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Ballast Water Management Convention from Owner's Perspective

Diploma Thesis

Anastasia Megalokonomou (nm14046)

Division: Ship Design and Maritime Transport (SDMT)

Supervisor: Konstantinos I. Spyrou (Professor)

Co-supervisor: Eleftheria Iliopoulou (EDIP)

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Περίληψη

Για πολλά χρόνια, τα πλοία εκτελούσαν τα ταξίδια τους χρησιμοποιώντας το θαλασσινό νερό για να πετύχουν την απαραίτητη ισορροπία βάρους ώστε να φτάσουν στην επιθυμητή κατάσταση φόρτωσης, ευστάθειας, πρόωσης του πλοίου, βύθιση της έλικας και της πλώρης καθώς και για τη ρύθμιση της ταχύτητα λειτουργίας τους. Φόρτωναν βάρος σε ειδικές δεξαμενές των πλοίων για την επίτευξη επαρκούς ευστάθειας και έπειτα το ξεφόρτωναν είτε κατά τη διάρκεια του ταξιδιού – συνοδευόμενης και από της επαναφόρτωσης εν πλω -, είτε στο λιμάνι προορισμού τους. Αυτό το «βάρος» ονομάζεται *έρμα* και η εν λόγω διαδικασία *ερματισμός*.

Για πολλά χρόνια συνεχιζόταν αυτή η διαδικασία μέχρι που εντοπίστηκαν πολλά προβλήματα, προερχόμενα από την παρουσία στο έρμα των πλοίων ανεπιθύμητων οργανισμών όπως μικρόβια, βακτήρια, πλαγκτόν, ασπόνδυλα κ.λπ., όπως η μόλυνση του περιβάλλοντος, η διαταραχή των θαλάσσιων οικοσυστημάτων, η μετάδοση επικίνδυνων ασθενειών ανά τον κόσμο κ.α.. Γι' αυτό τον λόγο, ο Διεθνής Οργανισμός Ναυσιπλοΐας (International Maritime Organization - IMO), ένας πολυεθνικός, διακυβερνητικός Διεθνής Ναυτιλιακός Οργανισμός αρμόδιος για την ασφάλεια και την προστασία του θαλάσσιου περιβάλλοντος σε σχέση με ναυτιλιακές δραστηριότητες, επελήφθη για την αντιμετώπιση αυτών των προβλημάτων μέσω της Επιτροπής Προστασίας Θαλάσσιου Περιβάλλοντος (MEPC). Το αποτέλεσμα αυτών των συνεδριάσεων ήταν να επιφέρουν ως κανονισμό την ύπαρξη ενός συστήματος διαχείρισης έρματος πάνω σε κάθε πλοίο ώστε να καταστρέφονται οι μικροοργανισμοί που εμπεριέχονται σ' αυτό και να μένει μόνο «καθαρό» και «άκακο» νερό.

Σύμφωνα με τον κανονισμό κάθε πλοίο πρέπει να φέρει ένα σύστημα που να επεξεργάζεται το εισερχόμενο έρμα, να το αποθηκεύει στους ειδικούς χώρους και να ελέγχει την περιεκτικότητα σε μικροοργανισμούς –ή και να το επεξεργάζεται ξανά αν είναι απαραίτητο- πριν την αφερμάτωση. Υπάρχουν πολλές διαφορετικές τεχνολογίες που το επιτυγχάνουν αυτό, κάθε μία λειτουργώντας με διαφορετικό τρόπο έτσι ώστε να εξυπηρετείται κάθε πλοίο. Η επιλογή του κατάλληλου συστήματος εξαρτάται από διάφορους παράγοντες όπως ο τύπος πλοίου, η αναγκαία ποσότητα έρματος, το μέγεθος του πλοίου, τα νερά που πλέει αυτό το πλοίο (αλατότητα, κανονισμοί που ισχύουν κ.λπ.), η ισχύς που απαιτείται και η κατανάλωση του συστήματος καθώς και το κατά πόσο το σύστημα αυτό θα εγκατασταθεί εξ αρχής στο πλοίο – αφορά τα νέα πλοία που χτίζονται- ή αν θα είναι μέρος μετασκευής (retrofit).

Στην παρούσα εργασία αναλύονται όλες οι διαθέσιμες τεχνολογίες διαχείρισης έρματος, ο τρόπος λειτουργίας τους καθώς και η σύγκριση μεταξύ τους. Επιπλέον, αναφέρονται όλοι οι παράγοντες που παίζουν ρόλο στην διαδικασία επιλογής του κατάλληλου συστήματος. Ως εφαρμογή όλων των παραπάνω, η εργασία συμπεριλαμβάνει και μια συγκριτική αξιολόγηση δύο διαφορετικών συστημάτων διαχείρισης έρματος πάνω σε δύο υπάρχοντα αδελφά, δηλαδή όμοια, πλοία.

Τέλος, από τα συμπεράσματα αυτής της εργασίας παρέχονται πολλές χρήσιμες πληροφορίες αλλά και συμβουλές σε πλοιοκτήτες ως προς την επιλογή του κατάλληλου συστήματος, της διαδικασίας που πρέπει να ακολουθηθεί για να εγκριθεί ένα τέτοιο σύστημα καθώς και του χρονοδιαγράμματος που εμπεριέχει όλες τις διορίες από τους κανονισμούς ώστε ένας πλοιοκτήτης να προγραμματίσει σωστά τις απαραίτητες ενέργειες.

Abstract

For many years, the ships were sailing using seawater to achieve the necessary weight balance so they can reach the desired state of loading, stability, propulsion, sinking of the propeller and bow as well as to adjust the operating speed. This seawater was loaded into special tanks to achieve sufficient stability and then it was unloaded either during the voyage - accompanied by reloading at sea - or at their port of destination. This "weight" is called *ballast* and this process is called *ballasting*.

This process continued for many years until many problems were identified, arising from the presence of unwanted organisms such as germs, bacteria, plankton, invertebrates, etc. on the ballast. Such problems were environmental pollution, disturbance of marine ecosystems, transmission of many deadly diseases around the world etc. Therefore, the International Maritime Organization (IMO), which is responsible for the safety and environmental protection at sea, took action for resolving these issues, through its Committee for the Protection of the Marine Environment (MEPC), responsible for the prevention and control of ship-source pollution. The result of these conventions was to establish as a rule the existence of a ballast management system on each ship so that the microorganisms contained in it are destroyed and only "clean" and "harmless" water remains.

