verified ability to handle UV transmittance values of 50% or lower will ensure compliant disinfection in most harbours and ports.
- *Water salinity*
  UV treatment is not directly affected by water salinity. However, fresh water has lower average UV transmittance levels that may limit system performance as described above.
- *Water temperature*
  Medium-pressure UV lamps offer the widest spectrum of operating temperatures. In areas with near-freezing water temperatures, medium-pressure lamps will perform while low-pressure lamps may cease to function.

The right choice of lamps and sleeves can mean not only better performance, but also fewer and shorter lamps, with less vibration sensitivity and lower maintenance costs as a result. In addition, it is wise to consider the following factors:

- *Cleaning methods*
  Biofouling and accumulated deposits on quartz lamp sleeves and light- measuring sensors can lower UV transmittance and impair performance. While mechanical wipers can be used to remove them, this puts moving components within the reactor that may damage the quartz sleeves and will eventually need replacing. Cleaning-In-Place (CIP) with a mild acid avoids risk to the sleeves and also removes metal ion deposits that wipers leave behind.
- *Power management*
  Power management maintains treatment performance when moving between waters with varying UV transmittance. The system's power use is decreased when sailing in clear water, or increased under difficult circumstances where UV transmittance is low. To ensure compliance at all times, the adjustment should be fully automatic and immediately responsive to water changes.

5. Selecting a ballast water treatment system

The selection of a ballast water treatment system should be based not only on compliance factors, but also on economic considerations. The installation can have a large impact on a vessel's operating costs, as well as its total resale value. In addition, it is important to consider the potential impact on the vessel's existing equipment, operation and sailing profile.

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5.1. Cost factors

A number of factors determine a ballast water treatment system's impact on a vessel's total lifetime costs. The following should be weighed carefully:

- *Capital expenditure (CAPEX)*
  This includes the initial cost of the system itself, as well as the initial cost for any additional components required to ensure safe, compliant operation.
- *Operational expenditure (OPEX)*
  This is the annual cost of all consumables, including spare parts and energy usage. For chemical disinfection technology, this also includes the chemicals and costs related to their safe management and disposal. In most cases, OPEX will increase over time as system efficiency decreases.
- *Lifecycle costs (LCC)*
  These costs comprise any additional capital invested in the system throughout its service life, including for maintenance and repair, as well as for component replacements or upgrades. Depending on the system design, a lower CAPEX can lead to higher lifecycle costs in the long term.
- *Profitability*
  This refers to the ability to prevent income loss. Ballast water treatment systems can impact a vessel's revenues due to:
  - *Fines*
    If a system is unable to perform in all conditions under which a specific vessel sails, non-compliant ballast water exchange can result in fines.
  - *Restricted port access*
    Water quality (see 4.1) varies greatly between different ports (see table). Because all ballast water treatment systems have certain technical limitations, some systems may not be optimal for specific trade routes, which can impact a vessel's ability to compete financially. See the following table for more information.

Table: Water quality by port

Port	UVT(%)	Temp(°C)	Salinity (PSU)
Istanbul, Turkey	95	6	24
San Pedro, CA, USA	95	2	32
Halifax, NS, Canada	94	-0.8	20
Veracruz, Mexico	94	26	36
Rotterdam, Netherlands	93	5	0.3
Port of Singapore, Singapore	93	27	31.5
Houghton, MI, USA	91	-0.1	0.1
Erie, PA, USA	87	-0.1	0.3
Zeebrugge, Belgium	76	5	26
Gothenburg, Sweden	85	0	20
Charleston, SC, USA	84	10	24
Baltimore, MD, USA	83	11	12
Hong Kong, China	80	17	33
Houston, TX, USA	74	11	20
Hamburg, Germany	69	2	0.1
Antwerp, Belgium	66	5	6.5
Bremerhaven, Germany	60	2	4
Lisbon, Portugal	53	14	35
Southampton, England	51	5	32
Shanghai, China	49	4	1.2

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5.2. Ship-specific criteria

Specific information about the target vessel and its operation is important for understanding the type of system that can provide optimal treatment performance at the lowest total cost of ownership. Factors to consider when selecting a ballast water treatment system include:

- Vessel type
- Optimal ballasting/deballasting rates and ballast cycle times for the vessel
- Ventilation requirements for the system
- Space required by the system (footprint and volume)
- Flexibility in placing system components and the need for structural changes
- Effects of pressure drop
- Ex certification requirements
- Power availability and consumption
- Health and safety
- Impact of the system on tank structure/coatings
- Ease of operation and integration with existing systems
- Other planned retrofits
- Additional training needs and crew workload
- Certificates
- System availability and delivery times
- Availability of consumables, spares, technical support and optimization services

