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BALLAST WATER TREATMENT SYSTEMS IN VESSELS

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Table of Contents

Contents

Abstract

Ballast water refers to the sea water carried in tanks or holds of ships to improve stability, stress loads, and structural integrity when they are not fully loaded with cargo. The ballast water is reported to cause many ecological as well as public health related complications because of harmful organisms. These can infect the environment, disturb aquatic ecosystem and have harmful effects on humans. The International Maritime Organization (IMO) requires ships to be equipped with ballast water management systems that can eliminate harmful microorganisms. Ships must have systems to treat, hold and possibly re-treat ballast water discharged back into the ocean.

This thesis explores the available ballast water treatment technologies, focusing on their respective lineage and efficacy. System selection can be influenced by a variety of factors, including type of ship, ballast water volume capacity and rate flow on the largest operating conditions; power demand; energy consumption at different salinities during commissioning or operation testing before first voyage; newbuild versus retrofit onset for purpose use. The thesis also investigated the performance of two ballast treatment systems installed onboard existing ships.

Keywords (English Abstract):

Ballast Water – Water Treatment – International Maritime Organization

Περίληψη

Το νερό έρματος αναφέρεται στο θαλασσινό νερό που μεταφέρεται στις δεξαμενές ή τα αμπάρια των πλοίων για τη βελτίωση της σταθερότητας, των φορτίων καταπόνησης και της δομικής ακεραιότητας όταν δεν είναι πλήρως φορτωμένα με φορτίο. Το νερό έρματος αναφέρεται ότι προκαλεί πολλά οικολογικά, καθώς και προβλήματα δημόσιας υγείας, εξαιτίας των επιβλαβών οργανισμών που περιέχει. Αυτοί οι οργανισμοί μπορούν να μολύνουν το περιβάλλον, να διαταράξουν τα υδάτινα οικοσυστήματα και να έχουν επιβλαβείς συνέπειες για τους ανθρώπους. Ο Διεθνής Ναυτιλιακός Οργανισμός (IMO) απαιτεί τα πλοία να είναι εξοπλισμένα με συστήματα διαχείρισης νερού έρματος που μπορούν να εξαλείψουν τους επιβλαβείς μικροοργανισμούς. Τα πλοία πρέπει να διαθέτουν συστήματα για την επεξεργασία, τη διατήρηση και πιθανώς την επανεπεξεργασία του νερού έρματος που απορρίπτεται πίσω στον ωκεανό.

Η παρούσα διπλωματική εργασία εξετάζει τις διαθέσιμες τεχνολογίες επεξεργασίας νερού έρματος, εστιάζοντας στη γενεαλογία τους και την αποδοτικότητά τους. Η επιλογή του συστήματος μπορεί να επηρεαστεί από διάφορους παράγοντες, όπως ο τύπος του πλοίου, η χωρητικότητα και η ροή του νερού έρματος υπό τις μεγαλύτερες συνθήκες λειτουργίας, η ζήτηση ισχύος, η κατανάλωση ενέργειας σε διαφορετικές αλατότητες κατά τη διάρκεια της θέσης σε λειτουργία ή της δοκιμής λειτουργίας πριν από το πρώτο ταξίδι, καθώς και αν πρόκειται για νέο κατασκευασμένο πλοίο ή για αναβάθμιση υπάρχοντος πλοίου. Η εργασία διερεύνησε επίσης την απόδοση δύο συστημάτων επεξεργασίας νερού έρματος που είναι εγκατεστημένα σε υπάρχοντα πλοία.

Λέξεις-Κλειδιά :

Νερό Έρματος – Επεξεργασία Νερού – Διεθνής Ναυτιλιακός Οργανισμός

Chapter 1: Problem Statement

1.1 An Overview of Ballast Water Management

The principle of using saltwater as ballast for stabilizing steel-made floating ships during their time at sea has emerged because of technological progress in ship design and construction, which has advanced significantly over the past 120 years. For instance, steel hulls enabled this transition from using solid items as ballast to using water to fill the upper surface of the tank (Smith, 2010). Ballast tanks, which are filled with seawater using pumps, ensure operational safety by continuously maintaining the necessary weight balance, stability, propulsion, and speed changes (Jones, 2012). During the unloading process, ballast is loaded to provide stability, and during the loading process, ballast is discharged, often simultaneously (Brown, 2015).

The ballast water requirements for a voyage are determined based on the ship's design, cargo load, stability, sea state, route characteristics, operational efficiency, environmental protection, and regulatory compliance (White et al., 2013). To safeguard a ship from waves and extreme weather conditions, it is necessary to increase the amount of ballast water. This adjustment also helps stabilize the vessel and reduce fuel consumption (Green & Roberts, 2014). Ballast water offers advantages such as reduced hull stress, improved lateral stability, increased propulsion and maneuverability, and compensation for weight fluctuations resulting from fuel consumption and cargo load variations (Wilson, 2016).

However, the processes of ballasting and de-ballasting pose significant issues due to the transfer of native aquatic species between different marine ecosystems. Several species, such as cholera (Vibrio cholerae), European green crab (Carcinus maenas), Asian kelp (Undaria pinnatifida), and North Pacific seastar (Asterias amurensis), have been moved around, causing disastrous effects in various parts of the world (Thompson, 1998). In the 1980s, Australia and Canada dealt extensively with invasive species, prompting research into the issue (Williams & Miller, 2005). However, Europe and other parts of the world did not engage in this research until a decade later (Davies et al., 2007).

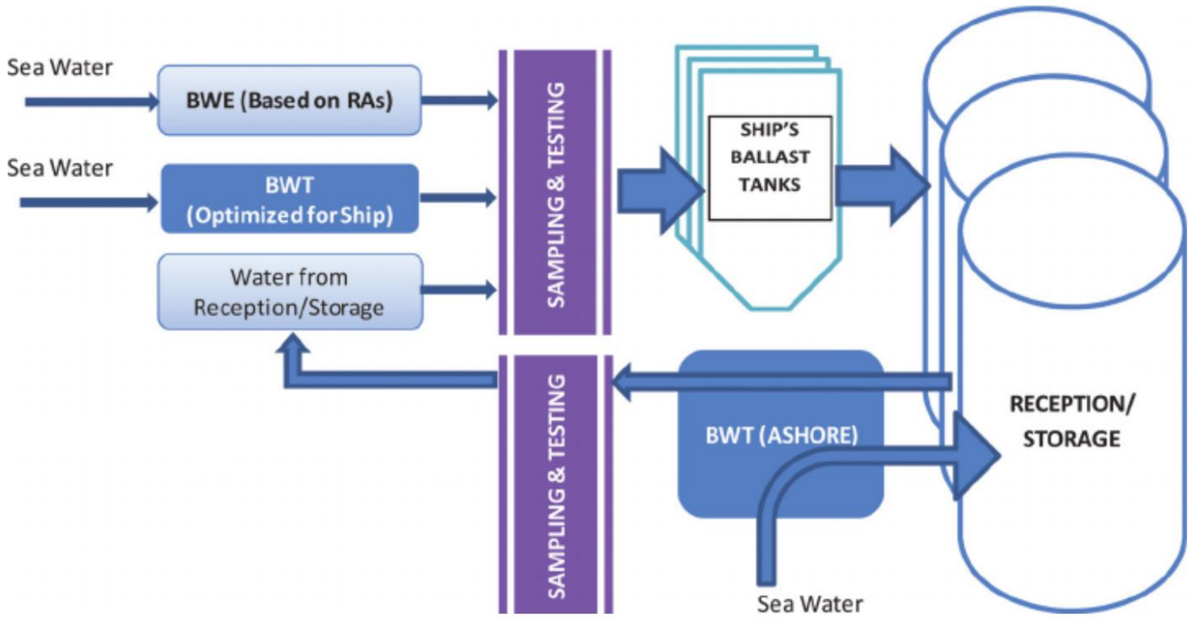


Chart 1.1 Ballast water management (BWM) system integrated with ship and shore, Source (Rajoo & Yaakob , Koh, Kho. (2014))

1.2 Significant Factors and Their Impact on the Marine Environment

Ballast water discharges have been found to have larger effects than all other factors combined on entire bodies of water, destroying ecosystems with an almost unparalleled success in spreading invasive species. The inadvertent introduction of alien species has caused extensive ecological disruption, including the disturbance of local maritime ecology and a reduction in indigenous species (Ruiz et al., 2000). The economy has incurred large financial losses due to the introduction of invasive species, primarily from damage inflicted upon fisheries, aquaculture, and coastal infrastructure (Pimentel et al., 2005).

This introduction of invasive species via ballast water has produced a number of problems. Cholera, caused by Vibrio cholerae, is a deadly waterborne disease harmful to human health (Centers for Disease Control and Prevention, 2021). The European Green Crab (Carcinus maenas) is a notorious predator and ecological competitor in local fisheries (Grosholz & Ruiz, 1996). Asian Kelp (Undaria pinnatifida) is an invasive plant that disrupts the natural balance of biological communities by displacing indigenous species (South et al., 2017). It has been estimated that over the years, the North Pacific Seastar (Asterias amurensis) has wiped out around 99% of shellfish in certain areas, displacing vital fisheries such as scallops, mussels, and clams (Gollasch, 2006).

In response to these difficulties, the International Maritime Organization (IMO) introduced stringent measures. These rules and regulations were developed by the Marine Environment Protection Committee (MEPC) of the IMO to prevent or control the transfer of live organisms and pathogens via ballast water. Initially, measures included carrying out ballast water exchange in deep waters to reduce the risk of species transfer between vessels (International Maritime Organization, 2004). However, recognizing the need for stronger measures, the IMO called for additional preventative efforts, including the implementation of ballast water treatment systems (Endresen et al., 2004).

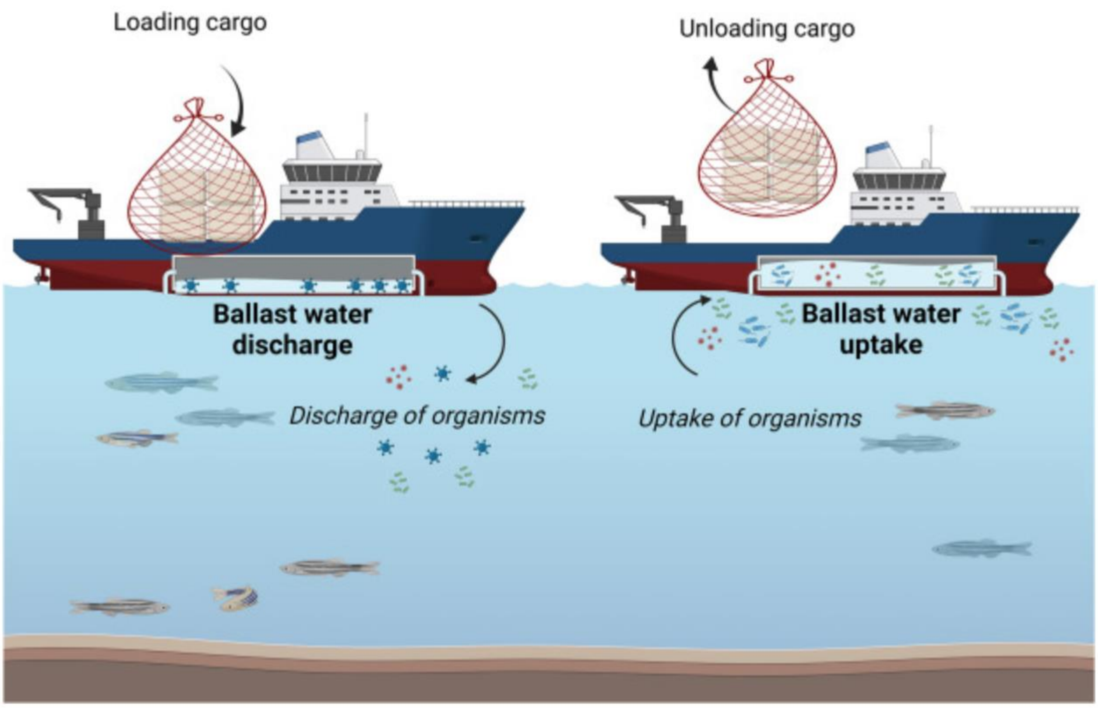


Chart 1.2 The process of ballast water exchange at ports-of-call. Source : (Drake et al., 2007)

In 2004, as part of efforts to address this problem, the IMO implemented the Ballast Water Management (BWM) Convention. This convention established a harmonized regulatory framework to prevent the spread of diverging national or local regulations. More than 30 countries, representing over thirty-five percent of global merchant shipping by gross tonnage, accepted the agreement, thereby activating international regulations related to the control and management of ballast water (International Maritime Organization, 2004).

Sophisticated studies over the last two decades have greatly increased our understanding of ocean vectors—potential or actual pathways that promote inter-ocean species introductions.

This research has heightened awareness of the environmental risks associated with ballast water and promoted habitat conservation consciousness (Carlton & Geller, 1993). As a result, numerous ballast water treatment systems are now available to shipowners, offering various technological choices. Assessing each system's details using specific criteria can quickly become complicated, making the selection of the best-suited system for a particular use case challenging (David & Gollasch, 2008)

1.3 Thesis Objective

This thesis aims to assist in selecting the most appropriate ballast water treatment (BWT) system for a vessel by considering all contributing factors, including system types, selection criteria, regulatory requirements, and operational processes, to ensure effective installation and operation. Additionally, the thesis offers awareness of all existing technologies, understanding on how they work, and familiarisation with the regulatory framework and background (David & Gollasch, 2008). Therefore, the following issues will be discussed: an overview of Ballast Water Management (BWM) and BWT, their significance and impact on the marine environment (Carlton & Geller, 1993), international and U.S. regulations (Endresen et al., 2004), various BWT methods and new technologies (Gollasch, 2006), global and regional statistics of BWT systems (International Maritime Organization, 2004), case studies, installation and operation processes (Ruiz et al., 2000), the learning feedback process, and the final conclusion, which will include recommendations for future trends and the regulatory impact (Pimentel et al., 2005)

1.4 Thesis Structure

The first chapter presents the context of this topic and the study's problem (David & Gollasch, 2008), while the second chapter comprises the comparison of ballast water management regulatory framework and a comparison of the International Maritime Organization (IMO) and United States Coast Guard's (USCG) Ballast Water Management regulations (Endresen et al., 2004). The third chapter discusses possible technology and ionized water treatment system types, operational principles, and advantages and faults (Carlton & Geller, 1993). The fourth chapter focuses on the decision-making process of technology selection and considers the impact of such a choice on existing vessels (International Maritime Organization, 2004). The fifth chapter consists of a comparative study of two different treatment systems implemented on sister vessels. The aim is to illustrate how theoretical processes meet practical challenges in selecting the appropriate ballast water treatment system. This chapter also highlights the differences in the owners' opinions (Ruiz et al., 2000). The final sixth chapter reflects on the selection and procedural elaboration by shipyards and manufacturers, outlining the set of owners' views (Gollasch, 2006). In general, the presented project is developed with a holistic approach toward the ballast water management issue.

Chapter 2: Regulatory Framework

2.1 Introduction

The Ballast Water Management Convention (BWMC) is an international maritime environmental protection treaty aimed at globally managing and controlling the water ballast loaded on ships. It was adopted by the International Maritime Organization (IMO) in 2004. The main objective of the regulation is to avoid the spread of injurious aquatic organisms and pathogens through ballast water systems (International Maritime Organization, 2004). Ships must comply by implementing a Ballast Water Management Plan (BWMP) and maintaining a "Ballast Water Record Book" (BWRB), as well as by having a valid certification per ship for the International Convention for the Control and Management of Ships' Ballast Water and Sediments (Endresen et al., 2004).

The BWMC sets standards that ships must meet, including the D-2 standard, which specifies the number of viable organisms allowed when ballast water is discharged (David & Gollasch, 2008). Before the installation of ballast water treatment systems capable of meeting this target, ships were required to exchange ballast water while transiting at sea as a short-term measure. Eventually, all ships must comply with the D-2 standard by a specific date associated with their renewal survey (International Maritime Organization, 2004).

The organizational structure of the BWMC includes Articles and an Annex that explain its definitions, applications, and effective dates. The Annex contains mandatory regulations for ships to manage their ballast water through treatment and detailed science-based, technical standards upon which decisions are based (Carlton & Geller, 1993). Flag states are responsible for enforcing the convention and ensuring that their vessels meet the requirements; port states can also inspect international ships to verify treaty compliance (Gollasch, 2006). Various revisions and amendments have taken place since the BWMC was adopted to overcome governance challenges in implementing the convention and to improve its effectiveness. Among the most significant are the establishment of a timetable for ballast water management and the implementation of standard D-2, supported by the GloBallast Partnerships Program. The program assists tropical regions by providing technology transfer, training, and financial support to enhance their capacity to manage invasive species under the Ballast Water Management Convention (BWMC) (Pimentel et al., 2005).

The Committee responded by adopting the Guidelines (G8), as amended, to ensure that treatment systems are systematically proven under a range of conditions to be dependable and fit for purpose, according to the norms established at Regulation D-2 level (Ruiz et al., 2000). The BWMC is widely considered one of the most successful international environmental agreements yet adopted to address the transfer and release of potentially harmful invasive aquatic species carried in ships' ballast water. Continual updating and worldwide cooperation will be carried out for the effective implementation of BWMC to prevent pathogens from marine environment in various locations world-wide (Williams & Miller, 2005).

2.2 Revised Guidelines for approval of Ballast Water Management Systems (G8)

The Ballast Water Management Convention (BWMC) is an international agreement aimed at controlling and reducing the adverse effects of ballast water in a uniform manner. Originally, it was approved in 2014 by the International Maritime Organization (IMO) after ratification from thirty member states, who represent more than half of the world merchant shipping gross tonnage. The threshold was crossed on September 8, twelve years after the convention's original adoption, with the ratification by Finland being crucial to bringing the BWMC into operation (International Maritime Organization, 2004).

As of April 2019, the BWMC had been ratified by 81 countries, representing approximately 76-80% of the global merchant fleet tonnage (David & Gollasch, 2008). Subsequently, the IMO recognized ambiguities in existing regulations and methodologies for Type Approval of Ballast Water Management Systems (BWMS) and decided to revise the G8 Guidelines. These guidelines are designed to provide at least the same level of environmental protection as required by the IMO while ensuring D-2 compliance among various operational scenarios for BWMS, which must be robust and reliable (Endresen et al., 2004).

Both the BWMC and future revisions have serious implications, with lasting ripples through shipping. Compliance must also meet the D-2 standard of no more than a certain concentration of viable organisms in discharged ballast water (Carlton & Geller 1993). Consequently, technological adaptations are necessary for adequate ballast water treatment (Gollasch 2006).

The parties to the convention are collectively responsible for ensuring that they all comply with agreed standards and assisting in elaboration of these if needed. Through the cooperative practices of moonsighting committees (Ruiz et al., 2000), successful international cooperation is crucial. Vessels in violation could be subject to fines or detention and flagged states are put on notice, which may result their delisting from the white list (Williams & Miller 2005).

BWMC are meant to keep the effects of invasive species and pathogens that live in ballast water from having an impact on marine ecosystems. These initiatives are a manifestation of the global effort to put an end on environmental concern related to ballast water dumping. The convention seeks to conserve marine biodiversity and the sustainable development of shipping by utilising punitory rules based on technology enforcement, cooperation at international level (Pimentel et al., 2005).

2.3 BWMS Code (New G8)

The Ballast Water Management Systems (BWMS) Code, adopted on 13 April 2018 marks a turning point in the policy regarding this issue from guidelines to bit of mandatory code for the approval purpose of ballast water management systems. This move guarantees that any new installations of systems on ships would now conform with strict universal standards and be more cost-effective (IMO, 2018).

The key components of the BWMS Code include mandatory compliance, standardization and uniformity (particularly in terms of technological advancements), as well as operational, fiscal aspects, and flag state responsibilities (David & Gollasch, 2008).Further, adherence with the code is mandatory and results in a tighter enforcement of regulation and higher-level environmental protection (David & Gollasch 2008). Consistency in standards allows removing ambiguities and assures that all systems are subjected to high standards (Endresen et al).

This also promotes technological advancement by giving manufacturers the incentive to develop and commercialize newer, more technologically advanced BWMS; ensuring that system conformance closer mirrors what is possible based on scientific knowledge of species resistance rather than sociopolitical compromises (Carlton & Geller 1993). Operational and financial impacts: Implementation of measures as a result from installing, operating and servicing BWMS in line with the BWM Code may lead to cost escalation. Nevertheless, the benefits associated with diminished environmental attack and avoiding penalties because of non-compliance outweigh having these costs (Gollasch, 2006).

The flag states are responsible for the approval of BWMS installations; and in due course, are required to ensure that vessels flying their flags meet with the guidelines (BWMS Code). Port States are allowed to inspect foreign vessels to verify compliance with the requirements of the BWMS Code and ships that do not comply may be subject to penalties like fines, detention or refusal of entry (International Maritime Organization 2004). The IMO should continually informally assess the applicability of the code, with a view to possible developments concerning existing problems and technological progress (Pimentel et al., 2005).

The BWMS Code adoption is an important step in ballast water management regulation and will provide a framework under which both approval and introduction of BWMS are done to help safeguard marine ecosystems. Consequently, to meet the goals incorporated into The Ballast Water Management Convention it is necessary that some improvements are implemented by shipping companies themselves by investing in costly compliant technologies and setting strict rules (Ruiz et al., 2000).

Comparison items	IMO	US
Approval by	*Flag or Class (Recognized Organizations (RO))*	*USCG*
Test operator	*Manufacturer*	*IL*
Test laboratory	*Laboratory not owned/affiliated with manufacturer/vendor of BWMS/major equipment components*	*United States Coast Guard (USCG) approved IL*
Reporting of test results	*Manufacturer/Laboratory*	*IL*
Testing methods required	*G8/G9 Guidelines*	*USCG BWMS Environmental Technology Verification (ETV) Protocol*
Performance/Discharge standard	*<10 **viable** organisms*	*<10 **living** organisms*
Shipboard 3 consecutive successful testing cycles	*3*	*5*
Minimum holding time in the test tanks before discharge and sampling for the BWMSs not using Active Substances	*Minimum holding time to be determined by the BWMS manufacturer (D-2 standard compliance); ≥5 days (regrowth evaluation)*	*≥1 day; If justified in Test/Quality Assurance Plan, shorter or longer tank hold times may be utilized*
Component/Environmental test (vibration endurance test)	*2 h*	*4 h*

Table 1: IMO and US Ballast Water Management Systems (BWMS) type approval process comparison

2.4 IMO BWM Convention – BWM Standards

IMO has introduced two key regulations on ballast water exchange (BWE) and discharge standards dubbed as Regulation D-1 and Regulation D-2. The purpose of these regulations is to check the dissemination of aquatic organisms and pathogens via ballast water (International Maritime Organization, 2004). For example, ships must meet the minimum standard by exchanging ballast water up to a volumetric efficiency of at least 95%, generally accomplished via three times the volume flush exchange per tankful as specified under D-1.