According to the regulation, each ship must have a system that performs a treatment on the incoming ballast, stores it in special tanks and checks the capacity in microorganisms - or performs the treatment again if necessary - before unloading. There are many different technologies that achieve this, each operating in a different way so that each ship is served. The choice of the appropriate system depends on various factors such as the type of ship, the required amount of ballast, the size of the ship, the waters in which this ship sails (salinity, applicable regulations, etc.), the power demand and the energy consumption of the system as well as whether this system will be installed on the ship from the beginning - it concerns the new building ships - or whether it will be part of a retrofit.

This thesis analyzes all the available ballast treatment technologies, how they operate and a comparison between them. In addition, all the factors included in the process of selecting the appropriate system are mentioned. As an application of all the above, the project includes a comparative evaluation of two different ballast treatment systems on two existing sister (similar) vessels.

Finally, the conclusions of this project provide a lot of useful information and advices for ship-owners regarding the selection of the appropriate system, the procedure that has to be followed for the approval of such a system, as well as the timetable containing all the deadlines derived from the regulations so that a ship-owner can properly plan the necessary actions.

1. INTRODUCTION

1.1 General

Developments in ship design and construction over several years, have led to the adjustment of the steel hulls of ships, allowing vessels to use water instead of solid materials as ballast. Ballast water is used for the stabilization of steel vessels at sea for more than 120 years. Water is pumped into the ballast tanks for the maintenance of safe operations, whilst cargo is being unloaded, and on the other hand it is discharged while cargo is being taken on board. Safety, weather conditions, the ship's load, and the route taken are the primary factors that determine how much ballast water is taken on board a vessel for a particular voyage. Further ballast is necessary for ships to sit lower in the water during stormy weather to avoid bottom impact from waves. Ballast water is also adjusted so as to balance the ship in order to consume less fuel during a long voyage. The advantages of this practice are:

a) Reduction of stresses on the hull,

b) Increased transverse stability,

c) Improved propulsion and maneuverability and

d) Compensated weight changes in cargo load levels and fuel consumption.

Among them, ballast water offered an easier ballast/ de-ballast procedure. Nonetheless it had a major problem which increased over the last few decades due to trades in the shipping world expanding in a large scale and vessel trips being multiplied. During ballasting and de-ballasting procedures, many invasive aquatic species were transported from one marine ecosystem to another and the effects have been devastating in many areas of the world. Some examples of such invasive species are:

i. Asian Kelp (Undaria pinnatifida)
ii. Cholera (Vibrio cholera)
iii. European Green Crab (Carcinus maenas)
iv. North Pacific Seastar (Asterias amurensis)

Australia and Canada experienced problems in the 1980s which were caused by such invasive species. In Europe and the rest of the world, studies on the dimension of the problem started at least a decade later. Commencing in the 1990s, international conventions and organizations - such as the United Nations' International Maritime Organization (IMO), responsible for the safety and security of global shipping and the prevention of marine pollution by ships - began to be concerned about and involved in the promulgation of regulatory frameworks to minimize the risks associated with the increasingly huge volumes of ballast water transfer (David, Gollasch, 2015).

The International Maritime Organization (IMO), the United Nations' specialized agency responsible for the safety and security of shipping and the prevention of marine pollution by ships, first responded to this issue by developing guidelines and recommendations aimed at minimizing the transfer of live organisms and pathogens by exchanging ballast water at sea, since prior experience has shown that ballast water exchange in deep waters reduces the risk of species transfers. At the same time, it was recognized that higher levels of protection could be reached with other protective measures e.g., through *ballast water treatment*. A self-standing international legal instrument for the regulation of ballast water management would be necessary to avoid regulatory action by national, provincial, or even local authorities. This could have resulted in a disintegrated management approach that had to be avoided by all means, especially for such an eminently cross-border industry like shipping.

Consequently, IMO developed the globally applicable *International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention)*, which was adopted in February 2004. This instrument enters into force 12 years after the date on which more than 30 nations, with combined merchant fleets not less than 35 % of the gross tonnage of the world's merchant shipping, have ratified it. (David, Gollasch, 2015). In the following years, that convention developed various regional regulations relative to ballast water requirements which had appliance on ships all over the world (IMO, 2020).

During the past two decades, tremendous progress had been made in research to understand both the importance of the vectors responsible for the transmission of organisms (including pathogens) across oceans, (creating serious concerns to maintain and sustain ecosystem integrity and ecosystem services) and the environmental risks associated with them. Multiple ballast water treatment systems have been developed, using different types of technology, which led to a wide range of choices for ship-owners along with a suitable treatment system for almost every type of vessel. The criteria to choose the best however, involves multiple factors, making the selection process a very difficult and extremely complicated case.

1.2 Objective Purpose

The purpose of this thesis is to assist any ship-owner in selecting the appropriate ballast management system for a vessel, taking into account all the factors involved. At the same time, it aims to familiarize the owner with all the existing technologies and how they operate, as well as the regulatory framework and background.

1.3 Project Structure

This project aims to provide the closest possible approach by starting with the regulatory frame which describes the beginning of the guidelines and their development over the years. Specifically, the first chapter consists of the introduction to the subject and the purpose of the study, while the second includes the regulations applied to the Ballast Water Management and the comparison between the IMO and USCG regarding the matter. In the third chapter, all the available ballast water treatment technologies are presented along with their operation principle and process. Also, a summary table is presented as an overview of the pros and cons of each technology. Moreover, the focus of the project is depicted in the fourth chapter, where the factors consisting in the decision-making process of an appropriate treatment system are presented and analyzed along with the implications involved in the most common types of vessels. The fifth chapter follows with a comparative assessment between two different treatment systems applied in a couple of existing sister vessels, as an example of the application of the previous chapters' information. The purpose of this chapter is to show in reality how the theoretical criteria meet the practical issues when it comes to deciding the appropriate technology for a vessel's ballast water treatment, as well as the difference between owners' perspective. Lastly, the selection of the makers, shipyard and all the procedural details are briefly presented in the final chapter for a comprehensive view of the owners' perspective.