5.3. System component considerations

Considering ballast water management in its entirety, including the operation of pumps, piping and valves, is important in matching the right treatment system to a vessel. Design factors that require evaluation include:

- *Need for eductors*
  As ballast pumps can lose suction when the tank is almost empty, stripping the ballast tank generally requires a jet-type pump called an eductor.
- *Risk of contamination*
  Piping and valves connect the ballast tanks to one another and to the treatment system, which creates the possibility for cross-contamination. Control over the entire piping system, including its valves, is necessary to prevent the cross-contamination of clean or disinfected water before it enters the tank or is discharged.
- *Compatibility of active substances*
  When disinfection involves active substances, many authorities require verification of compatibility between the chemicals and the materials used in the ballast and chemical supply piping. Prior to installing systems with active substances, it is also necessary to check the paints used in the ballast tanks and the effects on anodes.
- *Flow capacity and pump rates*
  The requirements for ballast water flow vary between different types of vessels and determine the ballast water pump capacity. The treatment system, in turn, should be based on the capacity of the vessel's pumps.

6. Installing a ballast water treatment system

Properly planning the installation of a ballast water treatment system is as important to securing compliance as the selection of the system itself. A system that is not correctly installed may not perform as expected and as required by legislation.

Furthermore, delays that result from a poorly planned installation can add unexpected expenses to the total cost of the system. It can therefore be useful to examine a supplier's previous experience with both newbuild and retrofit projects.

6.1. Differences between newbuild and retrofit installations

The engineering and installation of a ballast water treatment system on a newbuild is normally handled by the shipyard. The system is engineered into the vessel as a component during the vessel's design, with space and power requirements considered from the beginning.

The possibilities for adapting a new vessel are normally large, which makes the choice of ballast water treatment system less consequential from an installation perspective. The installation time is a period of months, which leaves room for adjustments and corrections if anything is done wrong from the beginning.

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Retrofitting a ballast water treatment system on an existing vessel is typically more complicated. Since ballast water treatment was not considered during the original construction of most vessels, the installation needs to be adapted to existing onboard circumstances and systems. The typical dockyard timeframe for a retrofit is two weeks, and any delay means lost income for the vessel owner.

6.2. Retrofit project management

The complexity of a retrofit installation necessitates thorough preparation and cooperation. A typical installation involves numerous partners:

- The ship owner
- The ballast water treatment system supplier
- An engineering company
- A shipyard

The ship owner is ultimately responsible for the vessel and ensuring the process is handled in a safe and correct manner. To facilitate as smooth an installation as possible, the ship owner should provide full vessel documentation to all parties involved.

The supplier, engineering company and shipyard should work together to adapt the treatment system's installation to the specific circumstances of the vessel in question, as much as is possible within the constraints of the system's Type Approval Certificate.

6.3. Phases of a retrofit project

A retrofit installation involves many phases, each with its own challenges and responsibilities for the partners involved.

Pre-project
The pre-project phase focuses on the selection of the system. Four main considerations are involved:

- The system
- Installation complexity (including placement of additional components on board)
- Safety (including ventilation, chemical storage and impact on safety routines)
- Supplier capability (including flexibility and ability to deliver on time)

Initial phase
The supplier and owner agree about the scope of supply and the execution of the project. The better the specification at this early point, the less risk there will be of mistakes later on in the project.

Pre-survey and vessel documentation review
A feasibility study conducted by the ship owner, the supplier or an engineering company determines how and where to install a ballast water treatment system on the target vessel, as well as the required characteristics of the system. This phase involves the collection and review of vessel documentation, including:

- Information on ballasting operations, such as the number of pumps used and the frequency of ballasting and deballasting
- Ballast pump specifications
- General arrangement drawings
- Piping and instrumentation diagram
- Amount of power available

Onboard survey
The supplier or an engineering partner conducts a survey to identify the best possible location for the equipment, gather information on ballasting operations and determine if hatches are available for bringing components on board. Ideally this includes a 3D scan to create a picture of the environment that will serve as the location for the treatment system, offering a clearer idea of the end result.

Pre-engineering
Using information collected in previous phases, the supplier or engineering partner evaluates the suggested installation and determines how piping should be routed, as well as the need for support of the components. Collisions between the proposed placement of the treatment system and existing equipment are identified to avoid later corrections.

Detailed engineering
The supplier or engineering partner creates manufacturing drawings of all piping, supports and foundations and selects suitable material for the piping.

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Class approval
Approval from the classification society requires the submission of all documentation prior to the start of the installation process.