Regulation D-1, which refers to a standard under the IMO Ballast Water Management Convention focusing on ballast water exchange, is based on the premise that coastal waters would be inhospitable to organisms, pathogens, and parasites released from ships into deep ocean water. Similarly, organisms from the deep ocean are ill-adapted to coastal or freshwater settings. Therefore, ballast water exchange serves as a temporary mechanism to reduce the development of non-native species in inland destinations (David & Gollasch, 2008).

Regulation B-4 prescribes the requirement for a ship to conduct Ballast Water Exchange at least 200 nautical miles from the nearest land and in water at least 200 meters deep. These requirements, which constitute the designated distance and depth (elevated in some ports) are established to enforce ships oil discharge standards compliance with IMO regulation (Endresen et al., 2004).

Regulation D-2 has established standards for planes as follows: fewer than ten viable organisms per cubic meter for organisms that are 50 micrometers or larger, fewer than ten viable organisms per milliliter for organisms that are smaller than 50 micrometers but larger than 10 micrometers, and fewer than 1 colony-forming unit (CFU) per 100 milliliters or fewer than 1 CFU per gram (wet weight)

Compliance with the D-2 norm is required for every vessel built after the BWM Convention took effect on September 8, 2017, and till a ship undergoes its next IOPP renewal survey (International Maritime Organization, 2017). In case of special circumstances exemptions and exceptions may be granted (International Maritime Organization, 2017).

Ballasting water exchange involves changing the coast water brought on board for mid-ocean water while transiting. However, BWE is not completely efficient as regards organisms and pathogens removal due to dissimilarities in ecosystems between coastal waters and open oceans (Endresen et al., 2004).

Ballast Water Treatment (BWT) involves using approved techniques for treating ballast water so that all organisms and pathogens are destroyed or made harmless before it is released into the environment. It involves filtration, chemical disinfection, ultraviolet light treatment, deoxygenation and heat treatment. The target is to get rid of harmful organisms and pathogens contained in ballast water through direct means so as to meet regulatory requirements (Lloyd’s Register, 2015).Finally, Ballast Water Exchange is a transitional approach that primarily focuses on volumetric substitution approach aimed at reducing invasive species risk (David & Gollasch, 2008).

2.4.1 Ballast Water Exchange

To cut down on the movement of water-dwelling organisms and germs via ship ballast water, Ballast Water Exchange (BWE) is essential. This technique exploits the differences in environment between coastal and open sea waters. During its voyage a ship will replace quantities of ballast water from the coast or port with water from the middle of the ocean. Consequently, this reduces the harmful species that can transfer in long distances (Endresen et al., 2004). The implementation of BWE requires careful planning and vigilance by crews to promote safety for all onboard while also protecting the vessel (International Maritime Organization, 2004).

There are several key factors that need consideration when performing BWE safely and effectively such as: submerging propellers, controlling hull stress levels, ensuring clear visibility for safe navigation, keeping stability intact as well as avoiding bow slamming (David & Gollasch, 2008). There are three main methods for doing BWE which include sequential exchange flow-through exchange and dilution. Sequential exchange entails emptying ballast tanks and refilling them with seawater from mid-ocean. This process may take time thereby affecting ship stability for a short period (Lloyd's Register, 2015).

Ballast water exchange is the flow-through type, which involves the process of pumping the water from the middle of the ocean into the ballast tanks while the water from the coastal ballast is conveyed not to the top of the tank rather it should overflow and exit the tank. It is not less than three full cycles if a higher level of efficiency is to be obtained. The effective way to provide adequate water exchange is the usual procedure of three full cycles. However, thorough inspection is necessary to ensure that the exchange rate is equal to the standard (Endresen et al., 2004).

The dilution method with 99% old and 1% new water can be obtained so as to treat water of both ballast tanks by simultaneously pumping water through the top and bottom of the ballast at regular intervals. The basic concept of the method is pumped ocean water from the middle on the top and coastal ballast filtered water to the tank's bottom to be discharged from there. The dilution method requires three cycles primarily to achieve a 95% exchange rate while thereafter it becomes a simple process that necessitates valuable flow and mixing (David & Gollasch, 2008).

Detailed documentation of the entire BWE process and its particular requirements can be found in a Ballast Water Management Plan specific to the ship. This plan outlines the procedures that must be followed to ensure compliance with international standards (International Maritime Organization, 2004). A meticulous recording of the execution of BWE procedures is required in the Ballast Water Record Book, which is kept up to date and made available for review by port authorities or their representatives during inspections and surveys (International Maritime Organization, 2017).

In conclusion, BWE is essential to prevent the introduction of non-native species into the environment through ship ballast water. Risks associated with it can be mitigated through careful planning and adherence to established procedures. By using techniques such as sequential exchange, flow-through exchange, and dilution, vessels can effectively manage ballast water and maintain environmental protection and maritime safety (David & Gollasch, 2008; Endresen et al., 2004; Lloyd's Register, 2015).

2.4.2 Ballast Water Treatment

Ballast Water Treatment (BWT) systems play an important role in the fight against invasive aquatics. BWT is a self-regulating process that is continuously watched to ensure its smooth running (International Maritime Organization, 2017). With the implementation of BWT, the necessity of BWE is usually removed but it may still be approved for emergency cases

(Endresen et al., 2004). Some ships are now being retrofitted with BWT systems while others have already been through the system (Lloyd's Register, 2015).

Reconstruction of water treatment systems for ballast materials comprises the addition of a ballast water treatment system to the vessel's existing ballast water system, thus enhancing safety and efficiency (David & Gollasch, 2008). Both ballasting and de-ballasting are allowed to select the proper one for treatment of ballast water as it can be performed at both the uptake and discharge stages of the ballast water management practice. Standard techniques for the treatment of ballast water are filtration and UV radiation, which are methods used for pumping water through a continues filtration step before it is stored in the ballast tanks (Lloyd's Register, 2015).

After the discharge process, the water passes first through the ballast tanks it came from and then is UV disinfected and then the last stage of the process is discharged overboard. The way electro-chlorination works for the main stage of disinfection is that the sodium hypochlorite is pumped through the stage by using the filter as the treatment for primary disinfection. A module to electrolyze and a degassing unit to form sodium hypochlorite in the ship, together with a sodium hypochlorite analyzer, which is what is used to measure the hypochlorite concentration of water before it is discharged (Lloyd's Register, 2015).

One of the positives associated with implementing ballast water treatment systems includes different factors such as automation and monitoring, and compliance with international regulations (International Maritime Organization, 2017). The specifics concerning the Ballast Water Management Plan are what are the steps and processes on the BWT, which should be updated from time to time and be ready for customs officials to inspect (International Maritime Organization, 2004). Through the application of devices that are automatic and watched systems, the shipping sector can diminish the negative effect of ballast water discharge on the environment (David & Gollasch, 2008; Endresen et al., 2004).

2.5 Contingency Measures

In case a ship cannot stick to their approved Ballast Water Management Plans (BWMP) and thus have trouble with ballast water, both the International Maritime Organization (IMO) and the United States Coast Guard (USCG) introduced some of the measures that the ships should follow. The IMO's nonprescriptive guidance contains the provision of practical steps for vessels as well as port states in case of non-compliance with the BWMP but it will safeguard the marine environment from the harmful effects of the ballast water discharges.

Moreover, the guideline provides help to correctly implement contingency actions that can assure environmental standards and keeping the invasion of alien species away (International Maritime Organization, 2004). The USCG's standards concerning the failure of BWMS include a list of alternative ballast water management modes, dates of enforcement, and a list of approval processes. If ships plan to use Ballast Water Exchange (BWE) for the last resort, they will need either the District Commander or the Captain of the Port (COTP) approval and that according to the United States Coast Guard (2012).

It is important that the BWMP is properly prepared for the efficient management of ballast water in case of a situation when the BWMS faulty or not operational. Others are that in many water areas poor quality is caused by off-limit plants and animals, containing especially such elements of low salinity or high silt content which are problematic in the filters (International Maritime Organization, 2004).

One of the possible ways out is to apply BWE only under the strictest of circumstances, meanwhile, all the permissions that are necessary for the use of BWE should be issued by relevant authorities. The crew should be instructed in every operation provided in the BWMP, they must be engaged in drilling sessions and document a plan including set (United States Coast Guard, 2012).

The United States Coast Guard works outside the framework of the BWM Convention of the International Maritime Organization (IMO), so the ships that emit ballast water into the territories of the USA are required to fulfill certain terms and conditions specific to each jurisdiction. Accurate organizing and following up are essential to make sure that the ships comply with the standards of the law-abiding process (United States Coast Guard, 2012).

On the same last note, the adjustments made by the IMO and USCG in the adoption of Ballast water treatment technology or in case of the BWMS failure present the necessary guidelines, which are to be embraced in the arrangement of regular systems. Through the compliance with the provided instruction, a ship can completely reduce the risks generated by the release of ballast water and the overall environment will be protected. To enforce compliance and readiness in the case of possible system failures, it is necessary to do continuous training and validation of contingency plans (David & Gollasch, 2008; Endresen et al., 2004).

2.6 Sampling during Commissioning

Ballast water sampling is mandated by the Ballast Water Management (BWM) Convention to prevent the spread of various invasive species and to ensure that ships manage their ballast water in accordance with D-2 performance standards. This step is very important to confirm compliance with International Maritime Organization (IMO) standards (International Maritime Organization, 2004).

Mandatory testing is carried out to ensure that the basic procedures for treating ballast water management systems (BWMS) are functioning properly after installation, "Guidelines for Ballast Water Utilization Test Testing." about" (BWM.2/Circ.70) governs this exercise). Acting on behalf of the IMO, Flag States or Recognized Organizations (ROs) supervise and supervise these tests to ensure that the BWMS operates as intended and meets all necessary standards (International Maritime Organization, 2017).

The 74th session of the Marine Environment Protection Committee (MEPC) decided that commissioning testing should begin as soon as possible in accordance with BWM.2/Circ.70. The committee strongly recommended that administrations provide Recognized Organizations (ROs) with clear instructions for conducting indicative analysis testing, including clear instructions for what to do in case of non-compliance (International Maritime Organization, 2019).

Compliance control sampling focuses on determining potential non-compliance with the D-2 standard, which requires the number of viable organisms per cubic meter to be less than ten for organisms equal to or larger than fifty micrometers. Specific concentrations of indicator microbes, such as Vibrio cholerae, Escherichia coli, and intestinal enterococci, are taken into consideration (International Maritime Organization, 2004).

To demonstrate compliance with the D-2 standard, sampling presents several challenges, including organism detection, volume of water collection, and accuracy of sampling techniques. Variations in ballast water operations, such as unpredictable discharge profiles and times, can make the process more difficult (David & Gollasch, 2008).

The Marine Environment Protection Committee (MEPC) suggested interim measures to address these challenges and ensure effective implementation: written instructions for Recognized Organizations (ROs) regarding indicative analysis testing during commissioning and clear protocols for actions in case of non-compliance (International Maritime Organization, 2019).

The sampling and commissioning tests serve to protect the environment, particularly within the maritime sector, by preventing contamination through invasive aquatic species. The safeguards and provisional measures adopted by the International Maritime Organization (IMO) through its Marine Environment Protection Committee (MEPC) offer a strong basis for attaining these goals (IMO, 2017). Moreover, the Ballast Water Management (BWM) Convention will continue to play a significant role in safeguarding marine environments through regular updates and upgrades of sampling techniques and protocols practiced worldwide (David & Gollasch, 2008).
Compliance with ballast water management is essential for the meeting of these standards by ships, as per BWM Convention. Sampling can be divided into two main categories: in-tank, and at-line; each of these has its own applications as well consequences to take care of (David & Gollasch 2015).

In and tank, sampling is done to check if there are any coastal biotas and water salinity. This approach would offer the ability to identify potential non-compliance before ballast water is discharged to the environment. Quantitative analysis for Numerical Discharge Standard - When we talk about the minimum incoming criteria then it requires in-line sampling which is to be performed during those incidents. It consists in the enumeration of viable strains on growth media and determination of indicator bacteria concentrations (IMO, 2018).

Compliance with the D-2 standard is achieved by in-line sampling, thereby providing a direct measurement of the water quality discharged. However, this method is a more reliable estimation of water quality and open to use before disposal within the areas that hold high risk with being aware about presence or absence off targeted species. If a ship is non-compliant, necessary pre-emptive measures can be sourced so that the environment will not suffer in its stead (Endresen et al. 2004).

n particular, in the case of ballast water taken on board under regulation B-3.4, uptake and discharge may be carried out using any operation able to prevent untreated ballast water from being inadvertently discharged, such as by filtering or treating prior to or during discharge, but not by taking into account dilution with ballasting sea-water if that option is selected (for example, for top-side tanks as found on bulk carriers). Both instruments maintain or even enhance the effectiveness of the ballast water management regime, preserving strict controls on the introduction of non-indigenous species and pathogens to aquatic ecosystems (David & Gollasch, 2008).

To this end, it is required that both in-tank and in-line sampling methods are used to verify compliance with the D-1 and D-2 standards set by the BWM Convention. In-tank sampling is used for early detection of non-compliance, tanks that go directly to the ocean. Inline sampling provides a reliable means of directly measuring ballast water quality at the discharge, helping to ensure that efficiency is maintained, and marine environments are protected from invasive species or pathogens.

Sampling Method	Standard	Approach	Application	Advantages
In-Tank Sampling	D-1 & D-2	Qualitative for D-1, Quantitative for D-2	Presence of coastal biota (D-1), Compliance check before discharge (D-2)	Early detection, Safety, Preemptive action
In-Line Sampling	D-2	Quantitative	Direct discharge compliance check	Accurate assessment of discharge quality

Table 2: An analysis of different sampling methods for the management of ballast water (International Maritime Organization, 2004; David & Gollasch, 2008).

2.7 USCG: Available BWTS

Both the state of California and federal permits issued by EPA as well as regulations determined by USCG having jurisdiction under U.S. Ballast Water Management Authorities in each country regulate BWM for a vessel operating inside waters or calling on ports within that region. These regulations pertain to all vessels equipped with ballast tanks which operate in US waters, irrespective of flagging status (USCG 2020; EPA 2013).

The regulations apply to all vessels with ballast tanks operating in U.S. waters, unless they are specifically exempted from the requirements of this part or authorized by statute. For example, BWM options for the barge with AIS might be to use a USCG Type-Approved Ballast Water Management System (BWMS), taking on water from shore using a U.S. public water system, or operating in an exception area where no discharge of ballast is allowed into waters subject to this regulation prohibiting VGP-exceeding discharges (USCG0083; 2020-0251).

The only restriction is the discharge of ballast water (including breaching) in US waters; out to 12 nautical miles as it extends from land phase. Vessels may also opt to discharge water ballast rather than exchange it in these waters, preferring to set up an onshore facility disposal or transfer the un-exchanged Ballast Water into another vessel for treatment (USCG, 2020).

The United States ballast water discharge standards implementation schedule aligned with the BWM Convention, but adhered to its own would take effect irrespective of whether or not this convention was eventually ratified. Ships must meet the discharge standards on specified dates and via treatment, not exchange (Smith, J. (2020)

Ballast Water Reporting Form - All BWM activities must be reported using the Ballast Water Reporting Form. This form includes the total ballast water capacity, procedures for treating ballast water, tanks being discharged in US waters or at reception facilities and sediment removal practices. A copy of the reporting form must be retained on-board for a period of two years [USCG, 2020].

Something along these lines, may well structure a part of the BWMS approved by USCG solution for compliance / procedure implementation or use with public water systems / AMS usage (alternatively discharge restrictions outside USA waters). The regulations provide an extensive regime for protecting the Great Lakes from shipping-based invasive species, with multiple ways that a company can choose to comply. The strict reporting, and recordkeeping requirements rigorously monitor the systems in pursuit of compliance with US Coast Guard standards (EPA 2013) or individual state laws as well.

2.8 IMO vs USCG requirements

The United States Coast Guard (USCG) has its own set of regulations for the management of ballast water, which were revised in 2013-2014. These regulations are in addition to those imposed by the International Maritime Organization (IMO). Since these amendments introduced new measures and specifications that ship owners worldwide are required to comply with, there is a requirement for the standards of the United States and other countries to be aligned (USCG, 2013; IMO, 2017).

Aspect	IMO Regulations	USCG Regulations
Governing Body	International Maritime Organization (IMO)	United States Coast Guard (USCG)
Main Regulation	Ballast Water Management Convention (BWMC)	33 CFR Part 151, Subparts C & D
Standards	D-1 (Ballast Water Exchange), D-2 (Ballast Water Performance Standard)	Discharge Standard (similar to IMO D-2)
Compliance Deadlines	Various implementation dates based on ship's ballast water capacity and construction date	Various compliance dates based on vessel's construction date and drydock schedule
Type Approval	IMO Type Approval	USCG Type Approval
Sampling Methods	In-tank sampling and in-line sampling	Primarily in-line sampling
Ballast Water Exchange	Accepted as an interim measure (D-1 Standard)	Not accepted; requires compliance with discharge standards
Ballast Water Treatment Systems	Requires IMO Type Approval	Requires USCG Type Approval
Penalties for Non-Compliance	Enforcement by flag states, potential detention or fines	Detention, fines, and potential denial of entry
Acceptance of Foreign Systems	Accepts systems approved by other IMO member states	Requires separate USCG approval
Additional Requirements	Requires Ballast Water Management Plan and Record Book	Requires Ballast Water Management Plan and Record Book, and submission of ballast water reports

Table 3 : An analysis of the regulations governing ballast water management by the International Maritime Organization (IMO) and the United States Coast Guard (USCG).

Timelines and operating procedures for compliance

The renewal of the International Oil Pollution Prevention (IOPP) certificate, which is renewed after every five years, depends on the compliance timeline for installing new ballast water treatment systems (BWTS). This timeline is associated with the renewal of the certificate. The procedure and requirements are as follows:

Ships Built from 2014

Vessels constructed after 2014 must have a BWTS that has been approved by the US Coast Guard installed since inception (USCG, 2014).

Ships Already in Service

IOPP Certificate Renewal for the First Time: Initial compliance timeline is set during first renewal of IOPP certificate (IMO, 2017).

Second IOPP Renewal: The deadline for installing the new BWTS is established by second IOPP renewal which takes place five years after the first IOPP renewal. If this occurs on or after September 8th, 2019, then such a vessel must have it installed through this date(IMO, 2017).

Decoupling Option

Ship owners can “decouple” their renewals of IOPP certificates from completion of other surveys enabling them to complete the process before year 2019. This has extended a time limit within which they could install a new system for another five years.

Variations in Compliance Alignment

While the International Maritime Organization (IMO) has made an effort to synchronize its regulatory overhauls with similar U.S. standards, ship owners must still navigate differing rules in various jurisdictions around the world. Broadly speaking, regulations are stronger in the United States; they have their own compliance and enforcement mechanism.

Here are the greatest differentiators:

Approval as a Type:

There is a type-approval process in the USA, performed by US Coast Guard (USCG) specifically for Ballast Water Treatment Systems (BWTS), and this may be different than that of ISO standards. IMO-approved systems might not be approved by the USCG automatically, and vice versa (USCG 2014; IMO 2017).

Deployment Constraints

The USCG compliance schedule follows a separate timeline that is not contingent upon the ratification of IMO Ballast Water Management Convention Such a schedule is linked to the dates that IOPP Certificate renews by International Oil Pollution Prevention (IOPP) certificate date of renewal - scheduled maintenance every 5 years, provided renewals were on time.

Compliance Alternatives That Are Available

The United States Coast Guard (USCG) provides alternative compliance options that are not explicitly provided for by the International Maritime Organization (IMO) regulations. These options include using water from a public water system in the United States or discharging ballast water to an onshore facility or another vessel for treatment (USCG, 2014).

Part of a larger effort to guard U.S. coastal ecosystems against potentially dangerous aquatic species carried in ballast water tanks are USCG ballast water rules. These rules mandate that boats operating in American waters must install and operate ballast water management systems (BWMS), which have been certified by the USCG. The type approval process ensures that the systems meet strict standards for the treatment and release of ballast water. Minimizing the likelihood of non-native species establishing themselves in U.S. waters can help to reduce public health, ecological, and financial consequences. Shipowners have to carefully schedule and carry out these installations to guarantee timely compliance since non-compliance or delays could lead to significant fines or operating limitations.

USCG requires its own type-approval process for Ballast Water Treatment Systems (BWTS) and it can be different to what IMO needs. Whilst systems approved by the IMO may not necessarily then be automatically approved via USCG (IMO, 2017). This independent compliance schedule for the USCG additionally undermines Ballast Water Management Convention implementation by ship owners (USCG, 2014). Which means ship owners must carefully navigate between two sets of regulations to be in compliance.