2. REGULATORY FRAMEWORK

2.1 First approach of Guidelines (G8)

Ballast Water Management Convention, adopted in 2004, established procedures and rules, in order to control ships' ballast water and sediments and limit ballast water and sediments carriage to certain standards according to a ship-specific ballast water management plan. In order to achieve its goal, IMO required from each and every ship to carry a ballast water record book as well as a ballast water management certificate. Furthermore, and until the appropriate ballast water treatment systems will be installed on-board, all ships were obligated to exchange ballast water mid-ocean as a temporary solution, but they would need to meet the ballast water treatment standard by the date of a specified renewal survey (DAMEN GREEN SOLUTIONS, 2020).

The Convention is divided into Articles and an Annex which includes technical standards and requirements in the Regulations for the control and management of ships' ballast water and sediments. The requirements and standards are applicable on vessels of any type designed or constructed to carry ballast water -with some exceptions-, including submersibles, floating craft, floating platforms, floating storage units (FSUs) and floating production, storage and offloading units (FPSOs) (IMO, 2019).

2.2 2016 Revised Guidelines for approval of Ballast Water Management Systems (G8)

In order for the Rules and Standards of the Guidelines to be approved and modified, all countries which are members of the Ship trade should vote for them. Each country-member has in a way a vote of a different weight according to the percentage of ships this country owns comparing to the world-trade market. On 08 September 2016, twelve years after the adoption of IMO BWM Convention, the entry into force prerequisite of at least 30 members States representing 35 percent of the world's merchant shipping gross tonnage was met (IMO, 2016). The ratification of the Ballast Water Management Convention from Finland on 8th of September 2016 -with a high percentage on the ship-trade market- let to the BWM Convention entering into force on **08 September 2017**. As of April 2019, 81 countries representing approximately 76-80% of the world's merchant fleet tonnage have ratified the BWM Convention.

Since 2014, IMO suspected some grey areas in the existing regulations and methodology of the Type Approval of a Ballast Water Management System, thus, it has started extensive studies and reviews which led to the revised G8 Guidelines from MEPC.70 on 28 October 2016 with a margin of application of up to 28 October 2018. Even so, the margins have been tight, a further extension has been granted until 2020, where only the new BWTS systems will be installed. (IMO, 2019).

2.3 BWMS Code (New G8)

Adopted on 13 April 2018, BWMS Code forms just the transition from *guidelines* to a *mandatory code* for approval of Ballast Water Management Systems. Vessels that have new BWMS installed on or after 28 October 2020 should be approved in accordance with the BWMS Code, otherwise they should be approved taking into account the respective Guidelines (IMO, 2018).

2.4 IMO BWM Convention – BWM Standards

In order to reduce the spread of aquatic organisms and pathogens, the BWM Convention includes two regulations for ballast water management standards: Regulation D-1 linked to ballast water exchange (BWE) and Regulation D-2 linked to the ballast water performance standard for the discharge of organisms from ships (IMO, 2020).

In the Regulation **D-1**, the Ballast Water Exchange Standard, states:

1) Ships performing Ballast Water exchange in accordance with this regulation shall do so with an efficiency of at least 95 percent volumetric exchange of Ballast Water.
2) For ships exchanging Ballast Water by the pumping-through method, pumping through three times the volume of each Ballast Water tank shall be considered to meet the standard described above. Pumping through less than three times the volume may be accepted provided the ship can demonstrate that at least 95 percent volumetric exchange is met.

The D-1 standard is based on the principle that organisms and pathogens contained in ballast water taken on board in coastal water will not survive when discharged into deep oceans and open seas because these waters have major differences in terms of temperature, salinity or chemical composition. In revert, the organisms from deep ocean or open seas' ecosystems, are less likely to adapt to the new coastal or freshwater environment. However, BWE is not considered to be completely effective at reducing the spread of unwanted aquatic organisms and pathogens, it is rather a temporary measure to reduce the spread of nonindigenous species through ship's ballast.

Further requirements regarding ballast water exchange are given in Regulation **B-4**.

1. A ship conducting Ballast Water exchange to meet the standard in regulation D-1 shall:
   .1 whenever possible, conduct such Ballast Water exchange at least 200 nautical miles from the nearest land and in water at least 200 meters in depth, taking into account the Guidelines developed by the Organization.
   .2 in cases where the ship is unable to conduct Ballast Water exchange in accordance with paragraph 1.1, such Ballast Water exchange shall be conducted taking into account the Guidelines described in paragraph 1.1 and as far from the nearest land as possible, and in all cases at least 50 nautical miles from the nearest land and in water at least 200 meters in depth.

The Regulation **D-2** standard states that ships meeting the requirements of the BWM Convention shall discharge:

• less than 10 viable organisms per cubic meter greater than or equal to 50 micrometers in minimum dimension, and

• less than 10 viable organisms per milliliter less than 50 micrometers in minimum dimension and greater than or equal to 10 micrometers in minimum dimension, and

• less than the following concentrations of indicator microbes, as a human health standard:

• Toxigenic Vibrio cholerae (serotypes O1 and O139) with less than 1 Colony Forming Unit (cfu) per 100 milliliters or less than 1 cfu per 1 grammar (wet weight) of zooplankton samples,

• Escherichia coli less than 250 cfu per 100 milliliters, and

• Intestinal Enterococci less than 100 cfu per 100 milliliters.

All ships constructed after the entry into force of the BWM Convention (08 September 2017) are required to meet the D-2 standard upon the vessel's delivery date. For the existing vessels, the Regulation D-2 compliance dates are determined based on the completion of the vessel's renewal surveys associated with the International Oil Pollution Prevention (IOPP) certificates pursuant to Annex I of the International Convention for the prevention of Pollution from Ships by MARPOL (1973). The ballast water management system of these vessels is required to meet the above-mentioned standards (IMO, 2020).