Prefabrication
The manufacturing drawings are used to prefabricate system components, which makes it possible to minimize the time for installation on board.

Installation
Installation can be performed at a shipyard, while sailing or through a combination of the two. Installations performed at sea can take up to six weeks and require certain crew safety considerations. Installation during dry docking, which normally takes around two weeks, is more common.

Verification of the installation
The installation itself must be verified and tested. Since shipyard time is limited, it is important that all components are installed correctly from the beginning to minimize the risk of a delay. Once the supplier has verified the installation from a technical perspective, its functions need to be demonstrated during a commissioning with an owner representative and class surveyor present.

6.4. Approval of installations

After installation, a surveyor from the relevant classification society must verify and confirm that the system is properly installed and functioning correctly from a class perspective. When this is done, the system receives the necessary supporting documentation regarding compliance.

Flag State Administrations do not generally verify compliance with basic classification requirements. A recognized classification society must therefore check and approve the treatment system to ensure compliance with national, regional and local ballast water regulations.

7. Supplier evaluation checklist

The checklist on the following page can serve as an aid in evaluating potential suppliers of ballast water treatment systems. The topics covered relate to system strengths and limitations, as well as the suppliers' own capabilities.

Suppliers should be rated on a scale from 1 to 5, where 5 indicates the strongest performance in relation to the questions. The higher the overall marks, the stronger the supplier.

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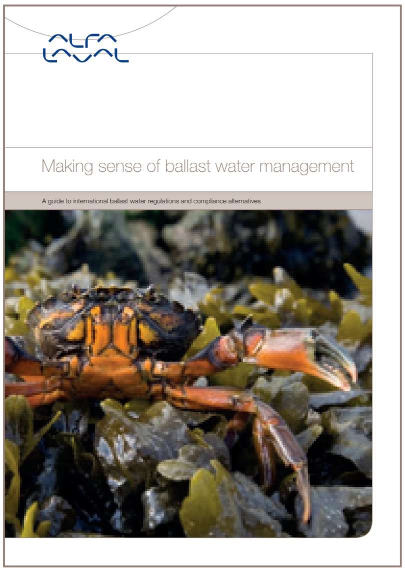
Key criteria	Supplier A	Supplier B	Supplier C	Supplier C
Can the supplier ensure performance in widely diverse operating conditions? The system provided should have all relevant type approvals and should not restrict the vessel's area of operations through performance limitations.				
Has an authorized third party conducted type approval tests of the supplier's equipment? Third-party testing is transparent and ensures realistic conditions that prevent system deficiencies from being overlooked.				
Does the supplier have a long track record of working in the marine industry? Experienced marine suppliers and systems specifically developed for marine use can avoid unexpected problems at sea.				
Is the supplier's system easy to install and operate? Especially in a retrofit, the system should offer a small footprint and simple integration. Fully automatic operation is preferred.				
Has the supplier received repeat orders from customers? An extensive reference list is valuable, but the most important references are those who have made the same choice multiple times.				
Has the supplier successfully installed a large number of ballast water treatment systems? Practical experience, especially in retrofit projects, is the best assurance of a smooth installation and long-term system performance.				
Does the supplier have a track record of meeting delivery times? Delays in getting equipment to the shipyard within the scheduled time slot can mean a great deal of additional expense.				
Can the supplier minimize time out of service for installation and commissioning? Smart planning and supply solutions can limit downtime at a capable shipyard to two weeks. Installation while sailing may also be possible.				
Does the supplier have global support capabilities? A stable global supplier will be able to provide parts and support wherever the vessel sails and throughout the system's lifetime.				
Does the supplier have an extensive and flexible service offering? Expert maintenance secures lasting compliance. Periodic inspection and service from the original supplier can safeguard your investment.				

8. Further reading

This white paper is only an overview of the key issues in ballast water management. Greater depth and additional guidance in selecting a ballast water treatment system are readily available.

Alfa Laval has prepared a comprehensive book, "Making sense of ballast water management", which provides more detailed information about all of the topics covered in this white paper. The book contains technical facts, knowledge and insights from over a decade of work with ballast water treatment, as well as many illustrations, diagrams and reference tables. In addition, it provides an overview of Alfa Laval's own ballast water treatment system, Alfa Laval PureBallast 3.1.



The book is available for order or download from the "Knowledge" page on the Alfa Laval PureBallast 3.1 website. Throughout the website, you will find information and interactive tools for evaluating ballast water treatment systems and making the right selection for your vessel.

To obtain your copy of "Making sense of ballast water management", visit www.alfalaval.com/pureballast3

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