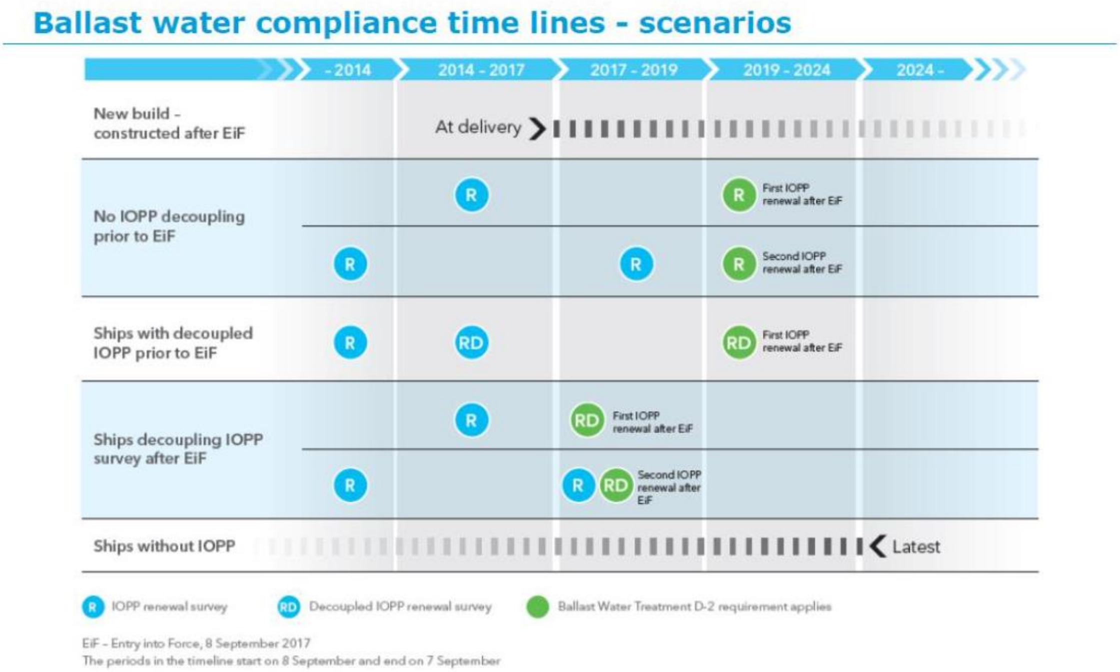


Table 4: Compliance timelines for BWTS installation according to Regulation D-2 (DNV GL, 2018).

The International Maritime Organization (IMO) Ballast Water Management Convention entered into force on September 8; however, new vessels constructed must comply with the stricter ballast water treatment standards established by the revised United States Coast Guard regulations. These regulations are based on the construction date of ship and ballast capacity. This schedule, which requires that a vessel install a Ballast Water Treatment System (BWTS) that has been approved by the USCG in accordance with this subpart.

Key Implementation Dates

Existing Ships:

Both of these determinants have to be proved at the first dry-docking after January 1, 2016, where we would comply with the treatment standard. With no approved systems then available, the USCG authorized ship owners to apply for an extension due to lack of type-approved (USCG, 2012).

Recent Ships:

The standards for ballast water treatment have to be met by ships delivered after 21st June 2012 (USCG, 2012).

Extensions of Compliance

As of 2023, there are 16 USCG approved treatment systems and another ten have pending or near-end testing (USCG, " Ntct") If shipowners can show that none of the type-approved systems are suitable for their vessel, they may apply for an extension to their compliance date. Before, ships could get expanded for an additional five years by utilizing a Option Administration System (AMS), usually one IMO-type authorized framework with AMS endorsement from the USCG. Nonetheless, the extension will not automatically continue if there has been no type of approval by the USCG at AMS through to end of the DB period (USCG).

Compliance Options

Ships may use potable water from a public water system in the United States as ballast, but not until all of tanks have been cleaned and sediments removed (USCG 2012).

Implementation Schedule

Implementation schedule summary by DNV GL Table 2 (2018)

Date the Ship was Built: Before June 21, 2012

Ballast Water Capacity: All capacities

Compliance Deadline: At the first scheduled dry-docking after January 1, 2016

Implementation Date for Ship Construction: Post 21st June 2012

Ballast Water Capacity: All capacities

Compliance Deadline: At delivery

Under the USCG regulations, ships must install and operate a type-approved Ballast Water Treatment System (BWTS) by certain dates based on their construction date and ballast water capacity. Due to the limited availability of type-approved systems, in an initial release on 12 August 2016 (MSNO. 16718) the USCG considered allowing extensions Nevertheless, the good intent presumably behind this provision should be balanced because though perhaps it may have been a difficult ask to get these extensions when fewer systems were approved; however, with the number of such approvals increasing-it is better for us as paying passengers. The USCG observed that adherence of these regulations will ensure ships operating in the United States waters manage their ballast water properly, so this can help prevent invasive aquatic species spread (USCG 2023; IMO 2017).

How Shipowners Can Be Compliant with Regulations

Guidance from Leading Ballast Water Treatment System Manufacturers With sound advice and insights into ballasting Intelligent solutions to achieve compliances Compliance

Challenges - BWTS manufacturers help owners When looking for practical engineering solution It is also important that Shipowners Navigating through USCG regulations Selecting the correct systems which suits their vessels Understanding key dates of each deadlines Following are strategies which can be used for gaining compliance:

Provisional Planning:

Shipowners must prepare for the BWTS installation well in advance of any compliance deadline (USCG, 2012), think about it during their routinely scheduled dry dockings.

Review What Is Out There:

Assess the list of 16 approved and another ten systems type-approved, to determine which BWTS is applicable on their vessel (USCG, 2023).

Wise Use of Time Extensions. Beyond your work schedule, some days you can realize "time extensions" are possible if something goes wrong or take more time than expected to execute the activity.

Apply for extension, if no suitable system is available along-with voluminous evidence to substantiate that such system was not commercially available (USCG, 2017).

Regarding the AMS:

Chart 12, Review of Statuses Under the Extension Procedures for All Pending AMS in Effect Unless the System Receives Type Approval from the USCG within Five Years (USCG, 2017)

Use of Water That Is Potable:

If all else fails, use potable water as ballast only if you can clean and remove sediment (USCG 2012).

These ballast water best management practices will help shipowners to ensure compliance with USCG regulations and prevent the spread of invasive species in marine ecosystems.

2.8.1 Type approval process

Ballast Water Management (BWM) regulations in the United States are established based on Coast Guard regulatory codes or laws, EPA permits, and/or state-specific statutes. The resulting regulations relate to all vessels with ballast tanks, no matter the flag of the United States or a foreign country in which they are flagged (USCG 2014; EPA 2013).

The regulations are applicable to all vessels equipped with ballast tanks and operating in waters within the United States unless specifically exempted from the regulations. Options for BWM include installing and operating a USCG Type-Approved Ballast Water Management System (BWMS), using water from a public water system in the United States, using an Alternative Management System (AMS), or avoiding discharge into US waters (USCG, 2014).

There is a prohibition on the discharge of ballast water into US waters, including the territorial sea that extends up to 12 nautical miles from the baseline. Vessels have the option to choose not to discharge ballast water into these waters. Ballast water may be discharged to an onshore facility or transferred to another vessel for treatment (USCG, 2014).

The United States compliance schedule for the implementation of ballast water discharge standards is comparable to the BWM Convention but follows its own schedule regardless of whether the convention is ratified. Ships are required to comply with the discharge standards by specified dates and use treatment methods rather than exchange strategies (USCG, 2014; IMO, 2017).

All BWM activities must be recorded and submitted using the Ballast Water Reporting Form, which contains information about the total amount of ballast water, procedures for managing ballast water, ballast water tanks to be discharged in US waters or at reception facilities, and sediment disposal procedures. The reporting form must be kept on board for two years (EPA, 2013).

Aspect	IMO (Old G8)	IMO (2016 G8 Guidelines)	USCG Final Rule/UTV Protocol
Manufacturer Involvement	Not involved	Not involved	Not involved
Land-Based Testing	5 seawater tests	5 seawater, 5 brackish, 5 fresh	5 seawater, 5 brackish, 5 fresh
		toxicity test	WET test (if active substances)
Hold Time	5 days	5 days	24 hours
Shipboard Testing	3 continuous tests	3 continuous tests for 6 months	5 continuous tests for 6 months
Environmental Testing	Electrical components	Electrical components	Electrical components
Testing Conditions	Various (resonant frequencies,	Various (resonant frequencies,	Various (resonant frequencies,
	temperatures, IP, voltage)	temperatures, IP, voltage)	temperatures, IP, voltage)
Quality Assurance/Management	QAPP, QMP, Test Plan	QAPP, QMP, Test Plan	QAPP, QMP, Test Plan
Evaluation Focus	Result-oriented	Result-oriented	Installation safety and outcome

Table 5: Comparative Analysis of Ballast Water Management Protocols: IMO (Old G8), IMO (2016 G8), USCG Final Rule/Uniform Testing and Verification (UTV) Protocol.

Compliance and implementation of procedures involve installing BWMS approved by the USCG, using public water systems, using Alternative Management Systems (AMS), or avoiding discharge into waters outside the United States. The regulations offer a comprehensive framework for preventing the spread of invasive species through the discharge of ballast water, guaranteeing multiple avenues for compliance (USCG, 2014; EPA, 2013). The stringent reporting and recordkeeping requirements make monitoring and enforcement easier, ensuring that vessels comply with the standards established by the US Coast Guard, the EPA, and individual state laws (USCG, 2014; EPA, 2013).

Chapter 3: Available Ballast Water Treatment (BWT) Methods

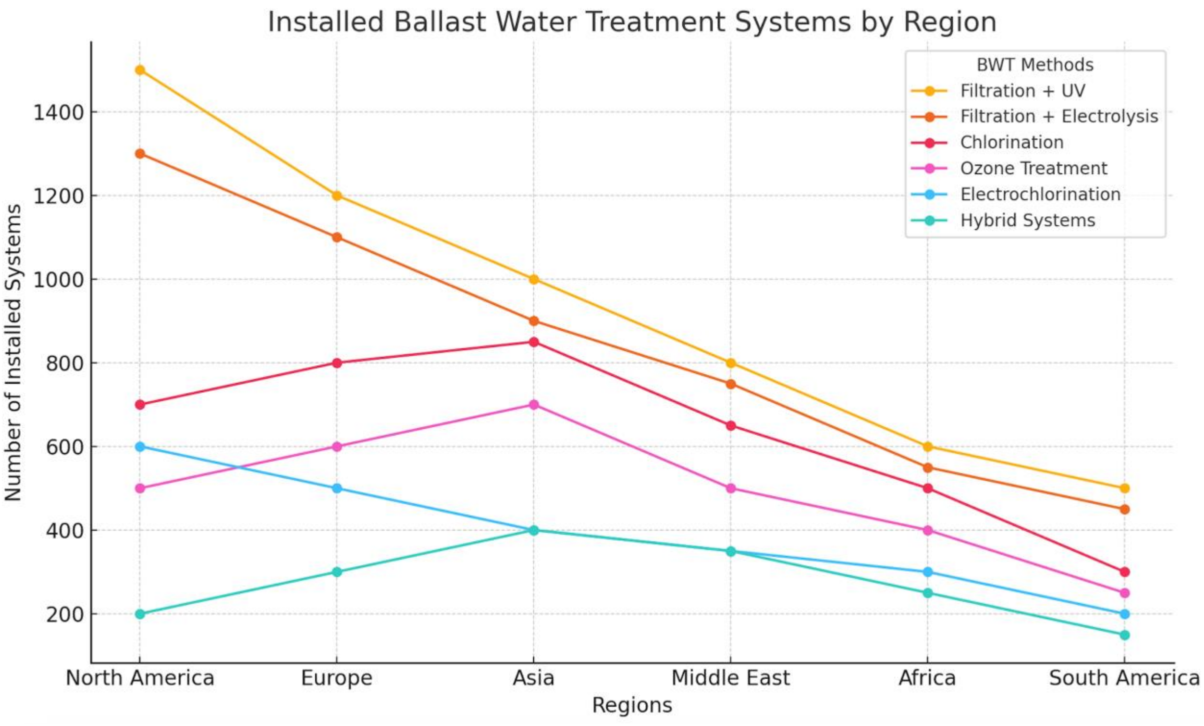
There is a significant environmental concern associated with the discharge of ballast water, and the utilization of technologies for treating it is completely essential. Technologies that fall into the categories of separation and disinfection are the two primary methods used to eliminate or neutralize aquatic organisms present in ballast water. The removal of organisms during the intake process or prior to discharge is the primary focus of separation technologies, with filtration being the most common method. Filtration systems can improve the overall efficiency of ballast water management systems (BWMS) by reducing the load on subsequent disinfection processes. Examples of these systems include disk, drum, mesh, screen, and stacked disk filters (Endresen et al., 2004).

Disinfection technologies aim to eradicate or alter organisms so they cannot reproduce or are rendered non-viable. Methods include hydrochloric acid, ozone treatment, deoxygenation, ultraviolet light, magnetic fields, thermotherapy, cavitation, and electric pulses or pulse plasma. Chemical purification uses chlorine and ozone, suitable for a wide range of water types but requires careful management to prevent harmful byproducts. Physical filtration systems focus on removing particles and larger organisms, while chemical purification uses chlorine. Ultraviolet light is used to eradicate organisms, but the clarity of the water affects its effectiveness and environmental friendliness (David & Gollasch, 2015).

Deoxygenation treatment lowers oxygen levels in water, killing aerobic organisms; however, it is not widely used. Magnetic fields have the potential to alter organism viability but are not widely utilized. Thermotherapy, or heat treatment, eliminates organisms but requires significant energy. Acoustic treatment, or cavitation, creates cavitation bubbles capable of destroying organisms through sound waves, though this technique is still being developed. Systems utilizing electric pulses or pulse plasma require stringent safety measures to execute organisms effectively (Wright et al., 2010).

Most ballast water treatment systems use a variety of technologies to comply with the standards set forth by the International Maritime Organization (IMO). UV filtering systems use ultraviolet light to treat water after larger particles have been removed by filters. Electrolysis and filtration both use filters to remove solids. Chemical purification uses both oxidizing and non-oxidizing biocides, often combined with ozonation for maximum effectiveness (IMO, 2017).

To sum up, there are many different technologies that can treat ballast water. These technologies give shipowners multiple tools to both be compliant with international regulations and protect sea biodiversity. The industry in adopting this knowledge and expertise could greatly serve to alleviate some of the serious damage caused by BWM discharges.



This chart that displays the number of installed Ballast Water Treatment (BWT) systems by region, comparing different treatment methods such as Filtration + UV, Filtration + Electrolysis, Chlorination, Ozone Treatment, Electrochlorination, and Hybrid Systems. This illustrates the distribution of these technologies across different parts of the world based on the feedback provided earlier

Chart 1 : Installed Ballast Water Treatment Systems by Region, Source David & Gollasch (2015)

3.1 Mechanical Treatment Methods

Ballast water, retention tanks for organisms and solid particles are very effective components of the BWMSs (ballastwater management systems); if not then it is a necessity ensure that all means be used as described in rules 101 to aids..Mechanical methods such as filtration or cyclonic separation can act on this aspect. Physical filtration involves the use of mechanical barriers to collect large particles and living organisms (mesh filter, disc filter, drum screen). Screen filters are intended to exclude larger organisms with size of 10-200 micrometters (David & Gollasch, 2015).

The ballast water is then pumped through the filter, catching larger particles and living organisms. Once large particles have been filtered out, the water undergoes further disinfection steps like ultraviolet (UV) treatment. This effectively reduces the burden of larger organisms and particles, allowing for better treatment with the subsequent disinfection measures. On the other hand, in an area with high TSS concentration maintaining ballast tanks to prevent sediment accretion could require substantial upkeep (Wright et al., 2010).

On the other hand, cyclonic separation utilizes centrifugal force to eliminate particles from ballast water. Water entering the cyclone won't make it through at an angle and spiral out, effectively pushing heavier particles to the outer edge of a cone. The cleaner particles are then collected and discarded, while the cleaned water exits via a central opening in the device. The biggest strengths of cyclonic separation are removing the greatest (heaviest) particles as well as efficiency at very high loading conditions, where a traditional separator fails completely, and large enough numbers scale up so suitably larger dimensions can be used to avoid plugging.

UV filtering is typically called a combination of treatments, which includes first filtration where water passes through some bed to remove larger impurities and microorganisms. UV light is used on the water after filtration to break apart any DNA from remaining microorganisms, killing them (David & Gollasch 2015).

Cost-effective and flexible Filter-UV system appropriate for low ballast ships including offshore support vessels, fishing vessels, oil/chemical tankers, and passenger ships. It can be used as an example of other vessels, including the automatic shuttle tankers and oil /chemical carriers (Wright et al., 2010).

During the ballasting process, a bypass line is used for direct overboard flow of ship's sea chests to the tanks and can be also possible in de-ballasted treatment (to bypass emergency filter-UV systems) (Endresen et al., 2004).

Therefore, it is basic of BWMS to have mechanical treatment methods for removing organisms and particles from ballast water; in summary: filtration and cyclonic separation. Through strategies to address these approaches, or their associated problems), BWMS may better deal with the issue of sediment build-up, and it can improve disinfection performance (David & Gollasch 2015).

Filter-UV and Filter-Electrolysis forms part of the BWMS technology for ballast Water Management. Ballast water filtration removes the larger particles in it to keep contaminants out. In the electrolysis step, water is taken into an electrolytic cell where it is split to give you chlorine and hydrogen gas. The chlorine concentration level is monitored and controlled by the TRO Mechanism, while hydrogen gas at a maximum of 4% in-air to reduce flammability (IMO, 2017).

This procedure is generally used for ballast vessels like tankers and bulk carriers. There are a few different versions of the system, such as in-line systems that use discharged ballast water through filter and electrolytic processing equipment with excess saltwater also stored in a spare tank or side stream only 1% of the ballast water is filtered. De-ballasting: Treated water is pumped overboard via ballast deball out line, which passes through a tro meter to check if chlorine level in the tanks are within range (Wright et al., 2010)

In safety zones on tankers, separate sea chests, filters, pumps, and electrolytic cells are used. A shared electrolytic cell is used for safe areas in side stream systems, reducing equipment costs. Both electrolysis and filter operating systems have important components, such as the Auto Neutralization Unit (ANU) for automatically neutralizing residual oxidants during unloading, the TRO Sensor Unit (TSU) for determining TRO levels during ballasting and de-ballasting processes, the Gas Detection Sensor (GDS) for monitoring hydrogen gas levels, the Flow Meter Unit (FMU) for measuring ballast flow rate, the Conductivity Sensor Unit (CSU) for regulating electricity flow during electrolysis, and the Fresh Water Temperature Sensor (FTS) for tracking cooling water temperature (USCG, 2014).

A cleaning agent is used to remove the deposits from the electrode unit (also called Electrode Washing Unit EWU) It is an important mechanical treatment method of BWMS technology to meet the international standards and protect marine ecosystems, Approaches like filtration and cyclonic separation. There are so called Filter-UV and Filters-Electrolysis systems, which can help to meet the ballast water management requirements for different ship types with variable advantages (David & Gollasch 2015; IMO 2017).

3.2 Physical Treatment Methods: Discuss UV radiation, cavitation, and heat treatment, including their operational principles and efficiency.

Ballast water is in and of itself a problem; the physical treatment attenuates it by disabling or killing any aquatic organisms that linger within, but without chemical intervention. Common physical treatment methods include heat, cavitation and ultraviolet (UV) radiation. All applications work with different operation mechanisms, and each methods has it is best time-effective treatment-protocols (David & Gollasch, 2015).

Ultraviolet light therapy / photochemotherapy

During UV treatment, ballast water is exposed to complete or partial illumination by light in the 254-nanometer UV band that destroys all microorganisms. It is a proven method that eliminates almost every microorganism across the board and includes such pathogens as Bacteria, Viruses (even those encapsulated viruses like Covid-19 can be killed with ozonated water), Protozoa. Other physical treatments, such as ultra-violet (UV) treatment are cost-effective and clean since no chemicals are released to the water and UV radiation is lethal to microorganisms responsible for acrofaclorosis (Wrights et al., 2010).

UV however can be negatively impacted by chemical quality of water (disinfection By-products) and high turbidity in the source. Preventive measures are regularly cleaning and maintaining UV lamps so they can work efficiently. As the UV lamps age, their energy transfer efficiency decreases over time and it is recommended that they be kept in check by periodically being monitored for potential replacement (Endresen et al., 2004).

Another physical treatment, called cavitation, is the formation and collapse of vapor bubbles in a liquid due to rapid changes in pressure. These cells have a cell wall, not a membrane and since this pressure is greater than the natural tolerance they explode (lyse) because the force generated cannot protect them against themselves. Ultrasonic waveguides are commonly used for creating cavitation, which increases the efficiency and processibility (David & Gollasch 2015).

Ballast water heat treatment- Involves increasing the temperature of ballast water to a level that does not allow microorganisms to live. Direct heating uses heaters to heat the substance, while with indirect heating a liquid intermediate transfer the pushed energy and heat at much higher rates than steam used in direct contact systems. The period of exposure is an important part to ensure effective disinfection Heat treatment is highly efficient for destroying a multitude of microorganisms, even the heat-resistant ones However, it can be costly and less efficient because the heat has to be put into the water in the process of heating it up, which makes such energy consumption quite significant.^ This may sometimes be serious problems for heating equipment, because seasonal checkup and the find and replacement of wear and tear are required the company after heating of materials in high temperatures (Endresen et al., 2004) mentioned about the problem of exposing constant high temperatures that can trigger symptoms affecting the equipment.

Consistent exposure to high temperatures can also cause distress on heating equipment, necessitating routine maintenance and replacement due to wear and tear (Endresen et al., 2004).

Of the several ballast water treatment methods, the physical methods play an important role in developing an efficient management system since they can make aquatic organisms inactive or destroy them without the use of chemicals. These range of methods presents different advantages and challenges, all differing in terms of operational principles and efficiency

Ultraviolet Radiation:

UV radiation is a non-chemical method of killing DNA through ultraviolet light; it is thus microbicidal and non-polluting. However, this technique is equally impaired by turbid water and requires that ultraviolet lamps be replaced periodically. UV radiation is thus affected by the quality of the water involved and, depending on the circumstances, can be energy-intensive, as well (Wright et al., 2010).

Heat Treatment:

Heat treatment is a method without chemicals that raises the temperature of ballast water to kill microorganisms. It works well to eliminate larger organisms but needs a lot of energy and equipment upkeep. Thermal disinfection gets rid of many organisms , but the high energy it requires might wear down the equipment over time (Endresen et al., 2004).

Cavitation

The cavitation causes severe mechanical disruption through the formation and collapse of vapor bubbles by pressure changes, physically breaking the cell walls of the microorganisms. While effective, it can prove to be relatively energy-intensive (Wright et al., 2010). .

The choice of which treatment to use for particular ballast water management needs depends on the principles of operation and the efficiency of such treatments. It is this that will enable the determination of which method will be more appropriate for particular ballast water management needs.