<u>NOTE:</u> Exemptions and exceptions under the BWM Convention can be granted under special circumstances (ref. to Regulation A-4 "Exemptions")

Difference between Water Exchange and Treatment

2.4.1 Ballast Water Exchange

Ballast Water Exchange is a very demanding procedure which required a tedious preparation because each exchange method has its own pros and cons. All procedures require continuous attention to keep the vessel and her crew safe. Points of attention are keeping the propellers submerged, keeping the hull stress within limits, maintaining the visibility for safe navigation, maintaining the (intact) stability, preventing possible slamming of the bow, etc. (DAMEN GREEN SOLUTIONS, 2020).

Most of the crew sailing on ships with ballast water tanks already use a Ballast Water Exchange (BWE) method to comply with regulations. A quick recap teaches us that Ballast Water Exchange is a method where coastal or port water is replaced by mid-ocean water during the voyage (Singh, 2020).

Acceptable Ballast Water Exchange methods in use are known as:

- **Sequential exchange**, where the ballast water tanks are made empty and filled with mid ocean water.
- **Flow through exchange**, where the mid ocean water, in three complete cycles, is pumped through in the tanks while the coastal ballast water leaves the tank simultaneously through the overflow.
- **Dilution method,** where the mid ocean water, in three complete cycles, is pumped in through the top of the ballast water tank, and where the coastal ballast water leaves the tank simultaneously through the bottom connection of the tank.

<u>NOTE:</u> The whole process and requirements are laid down in a Ballast Water Treatment Plan where the execution of the Ballast Water Exchange procedures is recorded in a Ballast Water Record Book which is to be kept up-to-date and available for review and survey by the port authorities or there representative.

2.4.2 Ballast Water Treatment

Ballast Water Treatment is often, when started up, a fully automatic procedure which must be monitored for correct operation. When Ballast Water Treatment is applied, it is no longer needed to apply the Ballast Water Exchange procedures. Of course, Ballast Water Exchange can be used, after approval for contingency operation. Many vessels are in the process of or have already been retrofitted with a ballast water treatment system. A typical retrofit installs a ballast water treatment in the existing ballast water system.

Depending on the system in use, ballast water treatment is required at ballast water uptake and during ballast water discharge. As an example, when continuous filtration and UV disinfection, in an automatic and monitored process, is applied; during ballast water uptake, the ballast water is pumped by the own ballast pump through the continuous filter stage followed by UV-disinfection into the selected ballast water tank(s) as usual. During the uptake the filter is automatically cleaned (backwash) while the uptake procedure keeps ongoing. The backwash is pumped overboard by the backwash pump which is part of the ballast water treatment installation. During ballast water discharge, in an automatic and monitored process, the ballast water from the ballast water tanks is pumped with the ballast water pump through the UV disinfection stage only, overboard as usual.

When continuous filtration with electro-chlorination, in an automatic and monitored process, is applied; during ballast water uptake, the ballast water is pumped by the own ballast pump through the continuous filter stage (main stream) disinfection into the selected ballast tank(s) as usual. Directly after the ballast pump a water sample is taken to determine the amount of Sodium Hypochlorite which needs to be added to achieve the required level of disinfection. The Sodium Hypochlorite is injected in the main stream before the ballast water enters the selected ballast water tank(s). The Sodium Hypochlorite is, in a side stream, made onboard from seawater with the use of an electrolyzer and a degassing module to dilute and release the electrolyzer exhaust gases which are a residue of the Sodium Hypochlorite production. During ballast water discharge an analyzer connected to the ballast water piping before the overboard sea chest, determines the amount of Sodium Hypochlorite left in the ballast water to discharge. If necessary, residual chlorine is automatically neutralized with Sodium Sulphite before it is discharged overboard as usual, if no chlorine is measured, the ballast water is pumped, without further treatment, overboard as usual (Singh, 2020).

2.5 Contingency Measures

Contingency measures were raised by both IMO and USCG with differences though.

IMO issued “Guidance on Contingency Measures under the BWM Convention” in July 2017 and set a guidance for when it is non-compliant for a ship to discharge ballast water. This guidance offers practical measures in order to support ships and Port States in the case of a ship unable to manage ballast water in accordance with its approved Ballast Water Management Plan (DNV GL, BWMP).

USCG issued “Guidelines for evaluating potential courses of action when a vessel bound for a port in the United States has an inoperable ballast water management (BWM) system” in February 2018 for vessels operating in US water. A vessel that has passed its compliance date and has an inoperable BWMS may use one from a list of choices of BWM methods (Lloyd’s Register, 2018).

In general, clear contingency measures are recommended for the BWMP as well as clear plans for action should be available to the crew in the event of a malfunction or inoperable BWMS. The Master and crew should practice contingency measures to validate the feasibility of the BWMP. Examples of contingency measures may include conducting sequential BWE plus BWT during de-ballasting to alleviate water quality issues that may be encountered in some ports (i.e., low salinity for electro-chlorination based BWMS, high silt and sediment that affect filters, etc.). Performing BWE in lieu of treatment may be considered the last resort in the event of failure of the BWMS (ABS, 2019). If the vessel intends to use BWE, it must obtain the appropriate approval from the District Commander or Captain of the Port (COTP) first.

Note: USCG is separated from the IMO’s BWM Convention, so vessels discharging ballast into both waters of the US and non-US, must comply with both.

2.6 Sampling during Commissioning

After entry into force of the BWM Convention IMO Member States will be required to check vessels for compliance with the standards of the BWM Convention, and this will be undertaken by sampling ballast water on vessels.

The main objective of commissioning testing is not to validate the Type Approval but to demonstrate that the principal treatment methods of the system are capable of functioning as installed. It is based on the Guidance for the commissioning testing of ballast water management systems (BWM.2/Circ.70), and it will be required by the Flag State of the vessel or the Recognized Organizations (ROs) acting on their behalf. At the Marine Environment Protection Committee (MEPC) 74 session, that took place at IMO headquarters in London from May 13 to 17, 2019, it endorsed that commissioning testing should begin as soon as possible in accordance with BWM.2/Circ.70 and agreed to reflect this in the requisite resolution for the adoption of the relevant amendments to mandatory instruments. As an interim measure, the Committee urged Administrations to provide the ROs which act on their behalf with written and clear instructions in relation to the conduct of indicative analysis testing of BWMS at the time of their commissioning on board ships flying their flag, including what actions were to be taken in the event of this testing demonstrating non-compliance (ERMA FIRST, The Maritime Executive, 2019).