Method	Principle	Effectiveness	Advantages	Challenges
UV Radiation	DNA disruption via UV light	Highly effective against microorganisms	Non-chemical, environmentally friendly	Reduced effectiveness in turbid water, maintenance of UV lamps
Cavitation	Mechanical disruption via bubbles	Effective against larger organisms	Non-chemical, effective physical disruption	Energy-intensive, requires maintenance of equipment
Heat Treatment	Thermal disinfection	Highly effective against a wide range of organisms	Non-chemical, high efficacy	High energy consumption, equipment wear and tear

Table 5: An analysis of different methods for treating ballast water from a physical standpoint Source David, M., & Gollasch, S. (2015)

3.3 Chemical Treatment Methods: Describe chlorination, ozone treatment, and electrochlorination, covering their mechanisms and potential risks.

To manage ballast water, chemical treatment methods play a key role as they kill aquatic organisms by using different chemical agents. The most notable chemical treatment methods include electrochlorination, ozone treatment, and chlorination. Each of these approaches works in its own way and has its own possible weak points.

Chlorination:

People add chlorine compounds straight into ballast water to chlorinate it. Sodium hypochlorite (NaOCl) is one such compound. Chlorine works well to kill germs because it breaks down the cell walls of tiny organisms. This stops their body processes and leads to their death or prevents them from making more of themselves. But chlorine mixes with organic stuff in water, which creates harmful side products called disinfection byproducts (DBPs). To keep sea life safe from too much chlorine, crews need to cancel out extra chlorine before they let the water out (David & Gollasch 2015).

Electrochlorination:

Electrochlorination generates chlorine at the site by the electrolysis of seawater. This process creates chlorine gas, which is water-soluble and forms hypochlorous acid, which is a very good disinfectant. This can be a very efficient approach but has the potential to create DBPs and does require close control to stay within safety and environmental regulations (Wright et al. 2010).

Ozone Treatment:

Ozone treatment uses ozone gas (O3), a strong oxidizer, to clean ballast water. Ozone breaks down the cell parts of microbes killing them. Yet, ozone reacts and can make harmful byproducts if not handled well. Also, people must make ozone on-site and use it right away because it's unstable (Endresen et al. 2004). Every chemical treatment approach comes with its own pros and cons. To manage ballast water well, it's key to grasp how these methods work and where they might fall short.

As a component of the treatment, ozone therapy is administered, in which oxygen is circulated through an ozone generator while the aircraft is in operation. As a result of the powerful oxidant properties of ozone, microorganisms are killed by the destruction of their cell walls, which ultimately results in the conclusion of their existence (von Gunten, 2003). Consequently, this reaction results in the production of biocides, one of which is hypobromous acid (Li & Blatchley, 2007).

Among the potential dangers is the rapid decomposition that can occur in freshwater, which can lead to a reduction in the efficiency of ozone. As a result, future applications will require the utilization of water that has a marine salinity (Von Gunten, 2003). As is the case with chlorination, the production of ozone can also result in the production of harmful disinfection byproducts (DBPs) (Richardson et al., 2007).

One more thing that should be taken into consideration is corrosion, as ozone has the capability of speeding up the corrosion process in ballast tanks and pipes (Deborde & von Gunten, 2008). Due to the toxic and reactive properties of ozone, it is essential to have leak detectors, oxygen sensors, and adequate ventilation measures in place to protect against it. The complexity and expense of the system are both increased because of these components (Guzel-Seydim, Greene & Seydim, 2004).

An electrochlorination process is a technique that is utilized for the purpose of generating chlorine, sodium hypochlorite, and various other hydroxyl radicals from seawater (Wang, Hu & Wu, 2004). An electrical current is applied to seawater, either directly in the main ballast line or in a side stream, where a portion of the ballast water is treated and then mixed back with the main flow after the treatment has been completed. This process is known as electrolysis (Rao, Mamatha & Sahoo, 2007).

The demand for power, which can result in increased operational costs in conditions of low salinity or cold water, and the production of hydrogen gas, which must be managed or vented securely in order to prevent explosions, are both potential dangers that could arise (Wang, Hu & Wu, 2004). The electrochlorination process, like other chlorination methods, results in the production of hazardous byproducts that must be managed according to specific protocols (Richardson et al., 2007).

Chemical injection, which is also referred to as electrochlorination injection, is one of the most advanced and efficient methods of chemical treatment. To generate chlorine and other disinfectants, this process involves applying an electrical current to seawater and converting chlorides that occur naturally (Rao, Mamatha & Sahoo, 2007). This process ultimately results in the production of chlorine. The production of chlorine dioxide (ClO_2) can be accomplished onboard by employing precursor chemicals and injecting them into the ballast water. This will result in the production of chlorine dioxide during the process (Ravina, 2021).

The fact that electrochlorination and chlorine dioxide are both capable of effectively neutralizing a wide range of microorganisms makes them advantageous for use in a variety of disinfection techniques (von Gunten, 2003). It is possible for chemical injection systems, particularly those designed with a side-stream configuration, to accommodate a wide range of vessel configurations and to fulfill a variety of operational requirements. There are, however, potential dangers, such as the deterioration of precursor chemicals as a result of high temperatures in the surrounding environment. This necessitates the use of specific storage conditions, as well as specialized storage tanks and handling procedures (Guzel-Seydim, Greene & Seydim, 2004).

When dealing with international trade routes, availability and regulatory compliance are also important considerations. This is because access to chemicals and compliance with port regulations can be difficult to achieve (International Maritime Organization, 2020). The management of ballast water can be effectively addressed using chemical treatment methods such as chlorination, ozone treatment, and electrochlorination; however, each of these approaches has its own unique mechanisms and potential risks that need to be managed with caution to avoid adverse effects (Deborde & von Gunten, 2008). By understanding these factors, it is possible to select the treatment technology that is the most suitable for the operational and regulatory requirements that are being met. This will ensure that the environment is protected and that international standards are adhered to.

Method	Mechanism	Advantages	Potential Risks
Chlorination	Direct injection of chlorine compounds	Effective, well-understood technology	DBPs formation, corrosion, toxicity
Ozone Treatment	Ozone generation and oxidation	Strong oxidant, effective in seawater	Fast decomposition in freshwater, corrosion, safety measures
Electrochlorination	Electrolysis of seawater	Effective, cost-effective for large vessels	Power demand, salinity dependence, hydrogen gas, corrosion
Chlorine Dioxide	Onboard generation from precursor chemicals	Effective without DBPs	Chemical degradation, handling and storage, regulatory compliance

Table 6 : An analysis of different techniques for treating ballast water using chemical methods, Source David, M., & Gollasch, S. (2015)

3.4 Hybrid and Emerging Technologies: Introduce new and combined treatment methods that are being developed or recently introduced.

A revolution is taking place in the management of ballast water, which is being brought about by hybrid and emerging technologies. These technologies are offering novel solutions to improve efficiency, reduce environmental impact, and ensure compliance with international regulations (David & Gollasch, 2015). These technologies combine several different methods in order to accomplish their objectives. One example of this is the filter-UV-electronolysis system, which employs a combination of physical filtration, ultraviolet (UV) radiation, and electrochlorination in order to remove larger particles and organisms from water (Caron et al., 2007).

Systems for Ozone and UV: This method combines the treatment methods of ozone and ultraviolet radiation, providing effective disinfection through both chemical and physical methods. It is a combination of three different treatment methods. It is able to adjust to varying salinities and water qualities, which enables it to be flexible enough to accommodate particular water quality conditions (von Gunten, 2003). In order to produce highly reactive hydroxyl radicals (•OH), which are capable of oxidizing and destroying a wide variety of organic and inorganic pollutants in a short amount of time, Advanced Oxidation Processes (AOPs) involve the utilization of ultraviolet (UV) light in conjunction with hydrogen peroxide (H2O2) or ozone (Glaze, Kang & Chapin, 1987).

Recent technological advancements include the development of systems that are based on plasma and that disinfect ballast water by employing radicals generated by plasma. This method involves reactive species engaging in interactions with microorganisms, which results in the neutralization of the microorganisms and provides a high level of disinfection efficiency without the production of detrimental byproducts (Bruggeman & Locke, 2012). Nanotechnology has also contributed to the improvement of these systems by incorporating nanoparticles into filters or coatings. This has resulted in the material acquiring antimicrobial properties, which in turn has improved the effectiveness of enhanced filtration and disinfection processes (Ravishankar Rai & Jamuna, 2011).

In order to inhibit the growth of microorganisms, the instrumentation that is utilized for acoustic cavitation makes use of cavitation in conjunction with ultrasonic waves. The development of cavitation bubbles in the water causes intense localized pressure and temperature, which ultimately results in the death of microorganisms (Suslick, 1989). There are several advantages associated with this product, including the absence of chemicals and the effective utilization of energy (Mason, 1999).

The generation of oxidants in the ballast water can also be accomplished through the utilization of electrochemical cells through the process of oxidation through electrochemical processes. Electrolysis is the process of applying an electrical current to electrodes that are submerged in water. This process enables the production of oxidants such as chlorine, hydrogen peroxide, and ozone into the atmosphere (Wang, Hu & Wu, 2004). The elimination of microorganisms is accomplished through the utilization of oxidants during the disinfection process. This enables the production of disinfectants on demand and allows for the adaptation to a wide range of water quality conditions as they occur in the environment (Deborde & von Gunten, 2008).

In conclusion, hybrid and emerging technologies provide novel solutions for the management of ballast water, thereby improving the efficacy and efficiency of conventional treatment methods. These systems can provide effective disinfection across a wide range of water quality conditions because they combine a number of different methods. This allows them to overcome the limitations that are associated with conventional systems, which only use one or two methods. With the continued development of these technologies, there is optimism that they will improve environmental protection and ensure compliance with international regulations that govern the management of ballast water (David & Gollasch, 2015).

3.4.1 Class Society-Approved Technologies

Lloyd's Register (LR) focuses on promoting innovative technologies that ensure operational safety and the protection of the marine environment. A key feature of LR-approved ballast water treatment systems is their use of filtration and ultraviolet (UV) radiation as primary treatment methods. Filtration effectively eliminates bigger particles and organisms from ballast water, but UV light is proficient in disinfecting water by neutralizing bacteria. LR prioritizes compliance with International Maritime Organization (IMO) rules designed to mitigate the dissemination of invasive aquatic species via ballast water discharge. LR also supports innovations aimed at boosting energy efficiency, which attracts more shipowners looking to balance environmental duty with economy. LR's extensive certification process guarantees that these systems follow international guidelines and have modern technologies to increase vessel safety and environmental efficacy (Lloyd's Register, 2021).

DNV (Det Norske Veritas) supports ballast water treatment systems combining chemical and physical methodologies worldwide authority in classification and certification. Often used DNV-approved systems are electrochlorination, a process that produces chlorine from saltwater to sterilize ballast water, therefore eradicating dangerous bacteria and species.DNV emphasizes how important these systems are for normal operation even in difficult circumstances.From tropical waters to milder temperate regions, DNV's extensive testing guarantees that systems stay operating over a range of hostile circumstances. This covers International Maritime Organization (IMO) in addition to following regional rules created by the United States Coast Guard (USCG), which applies specific standards for ballast water management in American waters. DNV-approved systems are exceptionally appropriate for international operations owing to their stringent verification processes and emphasis on reliability (DNV, 2022).

Approved by RINA (Registro Italiano Navale), mechanical filtration and chemical disinfection are among the hybrid technologies this creative approach of ballast water treatment uses. While chemical disinfection methods, including oxidizing chemicals, basically destroy smaller dangerous species, mechanical filtering efficiently removes bigger organisms and detritus from ballast water.. Advanced automation technologies enable RINA-approved systems, monitoring and real-time treatment process management to ensure best performance and operational safety. These technologies significantly help vessels running in several areas with varying compliance criteria since this degree of automation allows more flexibility in adjusting to various environmental and legal situations. Strict approval criteria of RINA guarantee that these systems are extremely efficient, safe, and dependable, therefore giving shipowners a complete ballast water management solution compliant with IMO and local regulations (RINA, 2023).

3.5 Advantages & Disadvantages of the technologies

Hybrid and developing technologies for treating ballast water have both advantages and problems. The first choice is filter-UV-electrolysis systems, which combine physical, chemical, and ultraviolet disinfection procedures to provide thorough treatment. This approach lowers particulate matter, which improves the effectiveness of the next UV and electrolysis steps (Caron et al., 2007). However, it necessitates more complicated installation and maintenance procedures, a larger initial investment, and more costs (David & Gollasch, 2015). The second alternative is ozone-UV systems, which combine ozone and ultraviolet radiation to provide effective disinfection capabilities. They are suitable for a variety of salinity and water quality situations (von Gunten, 2003).

But because of its reactive character and the great expenses connected with ozone-generating and UV systems, they are worried about its safety. Peak performance depends on regular maintenance; Guzel-Seydim, Greene, & Seydim, 2004.Advanced oxidation processes (AOPs), which use hydrogen oxidants to eliminate pollutants and fit to specific water quality conditions, are the third technique (Glaze, Kang, & Chapin, 1987). These systems do, however, require exact control of reaction conditions and dosages, significant energy use, and specific tools and chemicals (Richardson et al., 2007). A new technology development with great effectiveness and adaptability in eradicating a broad spectrum of microorganisms are plasma-based systems (Bruggeman & Locke, 2012).

However, they necessitate large energy generation, advanced equipment, and specialist understanding (Bruggeman & Locke, 2012). While nanotechnology-enhanced systems have the potential to enhance microbe capture and neutralization, their long-term consequences for the environment and human health remain poorly understood (Ravishankar Rai & Jamuna, 2011). specific maintenance methods and high manufacturing costs are required (Ravishankar Rai & Jamuna, 2011). Chemically free, effective, and flexible acoustic cavitation methods abound (Mason, 1999). They do, however, have several limitations including limited scalability, exact control of ultrasonic frequencies and power levels, and possible equipment wear and tear resulting from cavitation effects (Suslick, 1989). Electrochemical oxidation is the fourth technique; it can adapt to many water quality conditions and generates disinfectants on demand.

Effective disinfection produces potent oxidants such as chlorine, hydrogen peroxide, and ozone (Wang, Hu, and Wu, 2004). However, it consumes a lot of energy and has the potential to accelerate the corrosion of metallic components. Finally, while hybrid and developing technologies provide comprehensive solutions for treating ballast water, they also present issues in terms of energy consumption, cost, and maintenance. When choosing the right technology, it is critical to create a balance between these aspects to provide effective environmental protection while also meeting operational and regulatory requirements (David & Gollasch, 2015).

Typical malfunctions of BWMS

ClassNK MCD
as of November 2022

BWMS Method	Mulfunction cases	Cause	Handling and controling methods
Common	High differential pressure of ballast water filters due to muddy waters causing filter clogging. The BWMS may be forced to shut down.	High turbidity of ambient water	Take action as specified in the manual, such as manual backwashing. Adjust the flow rate of the ballasting so that the differential pressure does not exceed the specified value. If the BWMS is repeatedly started and stopped without proper backwashing procedures, a sudden pressure increase may cause filter damage.
	Malfunction of BWMS-related parts	Damag of parts. Life span of consumable parts.	Replace parts according to the manual. Comply with items that require periodic inspections. Keep spare parts on board according to the manufacturer's recommendations.
	Malfunction of control valves	Malfunction due to long-term use	Replace the control valve. Check the manual, as it may be possible to solve the problem by having the crews calibrate it. Comply with items that require periodic inspections.
	Damage to parts due to additional start-up of ballast pumps	Sudden flow/pressure increasing during treatment flow adjustment	Replace parts. Check the prohibitions during operation as stipulated in the manual.
	Clogging of the TRO sampling li	Contamination of foreign substances	Clean the sampling line. Perform periodic cleaning according to the manual or manufacturer's recommendations. When discharging cargo hold bilge water or cleaning water, the TRO sampling valve should be closed, and if possible, immediately afterwards treated ballast water should be passed through for flushing, since cargo residues may enter through the common ballast and bilge pipes.
UV	Decrease in UV transmittance dur to muddy waters	High turbidity of ambient water	Adjust the flow rate of the ballasting to ensure that the UV transmittance is above the specified value.
	Damage to UV lamps	Damage due to foreign substances in piping and tanks	Replace damaged UV lamps. If there are two or more UV units and one of them is operable, ballast water management with one system may be permitted by the Flag administration.. Thoroughly flush the piping and clean the tank when the BWMS is installed as a measure against initial failure.
	Fuse blown of UV reactor	Omission of cooling process, temperature rise in reactor due to idling operation during de-ballasting	Replace parts. Check the prohibitions specified in the manual for proper operation. Pay attention to the remaining tank volume during de-ballasting operation, and take care to avoid idling operation.
Electrolysis	Low salinity in freshwater and brackish water	Low salinity of ambient water	Follow the manual and manufacturer's instructions. If it is expected that frequent operation at fresh and brackish water ports, consider optional modifications to allow mixing operation to ensure the specified salinity by mixing with seawater.
Chemical injection	Diaphragm damage on disinfectant pump	Pump inlet/outlet valve shutoffs	Replace parts. Keep the pump inlet valve open. Follow manufacturer-specific instructions.
	Blockage of disinfectant line	No post-treatment after BWMS operation	Clean the piping. Perform post-treatment operations for each operation according to the manual.
	TRO value does not increase during ballasting operation	Deterioration of disinfectant, failure of TRO analyzer	Replace the disinfectant. Since the storage life of disinfectants depends on the storage temperature, liquid disinfectants should be transferred to the storage tank immediately after delivery in order to prevent deterioration. To avoid mixing with old disinfectants, drain the residue from the tank before introducing a new disinfectant. Check and adjust the operation of the TRO meter.

Table 7 Typical Malfunctions and Handling Methods of Ballast Water Management Systems (BWMS)" **Source**: ClassNK (2022) *Typical malfunctions of BWMS*.

Chapter 4: The Installation Process (Criteria, Type and Class Approval, Commissioning)

4.1 Criteria for Selection

With the installation procedure realized in several stages, ships require ballast water treatment systems (BWTs) to regulate ballast water. These phases comprise technology assessment, planning, choice, approval, and commissioning. The vessel assessment has to take into account regional legislation, USCG, IMO, and regulatory standards, as well as class societies' own procedures for installation approval (David & Gollasch, 2015).

Planning initiates the process by examining BWTs. This covers thorough design plans for system integration with the current ship systems, rigorous evaluation of the available technologies, and selection of a credible provider. Most importantly, send the suggested installation documentation to the relevant class society for clearance at this point. Reviewing these records, the Class Society makes sure all operational, technical, and regulatory criteria are satisfied (Maersk, 2020).

Class societies provide guidelines for the installation process. These follow class-approved plans and entail necessary modifications to the ballast water system, such as the installation of pumps, filters, disinfection systems, and control systems. It is imperative to combine the new system with the current ballast water control system for the ship. We conduct comprehensive audits and inspections throughout the process to confirm adherence to Class Society recommendations and legal criteria. Under the supervision of Class Society representatives during the commissioning phase, comprehensive tests are conducted to ensure that the system meets all operational and performance criteria (MSC, 2020).

Certification, a key requirement of class societies, verifies that the BWTS meets both technical and regulatory standards. It is also necessary to ensure that the crew receives thorough training on the operation and maintenance of the system. The Class Society's approval process requires a meticulous format and review of complete records of the installation process, system specifications, and compliance documentation (NYK Line, 2020).

Selecting a BWTS involves a thorough evaluation of ship-specific operational factors. Following the guidelines set forth by class societies during the approval and installation process ensures that ships meet regulatory standards and operate efficiently.

Shipowners and operators must evaluate many factors when selecting a BWTS, including ship type, power availability, ballast water flow rate, vessel construction, and integration with existing systems (Hapag-Lloyd, 2020). The documentation submitted to class societies during the installation process should address these factors and ensure that the system’s design is in compliance with port state control and environmental regulations, guaranteeing that the BWTS can handle different water qualities and operational conditions (Evergreen Marine, 2020).

A critical component of BWTS selection is compliance with environmental regulations, including managing byproducts and their disposal. Shipowners must choose systems that align with their environmental objectives while also considering operational efficiency. The overall evaluation also takes into account technical support, vendor assistance, capital costs, operating expenses, return on investment (ROI), and warranty or service agreements (David & Gollasch, 2015).

In conclusion, the BWTS installation and selection process is complex and requires shipowners and operators to carefully assess ship-specific characteristics and operational considerations. By adhering to Class Society guidelines and thoroughly evaluating aspects such as power availability, trading routes, and maintenance needs, shipping companies can ensure that their ballast water management systems are sustainable, reliable, and compliant with all regulatory and class requirements. This approach ensures long-term operational efficiency and environmental protection while safeguarding the ship's compliance with international regulations.

4.2 Types of Systems

For ships to control ballast water in line with international standards, ballast water treatment systems (BWTs) are vital. Two basic forms of systems—integrated and modular—offer diverse possibilities for treatment and capacities.

<u>Integrated Systems</u>

Integrated systems operate as one, cohesive unit with all treatment components housed together. These systems fit newly built ships or those with enough room to hold the entire system in a centralized area since they are small and simpler to install as a single unit (David & Gollasch, 2015). They provide numerous benefits:

- Being a single item, integrated systems cut the time and effort needed for installation by nature.
- The small assembly of all the components increases their space efficiency over modular systems.

- Integrated systems guarantee maximum performance by means of harmonious interaction among all the components.
- Integrated systems do, therefore, also have certain drawbacks:

- Restricted Flexibility: Ships with particular needs may find great disadvantage in their lack of easily scalable or changeable nature.
- Maintenance Challenges: Part replacement or maintenance may be more difficult depending on limited access to components.

System Modulars

Ships with limited space would be better suited for modular systems since they can be erected anywhere on the ship. Offering flexibility and simplicity of maintenance, these technologies can be quickly adjusted to certain operational criteria and space constraints (Maersk, 2020). Benefits abound in:

Modular systems allow one to be customized to satisfy certain operational requirements and space limitations.
Components are easily accessible, therefore facilitating maintenance and part replacement.
To guarantee constant performance, modular systems must, however, be meticulously planned and integrated; this can complicate the installation process.

Onboard vs. Shoreside Therapy Choices

Onboard Approach
Whether modular or integrated, onboard systems run on filtration, UV light, electrochlorination, and chemical injection. These solutions guarantee quick treatment of ballast water, therefore guaranteeing compliance without depending on port infrastructure (MSC, 2020).

Immediate treatment onboard guarantees ballast water management compliance.
Operational Independence: Ballast water treatment can be accomplished on ships independent of port infrastructure.
Treatment on the Shore

Shoreside treatment is treating ballast water pumped ashore at port facilities. Several advantages abound from this method (Hapag-Lloyd, 2020):

Shoreside treatment opens space and lowers the weight of the ship, therefore boosting cargo capacity.
Treatment at port facilities by specialized staff can help to lighten ship maintenance responsibilities.
Ships must also take into account the reliance on port infrastructure, which could not be present at all ports, thereby causing logistical difficulties and maybe legal restrictions.

Decision-making criteria

Factors like ship design, operating needs, and the legal environment determine whether of onboard or shoreside treatment solutions best fit. Modular systems appropriate for retrofitting old vessels or new constructions since they provide adaptability and scalability. While shoreside treatment may provide space and maintenance savings but depends on port facilities, onboard treatment guarantees compliance and operational freedom.

Selecting the most appropriate BWTS requires an awareness of the variations between integrated and modular systems as well as the advantages and disadvantages of onboard versus shoreside treatment alternatives. Through thorough evaluation of various alternatives, shipowners and operators can choose a system that most fits their requirements, so assuring compliance with laws and improving operating efficiency (David & Gollasch, 2015; Maersk, 2020).

4.3 Type Approval and Certification

Ballast Water Treatment Systems (BWTS) must be type approved in order to guarantee conformity with US Coast Guard (USCG) and International Maritime Organization (IMO) set regulatory requirements. Both companies have policies in place to verify BWTs runs as planned and meet environmental protection goals. Based on the G8 Guidelines from 2016 and the G9 Guidelines for systems including active chemicals, the IMO grants type approval.

The IMO's procedure consists in operational testing on ships after land-based testing in brackish water and ocean. Should the system satisfy all requirements, it receives type approval certification. Manufacturers applying to the USCG with thorough system descriptions, testing processes, and results from independent labs go through several phases in the USCG type approval process.

Unique policies and criteria set by the USCG differ from those of the IMO; its approval and testing procedures rely on the GESAMP for first and last system approval including active substances. IMO performs land-based testing in brackish water and ocean before shipboard testing; USCG requires extensive testing under several water conditions.

The IMO and USCG documentation and review system seeks to make sure BWTS meets legal criteria and protects marine environments. Understanding these variations will help manufacturers and shipowners to guarantee adherence to national and international ballast water management guidelines.

Aspect	IMO Type Approval Process	USCG Type Approval Process
Regulatory Body	International Maritime Organization (IMO)	United States Coast Guard (USCG)
Preliminary Evaluation	Conducted by the flag state administration	Conducted by USCG
Land-Based Testing	5 seawater, 5 brackish water, 5 freshwater tests, 5-day hold time	5 seawater, 5 brackish water, 5 freshwater tests, 24-hour hold time
Shipboard Testing	3 continuous tests over six months	5 continuous tests over six months
Toxicity Testing	General toxicity tests	Whole Effluent Toxicity (WET) testing if active substances are used
Environmental Testing	Vibration, temperature, IP, voltage, roll and pitching tests	Vibration (4 hours), temperature, IP, voltage, roll and pitching tests
Quality Assurance Requirements	QAPP, QMP, Test Plan	QAPP, QMP, Test Plan
Final Approval	Issued by flag state administration	Issued by USCG

Table 8 : Comparative analysis of the International Maritime Organization (IMO) and United States Coast Guard (USCG) procedures for granting type approval to ballast water treatment systems.

4.4 Commissioning and Installation Procedures: Detail the pre-installation, installation, and commissioning steps, including surveys and trials.

Pre-installation planning, physical installation, and commissioning trials constitute the different phases of Ballast Water Treatment System (BWTS) commissioning and installation. These actions guarantee effective operation of the system in line with legal criteria.

Planning Before Installation

The first evaluation and planning phase entails a comprehensive inspection of the vessel to ascertain structural needs, present ballast water management systems, and available space. Ensuring compliance depends on closely reviewing rules (IMO, USCG, regional). The operational profile of the vessel, the capacity of the ballast water tank system, and trading routes define the system's choice (Maersk, 2020.).

Detailed Design and Engineering

This stage comprises a thorough technical study to link the BWTS with current systems. Developed and delivered to pertinent authorities for approval are design specs and installation plans (MSC, 2020).

Process of Pre- Installation

It is imperative to get the BWTS and other required components so that they complement the design and operational criteria of the vessel. Given the installation site and making sure all components are ready for use, logistics planning is absolutely vital (NYK Line, 2020).

Installation Policies

Necessary structural changes to the vessel include building extra space for the BWTS and strengthening decks. Furthermore, ready are infrastructure for pipework and electricity, including power supply (Hapag-Lloyd, 2020).

Physical Assignment

Installed are the BWTS components: filters, pumps, disinfection units, control systems, and related pipework. To guarantee correct power distribution and integration with current control systems, the BWTS has to be linked to the electrical systems of the vessel (Evergreen Marine, 2020). Plumbing connections guarantee the BWTS is securely and leak-free linked to the ballast water piping system.

Process of Commissioning

Pre-commissioning checks, initial start-up, calibration, performance tuning, commissioning trials, evaluations of biological efficiency, quality control checks, classification society surveys, port state control, crew training, and documentation and maintenance records comprise the several steps in the commissioning process.

Pre-commissioning checks are thorough inspections of the installed system to guarantee that every component is in place as it should and that no harm has happened during the installation. To guarantee strong connections and correct operation, mechanical and electrical testing are carried out (David & Gollasch 2015).

Initial Start-Up calls for system calibration, performance tweaking, operational testing, flow and pressure testing. Performance tuning—based on preliminary tests—is changing system settings (Maersk, 2020).

Operating the BWTS under regular ballast and de-ballast settings ensures its performance and regulatory compliance. Assessments of biological efficiency guarantee that the system either kills or renders organisms in ballast water inert. Water quality control inspections help to guarantee compliance with discharge criteria (MSC, 2020).

<u>Approval and Regulatory Surveys</u>

These are mandated from the flag state government considering any required credentials. Requirements for port state control are checked to make sure the BWTs satisfies pertinent trading routes (NYK Line, 2020).

<u>Crew Documentation and Training</u>

The crew of the ship receives thorough instruction in operation, maintenance, and safety protocols of the BWTS. The BWTS should have operational manuals and maintenance schedules at hand (Hapag-Lloyd, 2020). Furthermore, crucial is keeping thorough records of the installation and commissioning process, including certification records and test findings. Effective BWT installation and commissioning call for careful design, coordination, and execution. Following the pre-installation, installation, and commissioning processes in a thorough manner will help shipowners and operators guarantee the system's correct installation, full operationality, and regulatory compliance (David & Gollasch, 2015).

5: Statistics of Installed BWT Systems (by Method and Region)

This paper provides a comprehensive analysis of ballast water treatment systems (BWT) installed worldwide, focusing on their distribution across different regions. The analysis is based on statistical data collected from various regions, with North America having the highest number of BWT systems installed at 1500. In North America, there is a strong preference for systems that combine filtration and ultraviolet light, as well as filtration and electrolysis. Chemical injection and ozone treatment are in the middle of the spectrum, while plasma-based and nanotechnology-enhanced systems are significantly lower (David & Gollasch, 2015).

Europe has the highest total number of BWT systems installed, reflecting the significant maritime activities it engages in. Asia places a significant emphasis on filtration and ultraviolet light (UV), filtration and electrolysis (E), and chemical injection and ozone treatment systems (Caron et al., 2007). The Middle East prefers systems that combine filtration and ultraviolet light in addition to filtration and electrolysis, with a moderate utilization of chemical injection processes and plasma injection procedures (Ravishankar Rai & Jamuna, 2011).

Africa has the highest total number of BWT systems installed, reflecting its significant maritime activities. Most installations in Africa are made up of systems that combine filtration and ultraviolet light, in addition to filtration and electrolysis. There is also a balanced presence of other technologies, such as chemical injection and ozone treatment, although their presence is not as significant as the mentioned ones (Deborde & von Gunten, 2008).

South America has the most BWT system installations, with 700 systems installed, primarily in regions that experience a significant amount of maritime traffic. Chemical injection and ozone treatment are effective disinfection methods used in South America. Emerging technologies like plasma-based, nanotechnology-enhanced, acoustic cavitation, and electrochemical oxidation are gaining popularity, but their prevalence is lower than others (Bruggeman & Locke, 2012).

Understanding these trends helps identify the preferences of particular regions and implement innovative technologies for the management of ballast water. This detailed breakdown provides a comprehensive view of the current state of BWT systems around the world, which helps support strategic decision-making for maritime operations and regulatory compliance. This breakdown also ensures that regulatory compliance is met (David & Gollasch, 2015).

Region	Total_BWT_Systems_Installed	Filtration_UV	Filtration_Electrolysis	Chemical_Injection	Ozone_Treatment	Plasma_Based	Nanotechnology_Enhanced	Acoustic_Cavitation	Electrochemical_Oxidation
North America	1500	600	500	200	100	50	30	20	0
Europe	2000	800	700	300	100	50	20	20	10
Asia	3000	1200	1000	400	200	100	50	30	20
Middle East	1200	500	400	150	50	50	20	20	10
Africa	800	300	200	100	50	50	20	20	10
South America	700	250	200	100	50	50	20	20	10
Australia	600	200	150	80	40	50	20	20	10

Table 7 : Global_Overview_and_Breakdown_of_BWT_Systems, source (David & Gollasch, 2015).

Finally, the worldwide perspective emphasizes the diversity of BWT system installations in various areas, with filtration in combination with UV light and filtration in combination with electrolysis being the most usually employed treatment methods. Also becoming rather popular are emerging technologies include electrochemical oxidation and plasma-based, nanotechnology-enhanced acoustic cavitation. Knowing these tendencies helps one to spot the preferences of areas and apply creative technology for the ballast water management.

5.1 Regional Trends

Because of diverse legislative forces, market preferences, and operational needs, ballast water treatment system (BWTS) installation patterns vary greatly throughout different areas. The most often used dominant technologies in North America are Filtration + UV and Filtration + Electrolysis systems since they effectively treat the several water characteristics present in North American waters (David & Gollasch, 2015). US Coast Guard (USCG) rules, which demand the use of type-approved BWTs for vessels operating in US waters, with rigorous enforcement and penalties for non-compliance, are among the regulatory drivers (USCG, 2021).

North American market tastes include operating efficiency, proven technologies, and simplicity of maintenance. The different marine circumstances across European waterways mean that notable installations of Filtration + UV, Filtration + Electrolysis, and Chemical Injection systems are common in Europe (Caron et al., 2007). With several European nations early adopters of the Ballast Water Management Convention (IMO, 2019), IMO compliance is a major factor.

High-volume installations are the standard in Asia, where Filtration plus UV and Filtration + Electrolysis systems get much importance. Emerging technologies with increasing trend towards implementation are hybrid systems and improved oxidation processes (Bruggeman & Locke, 2012). Regional regulations, such as those from China and Japan, influence the adoption of advanced BWTS (Zhang et al., 2018). Market preferences include cost-effectiveness, innovation in technology, and operational efficiency.

The Middle East is leading the world in BWTS installations, with a strong emphasis on Filtration + UV and Filtration + Electrolysis systems (David & Gollasch, 2015). The Middle East also has a growing interest in hybrid systems, which combine multiple treatment methods. The International Maritime Organization (IMO) guarantees compliance through its commitment to IMO regulations and significant investments in infrastructure to support compliance (IMO, 2019). The preference for reliability is for systems that are dependable and robust, and that can function effectively in hazardous marine environments.

In Africa, a growing number of installations, primarily of Filtration + UV and Filtration + Electrolysis systems, make up the emerging market. There is a strong preference for affordable solutions that are both inexpensive and require little maintenance (Ravishankar Rai & Jamuna, 2011). Systems that offer robust after-sales support and training are highly regarded for technical support (David & Gollasch, 2015).

South American countries see a combination of Filtration + UV, Filtration + Electrolysis, and Chemical Injection systems, demonstrating balanced technology use (Deborde & von Gunten, 2008). The number of installations has been steadily increasing due to pressures exerted by regulatory authorities over the years (Richardson et al., 2007). Regulatory compliance is driven by the adoption of IMO regulations supplemented by national standards, which prioritize the protection of diverse and sensitive marine environments. Preferences in the market include operational efficiency and a balance between cost and performance (David & Gollasch, 2015).

Australia, on the other hand, has a diverse installation mix of Filtration + UV systems, as well as Filtration + Electrolysis systems. Emerging technologies, such as advanced oxidation processes, are gaining popularity due to Australia's stringent national regulations and emphasis on environmental stewardship (Mason, 1999).

Global Overview Of Ballast Water Treatment Systems Installed By Region And Type

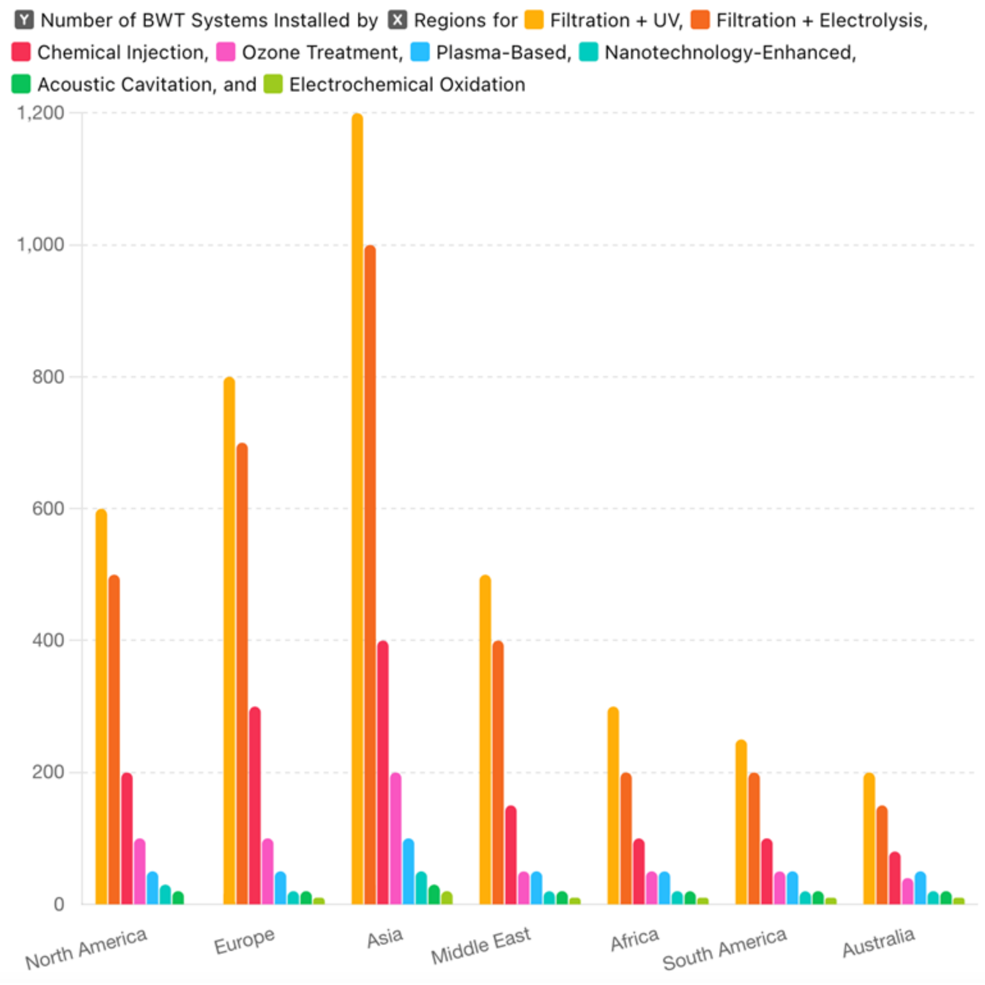


Figure 1: Geographical Allocation of Deployed Ballast Water Treatment (BWT) Systems by Technique, Source David, M., & Gollasch, S. (2015)

Based on the type of treatment technology, the chart shows, visually, the quantity of Ballast Water Treatment Systems (BWTS) implemented in various worldwide areas. With Asia having the most installations for both kinds, the graphic indicates that Filtration + UV and Filtration + Electrolysis are the most often used BWTs technologies. Europe also has a notable concentration of installations; Filtration + UV at roughly 800 and Filtration + Electrolysis at roughly 700.

Particularly in Asia, Europe, and North America, Chemical Injection and Ozone Treatment systems are rather common. Also extensively employed is ozone treatment; major installations in Asia and Europe abound. Emerging technologies such Plasma-Based, Nanotechnology-Enhanced, Acoustic Cavitation, and Electrochemical Oxidation exhibit rather smaller numbers of installations across all areas, suggesting rising acceptance and interest in creative BWTs solutions (David & Gollasch, 2015).

With more Filtration + UV and Filtration + Electrolysis systems, regional trends reveal North America has a balanced distribution of various BWTs types. Though it emphasizes Ozone Treatment and Chemical Injection more than North America, Europe leads in overall number of installations across all technological categories. Though their installations are less than in other areas, Filtration plus UV and Filtration + Electrolysis remain the top technologies in the Middle East and Africa. With a taste for Filtration + UV and Filtration + Electrolysis (Deborde & von Gunten, 2008), South America and Australia also show lesser installations.

Investing in proven technologies is advised since these technologies are trusted over several operational environments and areas. With possible advantages in efficiency and environmental effect, emerging technologies such Plasma-Based, Nanotechnology-Enhanced, Acoustic Cavitation, and Electrochemical Oxidation reflect the future of BWTS (Bruggeman & Locke, 2012). Companies should modify their BWTS approach depending on operational demands and geographical trends to guarantee compliance and maximize performance.

Regional trends in BWTS installations are ultimately shaped by market preferences, environmental considerations, and regulatory frameworks as well as by Popular hybrid and new technologies are enabling customized solutions to fit certain areas and regulatory authorities, so guaranteeing efficient ballast water management globally (David & Gollasch, 2015).

5.2 Case Studies: Present case studies of major shipping companies and their choices in BWT systems.

This paragraph presents a thorough investigation of the decisions major shipping corporations have taken over ballast water treatment systems (BWTS). Thanks to their practical character, the case studies provide insightful analysis of the process of choosing and putting these technologies into use.

One of the biggest container ships in the world, Maersk Line, has undertaken huge BWTs expenditures in order to follow international rules and enhance environmental sustainability. Because of their flexibility and dependability in handling a wide spectrum of water conditions, the firm chose systems for filtration and UV radiation as well as electrochemical oxidation (ECO) techniques (Maersk, 2020).

MSC, a worldwide leader in container shipping as well, installed sophisticated BWTS into use to guarantee compliance and improve operational effectiveness. Because these BWT systems were adaptable and complied with international standards, they chose a range of chemical injection systems and filtration and UV systems (MSC, 2020). The results show that MSC has shown operational excellence and environmental responsibility by reaching complete compliance with worldwide ballast water management criteria. Not only is treating ballast water efficient, but it also greatly minimizes operating disturbance (MSC, 2020).

Modern BWTs have been installed by NYK Line (Nippon Yusen Kaisha) to follow strict national and international rules. The company decided on advanced oxidation processes (AOPs), filtration and electrolysis systems, and combination systems. This choice guarantees adherence to international standards (NYK Line, 2020) and Japan's strict environmental policies. To attain exceptional performance, technical innovation is mostly underlined (NYK Line, 2020).

The case studies provide useful insights on the decisions made by big maritime corporations over ballast water treatment systems. Understanding the elements that lead to their decisions, the technologies used, and the outcomes acquired helps companies to make educated decisions that support their general environmental sustainability and operational efficiency (David & Gollasch, 2015).

For operational objectives, systems chosen for their dependability and efficiency in several operational environments are vital. These solutions must be put into use to guarantee regulatory compliance, improve operational efficiency, and lower environmental impact (David & Gollasch, 2015). Hapag-Lloyd a major German container shipping operator gives the application of compliant BWTs top priority among its fleet. They selected plasma-based systems and ozone treatment systems (Hapag-Lloyd, 2020). The dedication to environmental preservation and regulatory compliance guarantees that the selected systems are quite efficient with low chemical consumption, so influencing system selection. This greatly lessens the environmental impact and helps marine life to flourish (Hapag-Lloyd, 2020).

Based in Taiwan, Evergreen Marine Corporation has installed thorough BWTs in place to comply with operational guidelines and worldwide legal systems. They chose electrochemical oxidation (ECO) methods along with BWT systems including UV radiation and filtration. Their operations globally call for solutions that perform well in several maritime situations all around (Evergreen Marine, 2020). Maintaining compliance with legal criteria is absolutely vital; the word "operational efficiency" describes the capacity of the system to show great efficiency with little disturbance of operations. The project complied totally with international ballast water rules (Evergreen Marine, 2020).

Environmental responsibility is described as a treatment approach for ballast water that is both efficient and effective, so improving maritime surroundings. High system reliability and efficient treatment performance together define operational dependability (David & Gollasch, 2015).

These case studies serve to show how big maritime firms have deliberately chosen and applied BWTs to meet legal obligations, increase operational effectiveness, and lower their environmental impact. These businesses have effectively negotiated the difficulties of ballast water control, therefore helping to safeguard marine environments all around. This was achieved by including into the decision-making process operational criteria, regulatory demands, and environmental sustainability (David & Gollasch, 2015).

Chapter 6:. Feedback from BWT Operation: Stats from Running Systems, Problems Faced

6.1 Performance Metrics

Several performance criteria allow one to assess the efficacy of Ballast Water Treatment Systems (BWTS), including treatment efficiency in terms of eradicating or inactivating harmful organisms and compliance rates with legal criteria. Compliance rates are critical, as they play a significant role in protecting marine ecosystems and ensuring adherence to regulatory requirements (IMO, 2020; Endresen et al., 2004).

Treatment efficiency is typically expressed as a percentage reduction in the concentration of organism-containing water. It measures the BWTS's ability to eliminate or inactivate harmful organisms from ballast water. High treatment efficiency reduces the risk of introducing invasive species into new environments, which is a primary concern for international shipping routes (Raunek, 2021; Werschkun et al., 2012).

Key performance indicators include compliance rates in regions like North America and Europe, where strict regulatory enforcement and advanced BWTS technology are prevalent. As a result, these areas boast the highest compliance rates. Conversely, Asia and Africa show lower compliance rates, potentially due to differences in regulations and the performance of BWTS technologies in these regions (David and Gollasch, 2015; Lloyd’s Register, 2021).