Unlike sampling for approval of ballast water treatment systems, which need to meet D-2 standard, sampling for compliance control is required to identify any possible non-compliance with the D-2 standard.

If the sampling must demonstrate compliance with the D-2 standard, then documenting the number of organisms greater than or equal to 50 micrometers in minimum dimension is especially challenging since less than 10 viable organisms per $m^3$of water are acceptable. Various difficulties can be identified such as more than 1,000 l of water may need to be collected to proof compliance, and several replicates need to be sampled to meet general scientific standards and accuracy. The accuracy of the sampling technique must be determined; inefficient sampling techniques may result in false negatives as a result of missing organisms (ERMA FIRST, The Maritime Executive, 2019).

Different vessel specifics, such as types, sizes and cargo profiles result in very different ballast water discharge profiles and times. Also, the ballast water operation is frequently conducted in sequences over the time of the cargo operation.

SAMPLING METHODS

Sampling points may be divided into in-tank and in-line (at discharge) sampling points, according to the access point. In-tank sampling points enable ballast water access directly from a tank either via ballast tank manholes, sounding or air pipes. In-line sampling points include the ship´s pipe work after the ships ballast water pumps.

For compliance monitoring with the **D-1 standard** in-tank or in-line samples may be taken to either proof the presence of coastal biota or check the water salinity. This may be done by using all possible access points including sounding pipe, manhole and the vessels main ballast water line. However, the use of the latter is not recommended because a discharge to sea may occur during sampling and in case of non-compliance the non-complaint water would enter the recipient environment during the sampling event. As the D-1 standard is not a numerical standard no quantitative biological sampling is needed, but a qualitative approach to document the possible occurrence of coastal biota (ABS, 2019).

In contrast, the **D-2 standard**, being a numerical and biological discharge standard, the samples should be taken from the ballast water discharge line. Here, a quantitative biological approach is needed as the numerical standard applied to living organisms above 10 micrometers in minimum dimension no matter what type they are. For the indicator microbes as stated in theD-2 standard a qualitative and quantitative approach is needed so that the concentration of colony forming units of certain indicator microbes becomes known. Although in-line sampling seems most appropriate to assess the D-2 standard compliance as discharge standard, in case the ballast water originates from a high-risk area, i.e., an area with a known occurrence of target species, samples may be taken from the ballast tank prior discharge. This enables non-compliance actions before the water was discharged into the recipient environment. The in-tank approach is also advisable to proof compliance with the D-2 standard for tanks which have direct discharge to the sea, e.g., top-side tanks on some bulk carriers (ABS, 2019).

2.7 USCG: Available BWTS

USCG regulations, US Environmental Protection Agency (EPA) permits, and individual state laws form the Ballast Water Management requirement in the United States, which finalized in March 2012 and became effective on 21 June 2012 for all vessels, US and non-US flag, equipped with ballast tanks operating in waters of the US unless specifically exempt (i.e., crude oil tankers engaged in coastwise service, vessels that operate exclusively within one Captain of the Port (COTP) Zone). All ships calling at US ports and intending to discharge ballast water must either carry out ballast water exchange or treatment, in addition to fouling and sediment management. The US has its compliance schedule determining when a vessel must begin to employ treatment instead of exchange. US legislation requires the ballast water treatment system (BWTS) to be type-approved by the USCG (USCG, 2018).

The implementation schedule for USCG discharge standards is similar to the BWM Convention but not dependent to the ratification of the latter. Prior to the dates for implementation of the ballast water discharge standards, all vessels with ballast tanks, unless specifically exempt, must be in compliance with all aspects of the regulation (BWM, reporting and recordkeeping).

All the above vessels are required to meet the Ballast Water Discharge Standard by using one of the following BWM options (Lloyd’s Register, 2018):

• Install and operate a BWMS that has been type approved by the USCG (under 46 CFR Part 162)

• Use only water from a US public water system

• Use an alternate management system (AMS) limited for 5 years from the vessel USCG BWDS compliance date, provided that no USCG approved system is suitable for the vessel when the AMS is installed (Refer to Section 4 for more information on the applicability of USCG acceptance AMS)

• Do not discharge ballast water into waters of the United States (includes the territorial sea as extended to 12 nautical miles from the baseline).

• Discharge to a facility onshore or another vessel for treatment.

About Reporting and Recordkeeping there is a Ballast Water Reporting Form where all BWM activities are to be recorded and submitted. These activities are the vessel’s total ballast water, ballast water management practices (methods and plans on board), the ballast water tanks that are to be discharged in US waters or at a reception facility and the sediment disposal practices. That form must be signed and retained on board for two years.

2.8 IMO vs USCG

Except of the IMO regulations that are international, there are also US Coast Guard (USCG), which amended its regulations in 2013-2014, causing ship-owners around the world to have to comply with these new rules' measures and specifications. America did not approve of the reformulation of the regulations and therefore IMO tried to bring the regulatory framework closer to the new American.

It was decided to set some timelines for compliance with the new ballast water system that coincide with the renewal of the IOPP (International Oil Pollution Prevention) certificate, which is renewable every five years.

The procedure is as follows:

> Depending on the date when the first IOPP renewal of a ship took place, the second is set after five years and there are different cases. If the second renewal falls on a date after 08/09/2019, then the newly approved BWTS must be installed. There is also the option of Decoupling, that is, early renewal of the IOPP certificate before 08/09/2019, in order to extend the installation of the new system with a time limit of five years again.
>
> The new ships, built on 2014 onwards, are required to install the new system from the start. In addition, those that have already decoupled before 2017 are required to install the new system after five years after decoupling, as the 08/09/2019 limit date expires.

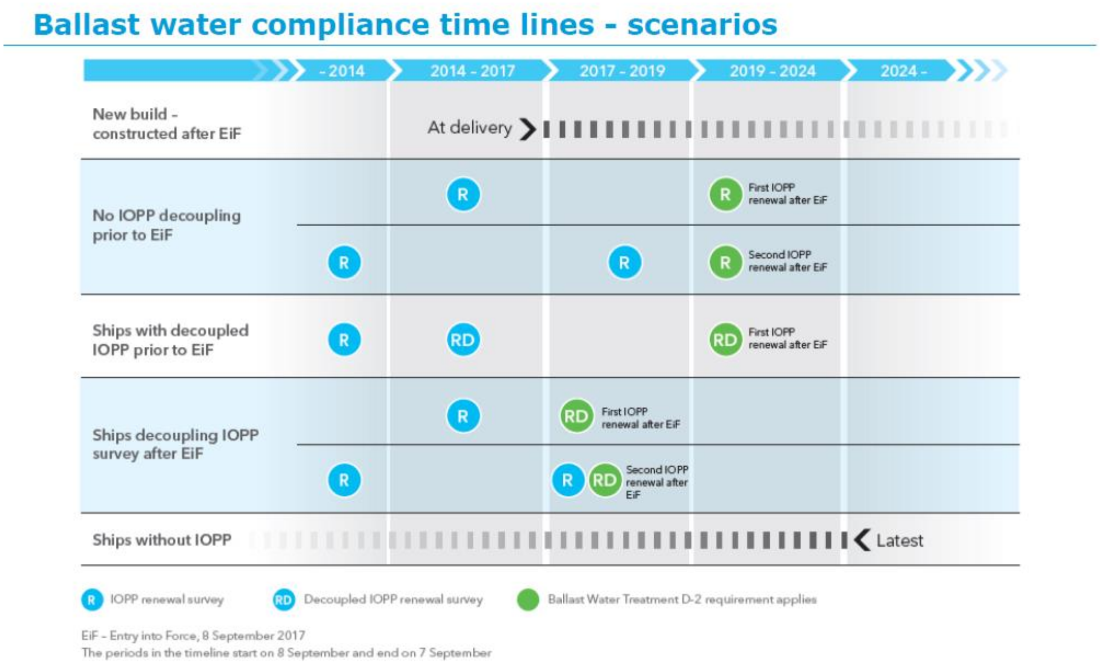

Table 1: Compliance timelines for BWTS installation according to Regulation D-2 (DNV GL, 2018).

On the other hand, USCG set the dates of installation of the new system depending on the date of construction of the ship and its ballast capacity.

USCG implementation schedule - BWTS

	vessel's ballast water capacity	date constructed	vessel's compliance date
new vessels	all	on or after 1 December 2013	on delivery
existing vessels	less than 1500 m^3	before 1 December 2013	first scheduled dry-docking after 1 January 2016
	1500 - 5000 m^3	before 1 December 2013	first **scheduled dry-docking** after **1 January 2014**
	greater than 5000 m^3	before 1 December 2013	first scheduled dry-docking after 1 January 2016

♦ **Scheduled dry-docking** instead of **IOPP renewal survey**

Table 2: Implementation Schedule of BWTS according to USCG (DNV GL, 2018).

The revised US Coast Guard (USCG) regulations on ballast water management entered into force 21 June 2012. The regulations require compliance with the treatment standard at the first scheduled dry-docking after 1 January 2016 for sailing ships, and at delivery for new buildings. Before any type-approved systems were available, the USCG allowed ship-owners to apply for an extension of their compliance date, on the basis of lack type approved systems available in the market. As of February 2019, there are 16 approved treatment systems which have obtained USCG type approval and 10 are under review. The USCG has not removed the extension option for ship-owners but obtaining on an extension due to lack of type approved systems will now be more difficult because ship-owners must prove that none of the systems available are suitable for their vessel.

Previously, vessels could receive an extension of 5 years by employing an Alternative Management System (AMS), normally an IMO-type approved system which had received an AMS approval from USCG. At the end of the 5-year extension period, if the AMS has not received USCG type approval, the AMS extension will not be automatically renewed. Another option to comply with the regulations is to use potable water (from the US public water system). In such cases the ballast tanks need to be cleaned and sediments removed beforehand.

2.8.1 Type approval process

Each of the two organizations - IMO and USCG - has defined a different procedure for Type Approval with different criteria, which makes the situation more difficult as some ships will have to meet both.

- IMO 2016 G8 Guidelines Type Approval Process
    - A system using active substances (G9) must have a basic and final approval from GESAMP.
    - The manufacturer is not involved during testing.

- Land-based Testing
  -5 consecutive successful Seawater Biological Efficiency Tests (> 28PSU)
  -5 consecutive successful Biological Efficiency tests in brackish water (10 <PSU <20)
  -5 Successful Freshwater Biological Efficiency Tests (<1PSU)
  - Toxicity test
  -A unit capable of handling more than 200 m3 ballast water should be used which should remain 5 days hold time before discharge
- Shipboard Testing
  -3 Continuous Ships Biological Efficiency Test for more than six months
- Environmental Testing (electrical components)
  -Vibrations at resonant frequencies (90mins)
  -high / low temperature
  -IP Testing
  -Voltage changes
  -Roll and Pitching
- Quality Assurance Project Plan (QAPP); Quality Management Plan (QMP); Test Plan

- USCG Type Approval Process

- The manufacturer is not involved during testing.
- Land-based Testing
  -5 ongoing Seawater Biological Efficiency tests
  -5 consecutive tests of Biological Efficiency in brackish water
  -5 Continuous Tests of Biological Efficiency in Freshwater
  -A unit capable of handling more than 200 m3 ballast water should be used which should remain 24 hours hold time before discharge
  -Operation and maintenance test cycles
  - Whole effluent toxicity (WET) testing (if active substances)
- Shipboard Testing
  -5 consecutive on-board Biological Efficiency tests for more than six months
- Environmental Testing (electrical components)
  -Vibrations at resonant frequencies (4h)
  -high / low temperature
  -IP Testing
  -Voltage changes
  -Roll and Pitching
  - Test sequence
- Quality Assurance Project Plan (QAPP); Quality Management Plan (QMP); Test Plan

(Tsami, 2018).

A main difference between the IMO and the USCG is how the former aims at a sufficiently satisfactory result without giving weight to the means used to achieve it or to the safe installation of the system, while the latter takes into account the safe installation of the system at some degree as well as evaluating the outcome.

The comparison table (*Table 3*) summarizes the differences and similarities between the old, new G8 Guidelines and the USCG Final Rule/ UTV Protocol.