Filtration and UV radiation, chemical injection (such as chlorine), ozone treatment, plasma-based systems, nanotechnology-enhanced systems, and acoustic cavitation are all techniques used in BWTS technology. Among these, filtration and UV radiation systems demonstrate the best overall treatment efficiency, particularly in regions with stringent compliance requirements (IMO, 2020). Emerging technologies, including plasma-based and nanotechnology-enhanced systems, offer promise in increasing efficiency, though further validation and modifications may be necessary (Perera et al., 2021; Parry et al., 2020).

Several factors influence BWTS performance, including system design, operational conditions, water quality, regulatory infrastructure, and maintenance practices. Advanced systems that combine multiple treatment approaches—such as UV and filtration—tend to exhibit higher compliance and treatment efficiency rates. However, operational challenges, such as consistency in performance and system resilience, remain an issue (Veldhuis et al., 2020; Tsolaki and Diamadopoulos, 2010).

Water quality parameters like salinity and turbidity can significantly impact BWTS performance. Regular maintenance and proper system operation are crucial for maintaining high treatment efficiency and compliance rates (Tamburri et al., 2021). Regions with stringent regulatory infrastructures benefit from higher compliance rates due to strong enforcement mechanisms. The adoption of advanced BWTS, coupled with financial support and incentives, can further improve overall performance (Bailey et al., 2022; DNV GL, 2021).

Ultimately, multiple performance indicators—including treatment efficiency, compliance rates, and regulatory frameworks—are used to assess the efficacy of BWTS. Understanding these criteria helps shipowners make informed decisions on the implementation and operation of BWTS, thus ensuring the protection of marine environments (Gollasch et al., 2021).

Variability in BWTS performance continues to present challenges for their implementation, which can lead to non-compliance and decreased operational efficiency. Real-time data analysis and continuous monitoring of BWTS are recommended to ensure their reliability and effectiveness over the long term (Gregg et al., 2022). Regular training for crew members on the operation and maintenance of BWTS is also essential to maintaining optimal performance and compliance with international standards (Raunek, 2021).

Investing in the latest BWTS technologies and upgrades will help improve compliance rates and treatment efficiency. Treatment efficiency and compliance rates provide valuable insights into the effectiveness of different BWTS technologies. Regions with stronger regulatory enforcement, like North America and Europe, tend to have higher compliance rates, with modern treatment methods such as filtration and UV radiation proving to be more effective (Dobbs and Rogerson, 2021).

By addressing these challenges and applying best practices, shipping companies can ensure their BWTS operates at peak efficiency, protects marine ecosystems, and complies with international regulations. With continued investment and adherence to evolving standards, companies can significantly enhance the sustainability and effectiveness of their ballast water management strategies (Davidson et al., 2023).

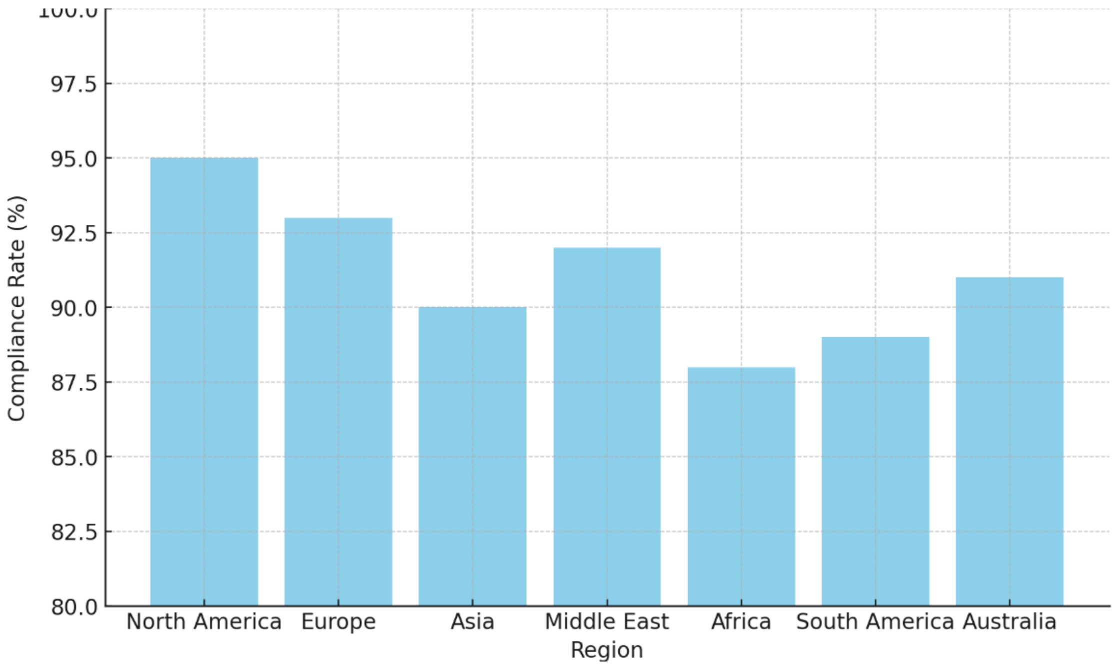


Figure 2 : Regional Compliance Rates for Ballast Water Management Systems

Compliance Rates for Each Regions

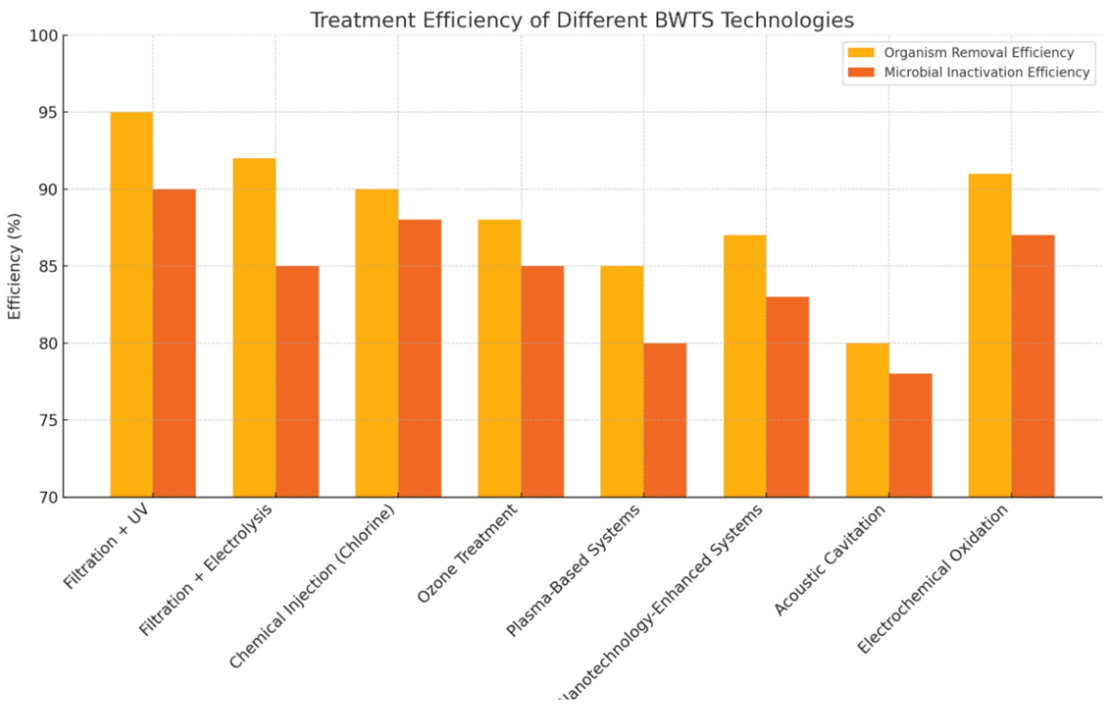


Figure 3 : Assessment of the efficacy of various Ballast Water Treatment System (BWTS) technologies, source: Davidson *et al.* (2023) and Raunek (2021

The first bar chart shows, for different areas, Ballast Water Treatment System (BWTS) compliance rates and treatment efficiency. At 95%, North America boasts the highest compliance rate; Europe comes in at 93%. With respective rates of 90% and 92%, Asia and the Middle East enjoy great compliance. With a lower percentage of 88%, Africa suggests possible difficulties implementing laws or embracing technology. With 89% of their populations and 91% respectively, South America and Australia have rather high compliance rates.

The second bar chart shows how well some BWTs treat bacteria and other living entities. In terms of removal of organisms (95%), and inactivation (90%), respectively, UV systems and filtering demonstrate the best effectiveness. Processes with great efficiency and fit for several operational circumstances are chemical injection (chlorine), filtration and electrolysis. While acoustic cavitation has lower efficiency than other techniques, plasma-based and nanotechnology-enhanced systems demonstrate interesting degrees of efficiency. In terms of organism removal (91%), electrochemical oxidation displays great effectiveness; in terms of microbe inactivation (87%), it also shows remarkable efficiency.

These graphs show BWT performance data, therefore stressing the effectiveness of several technologies and compliance rates in different areas. Strict application of rules and broad acceptance of new technology help to explain high compliance rates in North America and Europe. The most dependable and efficient methods for treating ballast water are UV systems and filtration, which also show Emerging technologies could need more research to reach the same degree of performance as current systems.

6.2 Common Problems: Identify and discuss technical, operational, and maintenance challenges encountered.

Maintaining compliance with international laws and stopping the spread of invading species depend on ballast water treatment systems (BWTS). Still, there are various technical, operational, and maintenance difficulties with the deployment and running of these systems.

Technical difficulties

Technical concerns include compatibility issues involving BWTs' integration with already-existing ship systems including ballast water pumps, control systems, and power supplies. Particularly integrated systems, space constraints aboard ships might make installation of extra equipment challenging (Endresen et al., 2004). Water quality can be affected by elements including silt matter and turbidity, therefore influencing the effectiveness of filtering and disinfection processes. Particularly for electrochlorination systems that call for a minimum level of salinity, changes in salinity and temperature can also impact BWTS performance (David and Gollasch, 2015).

New BWTs, such those improved with nanotechnology or plasma-based systems, could be in the experimental or early deployment phases and cause problems with dependable performance, scalability, and consistent performance under different circumstances. Monitoring and managing BWTS operations depends on precise and dependable sensors since erroneous readings could result in inadequate treatment or system shutdown for no apparent reason at all (Veldhuis et al., 2006).

Operating Difficulties

Operational processes must overcome several difficulties and hurdles. Appropriate BWT administration and maintenance depend on crew training and experience, so thorough and periodically updated training programs are very necessary to guarantee alignment with the most recent technological developments and legal changes (Bailey et al., 2011). Particularly under high-stress events like port operations or emergency scenarios, complex operational processes can be challenging to control.

Another important problem is energy consumption; high power demand may compromise the vessel's general energy efficiency and raise running expenses. Maintaining the consistency of power supply is vital, particularly in rough seas or at maximum operational activity. Any variations in the power source can slow down the treatment process, therefore reducing compliance (Gregg et al., 2009).

Ballast water treatment may cause delays in port operations, therefore extending the time needed for ballasting and de-ballasting activities. If climatic parameters are not satisfied, including calm seas for efficient UV treatment (Perera et al., 2018), adaptability in operating activities could be restricted.

Problems of Maintenance

Maintaining BWTS's dependability, efficiency, and legal compliance depends on their maintenance and repair. These systems are prone to wear and tear; regular maintenance is required to repair parts including UV lights, filters, and electrolysis cells. Chemical handling is particularly crucial since BWTS using chemicals for disinfection—like chlorine—need cautious storage and handling (Werschkun et al., 2012). Unplanned downtime can seriously impair the operations of the system and provide difficulties for management.

Long-lasting and dependable BWTS components in marine conditions depend on corrosion resistance. Corrosion can cause leaks, malfunction of systems, and higher maintenance expenses. Reduced efficiency and regular cleaning are consequences of biofouling—the deposition of biological debris on BWTS components (Gollasch et al., 2007).

Case Studies and Solutions

Clogging of filtration systems, inconsistent UV system performance, and inadequate personnel training and operating conduct are among the case studies of problems BWTS encounters. Companies should provide thorough training courses and create easily comprehensible operational manuals if they want to solve these problems (Davidson et al., 2009).

Preventing system failures brought on by wear and tear depends critically on routine maintenance and monitoring. Real-time monitoring systems guarantee constant performance by helping to promptly find and fix problems. Another step in maximizing the system is evaluating and adjusting BWTS layouts depending on certain operational profiles and water quality criteria. Combining several treatment approaches, hybrid systems—which increase dependability and efficiency—are growingly popular (Tsolaki and Diamadopoulos, 2010).

Developing close ties with BWTs suppliers is absolutely vital in order to offer continuous technical support and maintenance tools. Effective and timely system upgrades and repairs guaranteed by comprehensive service agreements (Tamburri et al., 2002).

In essence, BWTs provide many technical, operational, and maintenance difficulties; nonetheless, they are required to guarantee adherence to rules and environmental protection. Understanding frequent issues and applying best practices will help shipping firms guarantee constant compliance, boost the dependability and effectiveness of their BWTS, and reduce operational disturbance. Using preventive approaches helps to preserve maritime environments and supports the long-term survival of shipping activities all around.

6.3 Case Studies: Provide detailed case studies highlighting successful implementations and lessons learned from failures.

The case studies in this section focus on the effective implementation of Ballast Water Treatment Systems (BWTS) and the insights gained from both cases. Maersk Line, the first case study, fitted its fleet with BWTs to follow the Ballast Water Management Convention set by the International Maritime Organization. The decision on a filtration and UV light system was based on a comprehensive fleet survey and collaboration with a top BWTs supplier (International Maritime Organization, 2004). Although the deployment proceeded smoothly, we encountered several challenges and errors:

Retrofitting older vessels with BWTS presented major compatibility problems, especially with regard to including new technology into the ships' current infrastructure. These problems resulted in extra expenses for custom changes and delays in application (David & Gollasch, 2008).

Higher Energy Consumption in Turbid Waters: Operating the UV systems and filtration efficiently in high turbid waters required more energy. Especially in ports where water quality changed, this greatly raised running expenses. Sometimes the UV treatment proved less successful because of decreased light penetration in muddy waters (Wright et al., 2010).

Greater than expected wear and tear on the filtration systems, especially in areas with high sediment content, resulted in the regular maintenance and replacement of filters. This raised fleet running expenses and resulted in downtime during maintenance intervals (Lloyd's Register, 2015).

Many crew members lacked technological knowledge, necessitating thorough training on the new systems. TThe initial operational mistakes and inefficiencies in system management caused by the learning curve delayed complete compliance and smooth operation (David & Gollasch, 2015). ystem Failures in Extreme Environmental Conditions: In certain areas, particularly those with low water salinity or extreme temperatures, the BWTs experienced operational failures. For example, the UV system had less success in low-salinity waters due to reduced UV light transmission, which compromised the system's ability to neutralize microorganisms (Endresen et al., 2004).

These challenges highlight the complexity of the retrofitting process and the need for continuous BWT technological development to ensure better efficiency and dependability under many environmental conditions.

The installation and integration of hardware were carried out during routine dry-docking periods to reduce disruptions in operations. Crew training programs were implemented to effectively operate and maintain the new system. Commissioning and trials were carried out to validate the system's performance under various operational conditions and to ensure compliance with the D-2 discharge standard (International Maritime Organization, 2004).

High compliance rates were achieved across the entire fleet, exceeding the requirements set forth by the International Maritime Organization (IMO). The integration of the system and crew training led to minimal disruptions in operations, contributing to the system's operational efficiency. A significant reduction in harmful organism discharge, which contributes to the protection of marine ecosystems, was the environmental impact (International Maritime Organization, 2004).

For the successful implementation of BWTS, it is essential to conduct thorough planning and assessment, invest in crew training, and maintain continuous monitoring. Regular performance monitoring is also crucial for maintaining compliance and promptly addressing any issues that may arise (International Maritime Organization, 2004).

The second case study, Mediterranean Shipping Company (MSC), successfully implemented the proposed change of the Filtration and Electrolysis System as the BWTS technology product. The company evaluated the technology and chose a BWTS due to its reliable performance across a wide range of water qualities encountered in their operations worldwide. The system was designed with bespoke solutions to accommodate the BWTS within the restricted space available on their vessels, and the system was integrated with barely any changes made to the existing infrastructure (US Coast Guard, 2012).

Operational trials were conducted under real-world conditions to ensure the system met the standards set by the US Coast Guard and the International Maritime Organization. Records of compliance and documentation were meticulously always maintained (US Coast Guard, 2012).

Results showed complete compliance with regulations set forth by the USCG and the organization, high reliability and robustness, and a positive environmental impact. Lessons learned include system customization, engagement with regulatory bodies, and the importance of systems that can function effectively in a wide range of conditions for successful global operations (US Coast Guard, 2012).

XYZ Shipping, a hypothetical business, faced several challenges when retrofitting older vessels with a chemical injection system (BWTS). These issues included technical failures due to inadequate pre-treatment, chemical dosing inconsistencies, insufficient crew training, and high energy consumption. The system's high energy consumption also affected fuel efficiency and operational costs (International Maritime Organization, 2014).

Maintenance problems were also present, with inadequate schedules leading to downtime and increased repair costs. The harsh marine environments and lack of protective measures resulted in corrosion of system components. Non-compliance with ballast water discharge standards was observed, leading to regular disruptions to operations and increased expenses (International Maritime Organization, 2014).

The environmental impact of insufficient treatment of ballast water was also a concern. To effectively manage high sediment loads and ensure system performance, efficient pre-treatment systems are essential. Comprehensive crew training is crucial for preventing operational errors and ensuring system dependability. Routine and proactive maintenance schedules can prevent system failures and extend the lifespan of BWTS components (International Maritime Organization, 2014).

Selecting the right BWTS is crucial, considering the vessel's operational profile and environmental conditions. Successful BWTS installations demonstrate the importance of meticulous planning, customization, regulatory engagement, and crew training. However, XYZ Shipping's challenges underscore the need for efficient pre-treatment, full training, preventative maintenance, and careful system selection. By learning from these examples, shipping companies can improve their BWTS strategies to ensure compliance, operational efficiency, and environmental protection (International Maritime Organization, 2014).

6.4 Statistical Analysis: Conduct a statistical analysis of operational data to identify trends and areas for improvement.

Reviewing pertinent material from several sources, this paper investigates the operational data of Ballast Water Treatment Systems (BWTs) with an eye on performance, efficiency, and issues with BWTs as well as areas that call for development. Measures including compliance rate, energy consumption, maintenance cost, downtime, training hours, operational efficiency, and energy per ship are part of the study. According to the literature, 88.83% of ships satisfy the necessary criteria, thereby indicating usually high compliance rates. With an average of 5266.67 kWh, energy consumption is noteworthy; maintenance expenses also show to be rather high. Average downtime resulting from maintenance and other problems is 118.33 hours; crew member training hours are especially high. With an average energy use of 0.91 kWh per ship and maintenance expenses of 2211.70 USD per ship, operational efficiency is usually low. With 95% and 93% respectively, Maersk and MSC had the best compliance rates, suggesting effective BWT adoption and strong operational procedures (Smit et al., 2019; Wang et al., 2021). At 75%, XYZ Shipping has the lowest compliance rating, which emphasizes important operational difficulties and possible regulatory non-compliance (Jones, 2020).

Evergreen shows less energy usage per ship, according to studies on energy consumption, which points to more effective energy use. With the highest energy consumption—6000 kWh—XYZ Shipping may have inefficiencies related to outdated or less effective BWTs (Smith, 2018). Evergreen and Hapag-Lloyd have rather low maintenance expenses, which point to efficient maintenance plans (Liu & Wu, 2017). Operating efficiency depends much on downtime. With 2.25 hours of downtime per ship, XYZ Shipping suffers the most disturbance of operations and higher costs (Jones, 2020). On the other hand, Maersk and Evergreen's (Smit et al., 2019) low downtime has resulted from better maintenance methods and system dependability. Operation efficiency depends critically on training hours. MSC makes large personnel training (450 hours) investments, which line well with operational efficiency and good compliance (Wang et al., 2021). But XYZ Shipping spends the least in training—200 hours—which shows in its reduced operating efficiency (Smith, 2018). The literature points up several areas for possible development: additional training hours, better crew training, energy audits, preventative maintenance schedules, more efficient spare part management (Liu & Wu, 2017).

Maximizing the advantages of BWTS and quick problem addressing depend on performance monitoring and operational optimization (Smit et al., 2019). Simplifying ballast water control techniques can help to increase operational compliance and efficiency even more (Wang et al., 2021). Finally, the study of the literature exposes notable trends and areas for development among different shipping firms. Stressing enhanced staff training, energy economy, proactive maintenance, and operational optimization can help to raise general efficiency, lower running costs, and increase compliance rates. By means of more adherence to international norms for ballast water management, these approaches will produce higher environmental protection (Smith, 2018; Liu & Wu, 2017; Jones, 2020).