	Old G8 Guidelines / MEPC.174(58)	New G8 Guidelines / MEPC.279(70), MEPC.300(70)	USCG Final Rule/ ETV Protocol
Definitions of Viable Organisms	• Organisms and anything that has life into itself. • Viable/ unviable organisms are used to measure the efficacy of the BWMS.	• Organisms that have the ability to successfully generate new individuals I order to reproduce the species	• Same as the old G8 Guidelines • The number of living organisms is used to measure the efficacy of the BWMS. • Organisms that can no longer reproduce after ballast water treatment are not considered 'living'.

Type Approval Certificate	• Limited required information provided	• Inserted in a new part in the new G8 Guidelines.
		• More transparency to the Type Approval Certificate and Report
		• Additional requirements:
		  ○ System design limitations
		  ○ Limiting operational conditions (Temperatures, Salinities)
		  ○ Restrictions due to minimum holding time
		  ○ Shipboard and Land-based test results.
			• Conditions of approval applicable to the BWMS to be listed in the Type Approval Certificate

System Design Limitations (SDL)	• (No Requirements)	• Incorporated in Part 6 of the new G8 Guidelines • Known as Critical Parameters • To be identified by the manufacturer • Validate minimum and maximum to be indicated in the Type Approval Certificate	• Similar to the new G8 Guidelines • Conditions of approval applicable to the BWMS to be listed in the USCG Type Approval Certificate
Test Facilities	• Required to meet the International Recognized standard (ISO/IEC 17025) requirements	• To be conducted by an independent facility accepted to the satisfaction of the Administration.	• Similar requirements to the new G8 Guidelines

	• A quality control/ quality assurance program to be implemented. • Quality management plan (QMP) • Quality Assurance Project Plan (QAPP)	• Requires a Test/ Quality Assurance Plan (TQAP) in addition to the QMP and QAPP	• To be conducted by an independent laboratory (IL) designated by the USCG. • To be independent of the BWTS manufacturers
Control and Monitoring Equipment	• Limited monitoring f the treatment dosage or other aspect with regards to the operations of the BWMS	• Design requirements scope expanded. • Requires additional documentation (i.e., software change handling logbook, detailed functional description) • Self-monitoring parameters to be recorded automatically for the performance and safe operation of the BWMS. • More emphasis placed on the storage and protection of the recorded data	• Design requirements covered in the ETV Protocol and Final Rule
Installation Survey and Commissioning Procedures	• Provides Installation Survey and Commissioning Procedures	• Enhanced specification for required documentation. • Helps to assist the ship operators and Administration	• Covered in the Final Rule and ETV Protocol
Bypass Arrangement	• Requires bypass alarms to be recorded in the Control Equipment	• Bypass events to be recorded in the Ballast Water record book. • Requirements are in addition to the Control Equipment in the old G8	• Similar to the old G8 Guidelines

• **Land-Based Testing**			
Challenge Water Types and its Salinity Range (PSU)	• <3 PSU • 2-32 PSU • >32 PSU	• Fresh (<1 PSU), Brackish (10-20 PSU), Marine (28-36 PSU)	• Fresh (<1 PSU), Brackish (10-20 PSU), Marine (28-36 PSU)
Minimum challenge Water Quality Characteristics • **Dissolved Organic Carbon (DOC)** • **Particulate Organic Carbon (POC)** • **Total Suspended Solid (TSS)**	• No augmentation requirements	• Varies with Salinities. • Requires validation for augmenting the test water with DOC/POC/TSS effects (i.e., UV absorption, oxidation demand, TRO decay, particle size distribution of suspended solids) • Allows assessment of the impact of TSS and the DOC source on the BWMS	• Allows the augmentation of the challenge water using the DOC/TSS/POC • Source of augmentation to be validated by the Test Facility (TF)
Standard Test Organism (STO)	• Naturally occurring in the challenge test water of cultured species added to the challenge test water	• Supplemental use of STO to ensure adequate robustness in Land-based testing is introduced. • Requires procedures and guidance together with an assessment on the use of STO to be reported in the test report	• Allows ETV recommended STOs to be replaced with other rest organisms. • Requires sufficient experiments o be conducted with supporting documentation to validate the use of alternative test organisms.
Consecutive Testing/ Test Cycles	• Five valid test cycles for any two salinities (with Δ10 PSU)	• Five consecutive valid tests cycled (D-2 compliance) for each of the three water salinity ranges (i.e. Fresh, Brackish and Marine water)	• Five consecutive, valid and successful replicate test cycles for the salinity range for which the BWMS will be approved (Final Rule) • Minimum 3 valid test to be conducted for at least 2 salinity conditions (ETV Protocol)
Minimum holding time	• $\geq 5\ days$	• Minimum holding time to be determined by the BWMS Manufacturer (D-2 Compliance) • $\geq 5\ days$ (Evaluation of Regrowth)	• $\geq 1\ day$ • Shorter or longer tank hold times may be utilized (to be justified in the TQAP)

Sample volume for organism enumeration • **Organisms ≥ 50µm** • **50µm > Organisms ≥ 10µm** • **Bacteria**	• 3 sampling replicates to be collected for the influent, control and treated water. • Sample collection are to take place over a period of uptake and discharge of the tank (e.g., beginning, end, middle) for each test cycle	• 1 continuous time integrated sample • In line with the ETV Protocol	• Sample collection replicates are based on Time-integrated sample volumes collected during each test cycle.
Methods for Counting	• No specific methods listed	• No specific methods listed	• Recommended test methods are based on organism sizes
• **Shipboard Testing**			
Temperature assessment of the BWMS from operating in cold and tropical conditions	• No requirement specified	• Requires testing over a range of temperatures from 0 to 40℃ (2 to 40℃ for fresh water) and a mid-range temperature of 10 to 20℃	• No requirements for a specific temperature range • Testing to include temperate, semi-tropical or tropical locations with ambient organism concentrations
Consecutive Testing/ Test Cycles	• 3 consecutive valid test cycles (D-2 compliant) • Spa over a period of no less than 6 months • Invalid test cycles do not affect consecutive sequence	• Same requirements as per the old G8 Guidelines	• 5 consecutive valid test cycles • Span over a period no less than 6 months • Unsuccessful test cycles are to be recorded in the Test Report
Scaling of BWMS	• No specification	• Most vulnerable models to be identified. • Mathematical modelling and/or calculations to demonstrate that any scaling of the BWMS will not affect the functioning and effectiveness on board the ship	• No requirements for Shipboard testing