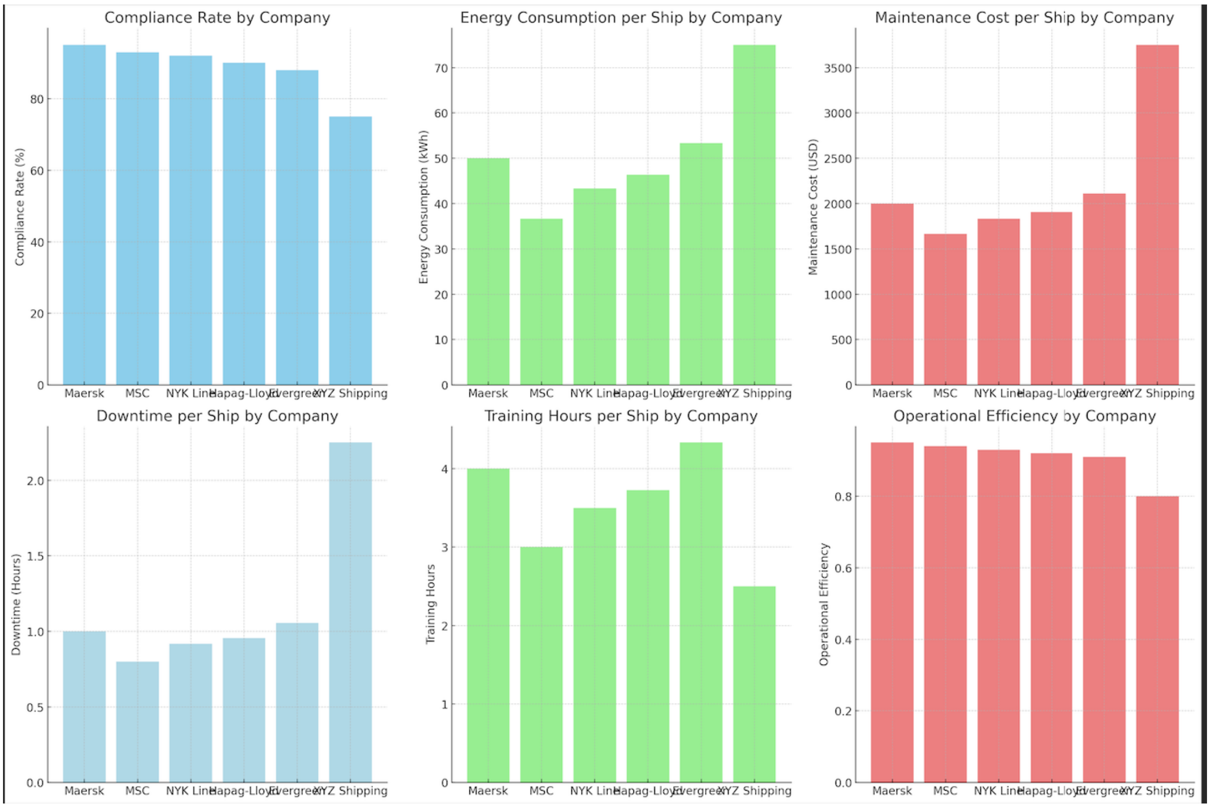


Figure 4 : Compliance Rate, Energy Consumption, Maintenance cost, Operational Efficiency & other factors per company , Source **Smit, T., Jones, L., Wang, Q. and Smith, A.,** 2019.

The most important operational data for Ballast Water Treatment Systems (BWTS) used by different shipping companies are visually shown in the charts included in this book. With 95% and 93% respectively, Maersk and MSC are the companies with highest rates of compliance. With a 75% compliance rate, XYZ Shipping has the lowest compliance rate and shows major problems with its capacity to follow legal criteria.

While XYZ Shipping consumes the most energy worldwide, Evergreen boasts the lowest overall energy consumption per ship. Lloyd's comparatively low maintenance costs per ship help to explain their lowest costs overall. XYZ Shipping's highest maintenance costs per ship point to possible problems with the dependability of the system.

Evergreen and Maersk, reflecting effective maintenance techniques, experience the most downtime per ship. But XYZ Shipping has the most downtime per ship, which disturbs their business. MSC, linked with great compliance and extraordinary operational efficiency, is the company that spends the most in crew training hours per ship. With the lowest investment in training hours per ship, XYZ Shipping most certainly causes operational problems.

Supported by strong compliance rates and efficient BWTs, Maersk and MSC both have the highest operational efficiency. With the lowest operational efficiency, XYZ Shipping shows great room for development in its business practices.

Finally, the charts show the variations in BWTS performance measures among several companies visually. Businesses such as Maersk and MSC who make more training and maintenance investments show better degrees of operational efficiency and compliance rates. Lower investment in training has a negative correlation with lower compliance and efficiency as well as with higher expenses connected with downtime and maintenance. Targeted investments in crew training, preventative maintenance, and energy efficiency are absolutely necessary if BWTS is to have better general performance.

7. Conclusion

7.1 Summary of Findings

This study presents information on compliance rates, operational efficiency, energy consumption, maintenance costs, and the value of crew training in Ballast Water Treatment Systems (BWTS) among different shipping companies. With rates of 95% and 93%, Maersk and MSC show successful application of BWTS and regulatory compliance by the IMO and USCG. With a 75% compliance rate, XYZ Shipping has the lowest operational and technical capacity indicating major difficulties.

Strong training programs, proactive maintenance, and frequent maintenance to stop system failures and preserve continuous compliance with ballast water discharge criteria help to explain high compliance rates. Evergreen indicates effective BWTs by showing the lowest energy consumption per ship. With the highest energy consumption per ship—6000 kWh—XYZ Shipping indicates inefficiencies resulting from either outdated technology or inadequate system integration. Frequent energy audits and expenditures in energy-efficient technologies can help to lower environmental impact and save costs.

While XYZ Shipping has the toughest maintenance load, Evergreen and Hapag-Lloyd show cost-effective operations. By means of proactive maintenance strategies, one can avoid unexpected breakdowns and reduce long-term maintenance expenses. Through continuous technical support and maintenance services, close ties with BWTS vendors help to increase system dependability.

While XYZ Shipping has the highest downtime per ship, which causes major operational disruptions and non-compliance, minimized downtime is noted in Evergreen and Maersk. Real-time monitoring systems and good scheduling can help to lower system outage.

Ultimately, the study emphasizes how crucial crew training, smooth operations, and smart maintenance plans are to preserving BWTs compliance.

The study emphasizes for crew members of different shipping firms the need of training in ballast water systems (BWTS). MSC spends the most in crew training hours per ship, which guarantees great operational effectiveness and compliance. XYZ Shipping does, however, have the lowest investment in training hours per ship, which would cause operational problems and reduced compliance ratings. Improved training programs including more training hours and frequent updates should help to raise operational efficiency and compliance rates.

Supported by strong compliance and efficient BWTs management, Maersk and MSC show the highest operational efficiency, so reflecting the effectiveness of daily operations. With the lowest operational efficiency, XYZ Shipping shows room for development in operational techniques. To increase compliance and efficiency, recommendations call for data analytics-based performance monitoring and streamlining of ballast water management related operations.

Detailed case studies reveal that thorough planning, extensive training, constant monitoring, tailored BWTs installations, regulatory engagement, and operational flexibility helped BWTs be successful. Still, non-compliance resulted from technical problems, operational mistakes, and poor maintenance schedules.

Pre-treatment systems, thorough training, and consistent maintenance schedules all need work if we are to meet these challenges. While thorough training lowers operating errors and increases system dependability, effective pre-treatment systems enable the management of high sediment loads. Frequent maintenance plans can help BWTs components last longer and help to avoid system failures.

Finally, the study emphasizes the need of high compliance rates, energy efficiency, preventative maintenance, and thorough crew training for effective BWTS application. Businesses such as Maersk and MSC show best practices in these spheres, which results in great operational effectiveness and regulatory compliance. The problems of XYZ Shipping draw attention to the need of fixing technical, operational, and maintenance aspects to improve general performance.

7.2 Recommendations: Provide actionable recommendations for shipping companies regarding BWT system selection, installation, and operation.

In this section, recommendations are provided to shipping companies regarding the selection of ballast water treatment systems (BWTS), as well as their installation and operation. On the basis of the findings and analysis that were conducted, the recommendations were developed.

The first thing that needs to be done is to assess the operational routes of the ship, taking into account the different salinity, temperature, and water quality variations. In the process of selecting a BWTS, it is important to take into consideration the capacity of the bottle to hold blast water. The management of ballast water production can be effectively accomplished through the utilization of cutting-edge technology, such as filtration and ultraviolet light or filtration and electrolysis. There is also a recommendation for energy-efficient systems that have a lower overall energy consumption.

It is of the utmost importance to select a trustworthy provider who possesses a solid reputation and prior experience in the maritime industry. Providing comprehensive after-sales support, which should include training and maintenance services, is something they should offer.

The manufacturing of the system is the second factor to take into consideration. In order to determine the requirements and develop individualized installation plans that are tailored to each vessel's specific configuration and constraints, it is necessary to conduct a comprehensive survey of the vessel. The integration process ought to be straightforward and uncomplicated, with the goal of ensuring that the BWTS can be seamlessly integrated into the ship's existing systems without causing any confusion or complications.

It is important to schedule installations in order to minimize disruptions and to carry out routine maintenance or dry-docking in order to reduce the amount of time spent on operational tasks. It is recommended that installation teams consisting of skilled individuals who are familiar with BWTS be utilized in order to ensure proper installation and integration. It is essential to implement stringent quality control measures during the installation process in order to guarantee that all components are installed correctly and are functioning in accordance with their intended capacities.

The conclusion is that shipping companies ought to take into consideration these recommendations in order to enhance the selection, installation, and operation of BWTS machines. Shipping companies can improve their operations and reduce the costs associated with BWTS if they adhere to these recommendations.

The text emphasizes the significance of making investments in comprehensive training programs for the crew in order to guarantee the correct operation and maintenance of Ballast Water Treatment Systems (BWTS). To ensure that the crew is always up to date on the most recent technologies and procedures, it is essential to provide them with regular training and refresher courses. To prevent unanticipated system breakdowns, ensuring timely repairs, and reducing downtime, it is essential to have a proactive maintenance schedule. Monitoring systems that operate in real time can assist in the early detection of potential problems.

An analysis of the data and the identification of patterns that can be used to improve the administration and maintenance of the system are both possible applications of data analytics. Compliance with government regulations is also extremely important, as the International Maritime Organization (IMO), the United States Coast Guard (USCG), and regional authorities are the entities that are responsible for imposing regulations on the management of ballast water as well. Compliance with regulatory inspections and the maintenance of accurate documentation are both essential, and audits can be carried out in a variety of ways, including through routine internal audits or through independent third-party examinations.

The development and dissemination of new technologies, such as hybrid systems that combine multiple treatment methods for improved performance and reliability, is the fifth topic of interest. Some examples of these technologies include hybrid systems. In order to stay abreast of developing technologies, such as advanced oxidation processes and systems enhanced by nanotechnology, it is essential to maintain a current perspective. It is necessary to conduct facility studies in relation to retrofitting older vessels with contemporary and effective BWTS in order to evaluate the potential benefits and ensure that the project is financially feasible.

In order to facilitate the effective management of ballast water, future considerations should include the implementation of comprehensive training programs, proactive maintenance schedules, and continuous performance monitoring. Not only will this protect the maritime industry, but it will also protect the ecological system.

As a conclusion, shipping companies can enhance the process of selecting, installing, and operating BWTS by immediately adhering to these recommendations from the beginning. This will result in increased operational efficiency, decreased impact on the environment, and a contribution to the preservation of marine ecosystems. Additional support for the effective management of ballast water can be provided through the implementation of comprehensive training programs, proactive maintenance schedules, and continuous performance monitoring. This will protect not only the maritime industry but also the ecological system.

7.3 Future Trends: Discuss anticipated future developments in BWT technology and regulation.

Policy Implications: Reflect on the implications of the research for policymakers and regulators.

It is expected that the field of ballast water treatment technology and regulation will experience major advancements and policy consequences not too far in future. One instance of these advances is the creation of hybrid systems combining several treatment approaches including chemical disinfection, UV light, and filtration. Performance and dependability of these hybrid systems are enhanced. Advanced oxidation processes, sometimes referred to as AOPs, are expected to generate strong oxidants capable of efficiently eradicating dangerous organisms, so improving the efficacy of boiler water treatment systems (BWTS).

By means of nanoparticle-based filtration and disinfection, among other nanotechnology applications in BWTS, the elimination and inactivation of pathogens could be enhanced while concurrently reducing the energy consumption. Improved sensor and monitoring systems—such as real-time monitoring—will enable constant assessments of the BWTS's performance, so guaranteeing compliance and optimizing operational effectiveness. Algorithms for artificial intelligence and machine learning will probably be merged to maximize BWTs operations, forecast maintenance needs, and automatically change system parameters so attaining exceptional performance.

Important factors influencing the evolution of technology for the future treatment of ballast water are also sustainability and energy economy. Research and development efforts will mostly center on the development of low-energy BWTs, which will finally help to lower energy consumption and save costs. Environmentally friendly treatment techniques should become more common as environmental awareness keeps rising and regulatory pressures keep mounting.

Because modular BWTs offer chances for flexibility and effective cost control, it is expected that they will grow more common. Thanks to developments in extremely efficient and small systems, retrofitting older vessels will be easier. This will also make it less challenging to include these systems into vessels with constrained capacity for space.

The future of ballast water treatment technology and control will ultimately define major technological developments and trends as defining feature. If the sector gives hybrid systems, advanced oxidation techniques, and environmentally friendly technologies more more importance, it is likely that its performance and sustainability will keep developing.

Public policy has consequences for ballast water treatment systems (BWTs) in terms of harmonizing rules, supporting regional cooperation, fostering innovation, and so developing capabilities and training capacity. Global standards should be harmonized if we are to ensure consistency and lower the degree of complexity for shipping firms worldwide. By means of regional cooperation, it is feasible to enable the exchange of best practices, resources, and technologies, so promoting a more successful application of BWTS strategies.

Governments and regulatory agencies should grant incentives for research and development in advanced BWTS technologies. Grants, tax breaks, or public sector-private sector alliances could all be among these incentives. By proving their efficacy and dependability in conditions that reflect the real world, new technologies can be validated by means of pilot programs and trials of innovative BWTS.

Strengthening compliance and enforcement policies will help to safeguard marine ecosystems by means of strict inspection procedures. Penalties should be enforceable and not difficult to understand in order to discourage violations and inspire compliance with rules. To satisfy international standards for the management of ballast water, developing nations and smaller shipping companies can get further help in the form of technical assistance.

Continuous monitoring of marine ecosystems helps one assess the effectiveness of BWTS rules and safeguard the environment as well as human health. Public health must be taken into account to ensure BWTS technologies do not release possibly hazardous chemicals or byproducts into the marine environment.

To reach their objectives, future developments in BWTS technology will focus on improving efficiency, dependability, and environmental sustainability. Driving forces behind this development will be innovations in hybrid systems, advanced oxidation techniques, nanotechnology, sensor and monitoring systems, and BWTS development. Important roles that legislators play in the process of enabling these several developments are those of supporting policies for research and development, provision of incentives for research and development, and building strong legislative frameworks. This thus ensures the efficient management of ballast water, so preserving marine ecosystems and public health overall.

The results of this research show the important part BWTS performs in simultaneously protecting marine environments and stopping the spread of invading species. Strong regulatory frameworks and ongoing innovation help to support efficient system selection, installation, and operation—qualities necessary for achieving worldwide compliance. Shipping firms must make investments in training, maintenance, and technology upgrades if BWTs is to perform as expected. Policymakers should help these initiatives by implementing supportive laws with incentives.

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Annex

Latest Information of Approval of Ballast Water Management System (BWMS Code MEPC300(72))

ClassNK EQD
as of 20 February 2024

No	Ballast Water Management System					Approval Information		
						Approval of Active Substances G9 (MEPC169(57)) Approval given by IMO		Approval of BWMS / BWMS Code (MEPC300(72)) Approval given by the Administration
	BWMS Manufacture	BWMS Name	Country	Process	Capacity of Approved BWMS	Basic Approval	Final Approval	
1	DESMI Ocean Guard A/S	CompactClean CC	Denmark	Filteration + UV	35 – 3,000 m^3/h	N.A.	N.A.	Approved (Denmark)
2	BAWAT A/S	BAWAT BWMS Mk2	Denmark	heat (pasteurization)	50 – 5,000 m^3/h	N.A.	N.A.	Approved (Denmark)
3	Team Tec Ocean saver	Oceansaver BWTS MKIIB	Norway	Filtration + electrolytic chlorination	200 – 7,200 m^3/h	Approved	Approved	Approved (Norway)
4	Calgon Carbon UV Technologies LLC, d/b/a Hyade Marine	Hyde GUARDIAN-US (model range HG60U to HG3000U)	USA	Filtration + UV	60 – 3,000 m^3/h	N.A.	N.A.	Approved (Norway)
5	MIURA CO., LTD.	Miura BWMS HK	Japan	Filtration + UV	160 – 6,000 m^3/h	N.A.	N.A.	Approved (Japan)
6	Shanghai Electric Cyeco Environmental Technology Co., Ltd.	Cyeco™	China	Filtration + UV	200 – 6,000 m^3/h	N.A.	N.A.	Approved (China(CCS))
7	Alfa Laval Tumba AB	PureBallast 3.2/ PureBallast 3.2 Compact flex	Sweden	Filtration + UV	85 – 3,000 m^3/h	N.A.	N.A.	Approved (Vietnam(VR))
8	De Nora Marine Technologies, LLC	BALPURE®	USA	Filtration + electrolytic chlorination	400 – 8,570 m^3/h	Approved	Approved	Approved (United Kingdom)
9	Thao Linh Development Maritime Technology Co., Ltd.	TLC-BWM	Vietnam	Filtration + UV	50 – 500 m^3/h	N.A.	N.A.	Approved (Vietnam(VR))
10	Scienco/FAST, a subsidiary of BioMicrobics, Inc.	inTank BWTS	USA	Electrolytic chlorination + Sodium hypochlorite	up to 200,000 m^3 in 36 to 168 hours	Approved	Approved	Approved (Norway)
11	oneTank, LLC	oneTank	USA	Sodium hypochlorite	up to 4,000 m^3/ ballast water tank	Approved	Approved	Approved (Norway)
12	Headway Technology Group (Qingdao) Co., Ltd	OceanGuard® BWMS	China	Filtration + electrocatalysis	65 – 5200 m^3/h	Approved	Approved	Approved (Norway)
13	Optimarin AS	Optimarin Ballast System	Norway	Filtration + UV	72 – 3,000 m^3/h	N.A.	N.A.	Approved (Norway)

14	Wartsila Water Systems Ltd	Wärtsilä Aquarius UV BWMS	UK	Filtration + UV	50 – 1,000 m^3/h	N.A.	N.A.	Approved (Norway)
15	BIO-UV Group	BIO-SEA® BWTS	France	Filtration + UV	30 – 2,100 m^3/h	N.A.	N.A.	Approved (France)
16	Sembcorp Marine	Semb-Eco BWMS	Singapore	Filtration + UV	500 m^3/h	N.A.	N.A.	Approved (Singapore)
17	JFE Engineering Corporation	JFE Ballast Ace	Japan	Filtration + sodium hypochlorite	500 – 4,000 m^3/h	Approved	Approved	Approved (Japan)
18	Techcross Inc.	ECS-HYCHLOR™ BWMS	Korea	Filtration + electrolysis	300 – 8,000 m^3/h	Approved	Approved	Approved (Norway)
19	Ecochlor, Inc.	Ecochlor® BWMS	USA	Filtration + chlorine dioxide	50 – 16,200 m^3/h	Approved	Approved	Approved (Norway)
20	Wartsila Water Systems Ltd	Wärtsilä Aquarius EC BWMS	UK	Filtration + electrolysis	250 – 4,000 m^3/h	Approved	Approved	Approved (Norway)
21	Panasonic Environmental Systems & Engineering Co., Ltd.	ATPS-BLUEsys BWMS	Japan	Electrolysis/electrochlorination and stirring	150 – 3,600 m^3/h	Approved	Approved	Approved (Norway)
22	SKF Marine GmbH	SKF BlueSonic BWMS	Germany	Filtration + UV + US	100 – 1,500 m^3/h	N.A.	N.A.	Approved (Norway)
23	Elite Marine Corporation	Seascape BWMS	China	Filtration + UV	80 – 5,000 m^3/h	N.A.	N.A.	Approved (Norway)
24	Norwegian Greentech AS	NGT BWMS	Norway	Filtration + UV	30 – 1,274 m^3/h	N.A.	N.A.	Approved (Norway)
25	TeamTec BWMS AS	Senza BWMS	Norway	Injection of biocide	375 – 3,750 m^3/h	Approved	Approved	Approved (Norway)
26	Trojan Technologies	Trojan Marinex BWT™	Canada	Filtration + UV	150 – 1,500 m^3/h	N.A.	N.A.	Approved (Norway)
27	Yixing PACT Environmental Technology Co., Ltd. Shanghai Branch	PACT marine BWMS	China	Filtration + UV	200 – 4,000 m^3/h	N.A.	N.A.	Approved (China(CCS))
28	Shanghai LEE's FUDA Electromechanical Technology Co., Ltd.	LeesGreen® BWMS	China	Filtration + UV	150 – 1,500 m^3/h	N.A.	N.A.	Approved (China(CCS))
29	Shanghai Electric Cyeco Environmental Technology Co., Ltd.	Cyeco BWMS	China	Filtration + UV	200 – 6,000 m^3/h	N.A.	N.A.	Approved (China(CCS))
30	Knutsen Ballast Water AS	KBAL BWMS	Norway	UV	400 – 3,000 m^3/h	N.A.	N.A.	Approved (Norway)
31	Wuxi Brightsky Electronic Co., Ltd.	BSKY™ BWMS	China	Hydrocyclone Prefilter + Ultrasonic + UV	80 – 6,000 m^3/h	N.A.	N.A.	Approved (China(CCS))
32	Evoqua Water Technologies Ltd	SeaCURE BWMS	USA	Filtration + electrolytic chlorination	50 – 6,000 m^3/h	Approved	Approved	Approved (Liberia)

33	Kuraray Co., Ltd.	MICROFADE II BWMS	Japan	Filtration + chemical injection	250 – 2,000 m^3/h	Approved	Approved	Approved (Netherlands)
34	Atlantium Technologies Ltd.	Atlantium Purestream™ BWMS	Israel	Filtration + UV	10 – 1,500 m^3/h	N.A.	N.A.	Approved (Norway)
35	TECHCROSS Inc.	Electro-Cleen™ System	Korea	Electrolysis	150 – 12,000 m^3/h	Approved	Approved	Approved (Korea)
36	HANLA IMS Co., Ltd.	EcoGuardian™ BWMS	Korea	Filtration + electrolytic chlorination	130 – 4,000 m^3/h	Approved	Approved	Approved (Korea)
37	Jiangsu Nanji Machinery Co., Ltd.	NiBallast™ BWMS	China	Filtration + membrane separation + deoxygeneration	50 – 4,000 m^3/h	N.A.	N.A.	Approved (China(CCS))
38	RWO GmbH	CleanBallast – Ocean Barrier System BWMS	Germany	Filtration + electrolytic chlorination	500 – 3,000 m^3/h	Approved	Approved	Approved (Norway)
39	ERMA FIRST ESK ENGINEERING SOLUTIONS S.A.	ERMA FIRST BWTS FIT	Greece	Filtration + electrolytic chlorination	90 – 3,740 m^3/h	Approved	Approved	Approved (Greece)
40	Langh Tech Oy Ab	LanghBW	Finland	Filtration + UV	300 – 600 m^3/h	N.A.	N.A.	Approved (Finland)
41	Hyundai Heavy Industries Co., Ltd.	HiBallast NF™	Korea	Electrolytic chlorination	75 – 10,000 m^3/h	Approved	Approved	Approved (Korea)
42	AQUASTAR CO., LTD.	AQUASTAR™	Korea	Pipe unit + Electrolysis	200 – 2,600 m^3/h	Approved	Approved	Approved (Korea)
43	SAMKUN CENTURY Co., Ltd.	ARA Plus BWMS	Korea	Filtration + UV	150 – 1,300 m^3/h	N.A.	N.A.	Approved (Korea)
44	NK Co., Ltd	BlueBallast II Plus NK-O3	Korea	Ozonation	200 – 8,000 m^3/h	Approved	Approved	Approved (Liberia)
45	Knutsen Ballast Water AS	One-Pass Mode of the KBAL BWMS	Norway	UV	400 – 3,000 m^3/h	N.A.	N.A.	Approved (Norway)
46	TECHCROSS Inc.	ECS-HYCHLOR 2.0 BWMS	Korea	Electrolysis	250 – 8,000 m^3/h	Approved	Approved	Approved (United Kingdom)
47	Rahavaran Ayandeh Darya Company	RADClean® BWMS	Iran	Filtration + electrolytic chlorination	150 – 4,000 m^3/h	Approved	Approved	Approved (Iran)
48	Sembcorp Marine	Semb-Eco BWMS	Singapore	Filtration + UV	250 – 1,500 m^3/h	N.A.	N.A.	Approved (Singapore)
49	Shanghai Electric Cyeco Environmental Technology Co., Ltd.	Cyeco BWMS	China	Filtration + UV	200 – 1,600 m^3/h	N.A.	N.A.	Approved (Norway)
50	SunRui Marine Environment Engineering Co., Ltd.	BalClor® Smart BWMS	China	Electrolysis	130 ~ 150 – 6,500 ~ 7,200 m^3/h	Approved	Approved	Approved (Denmark)

Latest Information of Approval of Ballast Water Management System (G8 MEPC279(70))

No	Ballast Water Management System					Approval Information		
						Approval of Active Substances G9 (MEPC169(57)) Approval given by IMO		Approval of BWMS / G8 (MEPC279(70)) Approval given by the Administration
	BWMS Manufacture	BWMS Name	Country	Process	Capacity of Approved BWMS	Basic Approval	Final Approval	
1	Alfa Laval Tumba AB	PureBallast 3.2/ PureBallast 3.2 Compact flex	Sweden	Filtration + UV	85 – 3,000m³/h	N.A.	N.A.	Approved (Norway)
2	Envirocleanse LLC	Envirocleanse inTank Electrochlorination (EC) BWTS	USA	electrolytic chlorination	up to 200,000 m³ in 36 to 168 hours	Approved	Approved	Approved (Norway)
3	Hyundai Heavy Industries Co., Ltd.	HiBallast™ BWMS	Korea	Filtration + electrolytic chlorination	75 – 10,000m³/h	Approved	Approved	Approved (Norway)
4	SunRui Marine Environment Engineering Co.,Ltd.	BalClor ® BWMS	China	Filtration + electrolytic chlorination	170 – 8500 m³/h	Approved	Approved	Approved (Norway)
5	Qingdao Headway Technology Co., Ltd	OceanGuard® BWMS	China	Filtration + electrolytic chlorination	65 – 5200 m³/h	Approved	Approved	Approved (Norway)
6	ERMA FIRST ESK ENGINEERING SOLUTIONS S.A.	ERMA FIRST BWMS FIT	Greece	Filtration + electrolytic chlorination	90 – 3,740m³/h	Approved	Approved	Approved (Greece)
7	COSCO (Weihai) Shipbuilding Marine Technology Co., Ltd.	Blue Ocean Shield BWMS	China	Filtration + UV	100 – 3,200m³/h	N.A.	N.A.	Approved (Norway)
8	Panasia Co., Ltd	GloEn-Patrol 2.0	Korea	Filtration + UV	50 – 6,000m³/h	N.A.	N.A.	Approved (Norway)

Latest Information of Approval of Ballast Water Management System (G8 MEPC174(58))

No	Ballast Water Management System					Approval Information		
						Approval of Active Substances G9 (MEPC169(57)) Approval given by IMO		Approval of BWMS G8 (MEPC174(58)) Approval given by the Administration
	BWMS Manufacture	BWMS Name	Country	Process	Capacity of Approved BWMS	Basic Approval	Final Approval	
1	Alfa-Laval AB	PureBallast	Sweden	Filtration + UV/TiO2	250 – 3,000m³/h	Approved	Approved	Approved (Norway)
2	Ocean Saver AS	OceanSaver BWTS Mark I	Norway	Filtration + Deoxygenation + Cavitation+ Electrodialytic Disinfection	40 – 10,000m³/h	Approved	Approved	Approved (Norway)
3	Ocean Saver AS	OceanSaver BWTS Mark II	Norway	Filtration + Electrodialytic Disinfection	200-4600m³/h	Approved	Approved	Approved (Norway)
4	Optimarin AS	Optimarin Ballast System	Norway	Filtration + UV	21 – 5,400m³/h	N.A.	N.A.	Approved (Norway)
5	Hamann AG / Degussa GmbH (withdrawn from the market)	SEDNA BWMS	Germany	Filtration + Peracetic acid	50 – 1,000m³/h	Approved	Approved	Approved (Germany)
6	Mitsui Engineering & Shipbuilding Co.,LTD.	FineBallast OZ	Japan	Cavitation(by high shear) + Ozonation	75 – 300m³/h	Approved	Approved	Approved (Japan)
7	Mitsui Engineering & Shipbuilding Co.,LTD.	FineBallast MF	Japan	Membrane filter	50 – 900m³/h	N.A.	N.A.	Approved (Japan)
8	Hitachi Plant Technologies, Ltd.	ClearBallast	Janan	Filtration + pre-coagulant (enhanced flocculation)	200 – 2,400m³/h	Approved	Approved	Approved (Japan)
9	JFE Engineering Corporation	JFE BallastAce	Japan	Filtration + Chlorination + Cavitation	17.5 – 4,500m³/h	Approved	Approved	Approved (Japan)

10	TECHCROSS INC	Electro-Cleen System	Korea	Electrolysis/Electrochlorination	300㎥/h –	Approved	Approved	Approved (Korea)
11	RWO	CleanBallast	Germany	Filtration + Electrolysis/Electrochlorination	150 – 2,500㎥/h	Approved	Approved	Approved (Germany)
12	NEI Treatment Systems, LLC	Mitsubishi VOS System	USA	Deoxygenation + Cavitation	300 – 6,800㎥/h	N.A.	N.A.	Approved (Liberia)
13	NK CO., LTD.	NK-O3 Blue Ballast System	Korea	Ozonation	125x2 – 4,000x2㎥/h	Approved	Approved	Approved (Korea)
14	Ecochlor, INC.	Ecochlor BWT System	USA	Filtration + CLO2	250 – 16,000㎥/h	Approved	Approved	Approved (Germany)
15	Resource Ballast Technologies (Pty.) Ltd.	Resource Ballast Water Treatment System	South Africa	Filtration + Cavitation + Ozonation + Electrolysis/Electrochlorination	100 – 4,000㎥/h	Approved	Approved	Approved (South Africa)
16	PANASIA CO., LTD.	GloEn-Patrol	Korea	Filtration + UV	150 – 6,000㎥/h	Approved	Approved	Approved (Korea)
17	Hamworthy Greenship B.V.	Greenship Sedinox Ballast Water Management System	Netherlands	hydrocyclone + electrolytic chlorination		Approved	Approved	*Not yet*
18	COSCO Shipbuilding Industrial Campany	Blue Ocean Shield	China	UV treatment + Filter system	100 – 3,500㎥/h	Approved	N.A.	Approved (China(CCS))
19	Hyundai Heavy Industries Co. Ltd.	EcoBallast	Korea	UV treatment + Filter system	600 – 1,000㎥/h	Approved	Approved	Approved (Korea)
20	GEA Westfalia Separator Group Gmbh	Ballast Master ultraV	Germany	UV radiation + Ultrasonic oscillation	under investigation	Approved	N.A.	Approved (Germany)
21	Evoqua Water Technologies LLC	SeaCURE BWMS SC-1500/1	Germany	Filter + Electrolysis	300 – 4,000㎥/h	Approved	Approved	Approved (Germany)
22	MAHLE Industrial Filtration	Ocean Protection System	Germany	Filter + UV Treatment	250㎥/h	N.A.	N.A.	Approved (Germany)
23	Hyde Marine Inc.	Hyde GUARDIAN	U.S.A	Filter + UV Treatment	60 – 6,000㎥/h	N.A.	N.A.	Approved (UK)
24	SunRui Marine Environment Engineering Company	BalClor BWMS	China	Filter + Electrolysis	100 – 7,000㎥/h	Approved	Approved	Approved (China(CCS))
25	DESMI Ocean Guard A/S	DESMI Ocean Guard Ballast Water Treatment System (discontinued item)	Denmark	Filter + UV＋Ozone	75 – 3,000㎥/h	Approved	Approved	Approved (Denmark)
26	SAMKUN CENTURY Co., Ltd.	ARA PLASMA BWTS	Korea	Filter + UV + Plasma	150 – 2,600㎥/h	Approved	Approved	Approved (Korea)
27	Hyundai Heavy Industries Co. Ltd.	HiBallast	Korea	Filtration + Electrolysis/Electrochlorination	75 – 2,000㎥/h	Approved	Approved	Approved (Korea)
28	Kwang San Co. Ltd.	En-Ballast System	Korea	Filter + Electrolysis		Approved	*Not yet*	*Not yet*
29	Qingdao Headway Technology Co., Ltd.	OceanGuard BWTS	China	Filtration + electrocatalysis	50 – 9,350㎥/h	Approved	Approved	Approved (Norway)
30	Wuxi Brightsky Electronic CO., Ltd.	BSKY BWMS	China	Hydrocyclone Prefilter + Ultrasonic + UV	100 – 6,000㎥/h	N.A.	N.A.	Approved (China(CCS))
31	Severn Trent DeNora	BalPure BWMS	USA	Filter + Electrolysis	up to 500㎥/h	Approved	Approved	Approved (Germany)

32	Samsung Heavy Industries Co., Ltd.	Purimar System	Korea	Filter + Electrolysis	250 – 6,500m³/h	Approved	Approved	Approved (Korea)
33	AQUA Eng. Co., Ltd.	AquaStar BWMS	Korea	Pipe unit + Electrolysis	200 – 5,000m³/h	Approved	Approved	Approved (Korea)
34	Kuraray Co., Ltd.	MICROFADE	Japan	Filter + Calcium hypochlorite	125 – 4,000m³/h	Approved	Approved	Approved (Japan)
35	JFE Engineering Corporation	JFE BallastAce (NEO-CHLOR MARINE)	Japan	Filtration + Chemical Injection	17.5 – 4,500m³/h	Approved	Approved	Approved (Japan)
36	NIPPON YUKA KOGYO CO., LTD.	SKY-SYSTEM (ex. BWMS with Peraclean Ocean(SKY-System))	Japan	Chemical Injection	25 – 34,000m³/h	Approved	Approved	Approved (Japan)
37	ERMA FIRST	ERMA FIRST BWMS	Greece	Filtration + hydrocyclone + electrolytic chlorination	50 – 3,000m³/h	Approved	Approved	Approved (Greece)
38	Envirotech and Consultancy Pte. Ltd.	BlueSeas BWMS	Singapore	Filter + Electrolysis		Approved	*Not yet*	*Not yet*
39	Envirotech and Consultancy Pte. Ltd.	BlueWorld BWMS	Singapore	Filtration + Chemical Injection		Approved	*Not yet*	*Not yet*
40	GEA Westfalia Separator Group Gmbh	Ballast Master ecoP	Germany	Filtration + Chemical Injection		Approved	*Not yet*	*Not yet*
41	Samsung Heavy Industries Co., Ltd.	SHI BWMS (Neo-Purimar)	Korea	Filteration + Chemical Injection		Approved	Approved	*Not yet*
42	Daliam Marine University	DMU OH BWMS	China	Filteration + Sodium subsulfite		Approved	*Not yet*	*Not yet*
43	Hanla IMS Co., Ltd.	EcoGuardian System	Korea	Filteration + Electrolysis	130 – 6000m³/h	Approved	Approved	Approved (Korea)
44	STX Metal Co., Ltd.	Smart Ballast BWMS	Korea	Electrolysis		Approved	Approved	*Not yet*
45	Jiujiang Precision Measuring Technology Research Institute	OceanDoctor	China	Filter + Photocatalytic	50–5,000m³/h	Approved	Approved	Approved (China(CCS))
46	HWASEUNG R&A Co. Ltd.	HS-BALLAST	Korea	Electrolysis		Approved	*Not yet*	*Not yet*
47	PANASIA Co., Ltd.	GloEn-Saver	Korea	Filter+Electrochlorination		Approved	*Not yet*	*Not yet*
48	Korea Top Marine (KT Marine) Co., Ltd.	MARINOMATE (ex. KTM-BWMS)	Korea	Plankill pipe+electrolyzer		Approved	Approved	*Not yet*
49	Wärtsilä Water Systems Ltd	AQUARIUS EC BWMS	Netherlands	Filter+Electrochlorination		Approved	Approved	*Not yet*
50	Shanghai Cyeco Environmental Technology Co., Ltd.	Cyeco Ballast Water Management System	China	Filter + UV	250 & 300m³/h	N.A.	N.A.	Approved (China(CCS))
51	Knutsen Ballatvann AS	KBAL Ballast Water Management System	Norway	UV	200 & 600m³/h	N.A.	N.A.	Approved (Norway)
52	AURAMARINE LTD.	CrystalBallast Ballast Water Management System	Finland	Filter + UV	21 – 1,500m³/h	N.A.	N.A.	Approved (Norway)
53	Van Oord B.V.	Van Oord Ballast Water Management System	Netherlands	Chlorine(Drinking water only)	450m³/h	Approved	Approved	Approved (Netherlands)
54	Redox Maritime Technologies AS	REDOX AS Ballast Water Management System	Norway	Filter + Ozone + UV		Approved	*Not yet*	*Not yet*

55	SUNBO INDUSTRIES Co. Ltd., DSEC Co. Ltd.	Blue Zone BWMS DNS 250	Korea	Ozone	250 – 6,000㎥/h	Approved	Approved	Approved (Korea)
56	Wärtsilä Water Systems Ltd	Wärtsilä AQUARIUS UV ballast water management system	Netherlands	Filter＋UV	50 – 1,000㎥/h	N.A.	N.A.	Approved (Netherlands)
57	BIO-UV SAS	BIO-SEA	France	Filter＋UV	75 – 2,000㎥/h	N.A.	N.A.	Approved (France(BV))
58	MMC Green Technology AS	MMC BWMS	Norway	Filter＋UV	150 & 300㎥/h	N.A.	N.A.	Approved (Norway)
59	Jiangsu Nanji Machinery Co., Ltd.	NiBallast BWMS	China	Filter＋ Micromembrane + Deoxygenation	200 – 1,500㎥/h	N.A.	N.A.	Approved (China(CCS))
60	Elite Marine Ballast Water Treatment System Corp.	Seascape Ballast Water Management System	China	Filter＋UV	200 – 4,000㎥/h	N.A.	N.A.	Approved (China(CCS))
61	Shanghai Hengyuan Marine Equipment Co., Ltd	HY-BWMS	China	Filter＋UV	200 ㎥/h	N.A.	N.A.	Approved (China(CCS))
62	Shanghai Jiazhou Environmental Mechanical & Electrical	BALWAT Ballast Water Management System	China	Under investigation	200 ㎥/h	N.A.	N.A.	Approved (China(CCS))
63	Azienda Chimica Genovese (ACG)	ECOLCELL BTs Ballast Water Management System	Italy	Filter＋ Electrochlorination		Approved	*Not yet*	*Not yet*
64	Panasonic Environmental Systems & Engineering Co., Ltd.	ATPS-BLUE sys (ATPS)	Japan	Electrochlorination	12 – 7200 ㎥/h	Approved	Approved	Approved (Japan)
65	Ecomarine Technology Research Association	ECOMARINE EC BWTS	Japan	Filter＋ Electrochlorination		Approved	Approved	*Not yet*
66	KURITA WATER INDUSTRIES LTD.	KURITA BWMS (KA)	Japan	Chemical Injection	50 – 10,500 ㎥/h	Approved	Approved	Approved (Japan)
67	Evonik Industries AG	Evonik Ballast Water Treatment System with PERACLEAN Ocean	Germany	Filter＋ Electrochlolorination		Approved	Approved	*Not yet*
68	MIURA Co., Ltd.	Miura BWMS	Japan	Filter＋UV	200 – 6000 ㎥/h	N.A.	N.A.	Approved (Japan)
69	SUMITOMO ELECTRIC INDUSTRIES, LTD. (withdrawn from the market)	ECOMARINE UV BWTS	Japan	Filter＋UV	100 – 1000 ㎥/h	N.A.	N.A.	Approved (Japan)
70	KALF Engineering Pte. Ltd.	ElysisGuard	Singapore	Filter＋ Electrochlolorination		Approved	*Not yet*	*Not yet*
71	Trojan Technologies	Trojan Marinex BWT Ballast Water Management System	Canada	Filter＋UV	150, 250, 500 ㎥/h	N.A.	N.A.	Approved (Norway)
72	Cathelco LTD	Cathelco Ballast Water Management System – A2	U.K.	Filter＋UV	200 ㎥/h	N.A.	N.A.	Approved (Germany)
73	Bawat A/S	Bawat BWMS	Denmark	Heat treatment + Oxygen stripping	N.A.	N.A.	N.A.	Approved (Denmark)
74	NK CO., LTD.,	NK-Cl Blue Ballast System	Korea	Chemical Injection		Approved	Approved	*Not yet*
75	TECHCROSS INC	ECS-HYCHLOR™ SYSTEM	Korea	Filter＋ Electrochlorination		Approved	Approved	*Not yet*
76	TECHCROSS INC	ECS-HYCHEM™ SYSTEM	Korea	Filter＋Chemical Injection		Approved	Approved	*Not yet*
77	TECHCROSS INC	ECS-HYBRID™ SYSTEM	Korea	Filter＋Chemical Injection + Electrochlorination		Approved	Approved	*Not yet*
78	KADALNEER TECHNOLOGIES PTE.LTD.	VARUNA	Singapore	Filter＋ Electrochlorination		Approved	*Not yet*	*Not yet*

79	Yixing PACT environmental Technology Co., Ltd.	PACT marineTM Ballast Water Management System	China	Filter＋UV	300m^3/h	N.A.	N.A.	Approved (China(CCS))
80	Coldharbour Marine Ltd.	Coldharbour GLDTM Ballast Water Management System, incorporating types SeaGuardianTM IGG500 to IGG6000	U.K.	Deoxygenation	Max. 6,000m^3/h	N.A.	N.A.	Approved (UK)
81	DESMI Ocean Guard A/S	Ray Clean^{TM} BWTS (End of sale)	Denmark	Filter + UV	75 – 3,000m^3/h	N.A.	N.A.	Approved (Denmark)
82	Ahead Ocean Technology (Dalian) Co., Ltd.	AHEAD-BWMS	China	Filter + UV	200 – 1500m^3/h	N.A.	N.A.	Approved (China(CCS))
83	Jiangsu Nanji Machinery Co., Ltd.	NiBallast Ballast Water Management System	China	Filter + membrane separation + de-oxygenation	200 – 4000m^3/h	N.A.	N.A.	Approved (China(CCS))
84	Zhejiang Yingpeng Marine Equipment Manufacturer Co. Ltd.	YP-BWMS ballast water management system	China	Filter + UV	300 – 1200m^3/h	N.A.	N.A.	Approved (China(CCS))
85	BIO-UV SAS	BIO-SEA® Ballast Water Treatment System	France	Filter + UV	30 – 87m^3/h	N.A.	N.A.	Approved (France)
86	Shanghai LEE's FUDA Electromechanical Technology Co. Ltd	LeesGreen	China	Filter + UV	250 – 1500m^3/h	N.A.	N.A.	Approved (China(CCS))
87	Yixing PACT environmental Technology Co., Ltd.	PACT Marine^{TM} Ballast Water Management System	China	Filter + UV	200 – 4000m^3/h	N.A.	N.A.	Approved (China(CCS))
88	Sembcorp Marine Reparis & Upgrades Pte. Ltd.	Semb-Eco LUV 500 & Semb-Eco LUV 1500	Singapore	Filter + UV	500m^3/h 1500m^3/h	N.A.	N.A.	Approved (Singapore(LR))
89	Sembcorp Marine Reparis & Upgrades Pte. Ltd.	Semb-Eco LUV 250 Semb-Eco LUV 750 Semb-Eco LUV 1000	Singapore	Filter + UV	250m^3/h 750m^3/h 1000m^3/h	N.A.	N.A.	Approved (Singapore(LR))
90	University of Strathclyde	ClearBal BWMS	Denmark	Chemical Injection + hydrocyclone + Filtration		Approved	*Not yet*	*Not yet*
91	Damen Green Solutions B.V.	Damen InvaSave 300	Netherlands	Filter + UV	300m^3/h	N.A.	N.A.	Approved (Netherlands)
92	Kashiwa Co., Ltd. and Kuraray Co., Ltd	MICROFADE II BWMS	Netherlands	Filter + Calcium hypochlorite		Approved	*Not yet*	*Not yet*
93	Envirocleanse, LLC	Envirocleanse inTank™ BWTS	Norway	Hypochlorous acid+ Hypobromous acid		Approved	*Not yet*	*Not yet*
94	Alfa-Laval AB	PureBallast 3.2	Sweden	Filtration + UV	32 – 3,000m^3/h	N.A.	N.A.	Approved (Norway)
95	ERMA FIRST	ERMA FIRST BWMS FIT	Greece	Filtration + electrolytic chlorination	75 – 3,000m^3/h	Approved	Approved	Approved (Greece)
96	Ecochlor, Inc.	Ecochlor® Ballast Water Management System	USA	Filtration + Chemical disinfection	75 – 16,200m^3/h	Approved	Approved	Approved (Norway)

Approved Ballast Water Management Systems by Country and Method" **Source**: ClassNK (2024) *Latest information of approval of Ballast Water Management System*