		• Requires further validation during Shipboard testing at the upper limit of the rated capacity.	
Volume and Operational Testing period	• To be consistent with the normal ballast operations of the ship • To operate at the treatment rated capacity for which the BWMS is intended to be approved	• Same as per the old G8 Guidelines • Requires documentation to justify continuous operation of the BWMS throughout the test period (i.e., ballasting and de-ballasting)	• Volume and operational flow rate are representative of the upper end of the treatment rated capacity for which the BWMS is intended to be used. • Vessel tank size and flow rate are to be equal to or exceed those used during land-based tests
Shipbard Operation	• No requirement	• Operated and maintained by the ship's crew	• Operated by ship's crew
Sample Volumes	• 3 sampling replicates to be collected for the influent, control and treated water. • Sample collection over period of uptake and discharge of the tank (e.g., beginning, end, middle) for each test cycle	• Single, continuous time-integrated sample or composite • Sample collection at interval over a duration of uptake and discharge (e.g., beginning, middle, end of operation) for each test cycle • Use of control tank samples or control water in shipboard testing is no longer required except for land-based testing	• Specifies in-line sample port/facility for sample collection

Table 3: Comparison between the old Guidelines, the new ones and the USCG (ABS, 2019).

Guideline	Title
G1	Guidelines for Sediment Reception Facilities (MEPC.152(55))
G2	Guidelines for Ballast Water Sampling (MEPC.173(58))
G3	Guidelines for BWM Equivalent Compliance (MEPC.123(53))
G4	Guidelines for BWM and the Development of BWM Plans (MEPC.127(53))
G5	Guidelines for BW Reception Facilities (MEPC.153(55))
G6	2017 Guidelines for BWE MEPC.288 (71)), superseding MEPC.124(53)
G7	2017 Guidelines for Risk Assessment under Regulation A-4 of the BWM Convention (MEPC .289 (71)), superseding (MEPC.162(56))
G8 (New)	2016 Guidelines for Approval of BWM Systems (MEPC.279 (70), superseding MEPC.174(58) (Note: Resolution MEPC.279(70) will be superseded by the BWMS Code (resolution.300(72)) in October 2019)
G9	Procedure for Approval of BWM Systems that make use of Active Substances MEPC.169(57), superseding MEPC.126(53)
G10	Guidelines for Approval and Oversight of Prototype BW Treatment Technology Programs (MEPC.140(54))
G11	Guidelines for BWE Design and Construction Standards (MEPC.149(55))
G12	2012 Guidelines for Design and Construction to Facilitate Sediment Control on Ships (MEPC.209(63), superseding MEPC.150(55)
G13	Guidelines for Additional Measures Regarding BWM Including Emergency Situations (MEPC161(56))
G14	Guidelines on Designation of Areas for BWE (MEPC.151(55))
–	Guidelines for BWE in the Antarctic Treaty Area (MEPC.163(56))
–	Guidelines for Port State Control under the BWM Convention (MEPC.252(67))

Table 4: BWM Convention Guidelines

3. AVAILABLE BALLAST WATER TREATMENT TECHNOLOGIES

Ballast water treatment technologies fall into two groups: separation technologies or disinfection technologies. Separation technologies remove organisms from ballast water upon intake or prior to discharge, while disinfection technologies kill or render organism's incapable of reproducing. BWMS have been developed using various combinations of the technologies.

- *Separation:* The most common type of separation technology is filtration systems, which is usually used along with other disinfection methods to increase the efficiency of the ballast water management systems in the elimination of the aquatic organisms. Filtration systems lead to the elimination of larger organisms from the ballast water which also leads to reduced power demand for UV-based BWMS or other disinfection technologies. There are many types of filters such as disk, drum, mesh, screen, stacked disk etc., each of them with different arrangements, technical specifications and means for back flushing and with the ability to remove organisms on a range from 10μm to 200μm in diameter. However, in areas where water contains a significant amount of total suspended solid particles (especially for high ballast dependent vessels i.e., tankers, bulk carriers), large volumes of water and high pumping rates are required during the ballasting and de-ballasting operation and therefore, a heavy buildup of slit is accumulating in the ballast water tanks causing issues in sediment control and also clogging of the filters in the long run (ABS BWMS Advisory, 2019).
- *Disinfection:* This method kills or alters organisms in a way that they cannot reproduce or are no longer viable. There are several disinfection technologies that are used in BWMS, such as chlorination, ozone treatment, deoxygenation and ultraviolent (UV) treatment. Important factors for the effectiveness of each and every type of disinfection are the salinity, temperature, turbidity and other physical or chemical parameters of the water being treated (ABS BWMS Advisory, 2019).

The main types of ballast water treatment technologies available in the market are:

- Filtration Systems (physical)
- Chemical Disinfection (oxidizing and non-oxidizing biocides)
- Ultra-violet treatment
- Deoxygenation treatment
- Magnetic Field Treatment
- Heat (thermal treatment)
- Acoustic (cavitation treatment)
- Electric pulse/pulse plasma systems

A typical ballast water treatment system on board, uses two or more technologies together to ensure that the treated ballast water is of IMO standards. But the most common treatment technologies for ballast water are Filter-UV System, Filter and Electrolysis and Chemical Disinfection with oxidizing and non-oxidizing biocides with the method of ozonation.

After working as a trainee in IACS group classification society, a lot of information has been gathered regarding the most common technologies used for treating the ballast water.

3.1 Filter and UV System

The Filter-UV system comprises a network of pipes and pumps where ballast pumped ballast passes first through the Filter, which separates the larger substances or microorganisms removed. Then, the "stripped" ballast reaches UV (Ultraviolet) where the final cleaning of even the smallest of microorganisms takes place, resulting in the ship's Ballast Tanks.

However, when de-ballasting, starting with Ballast Tanks, the ballast must pass through the UV again for complete cleaning to be able to reach the waters of the port visited by the ship (it does not need to pass through the filter though). The latter is one of the disadvantages of this ballast management system, however, against many advantages such as simple application and maintenance, low cost and its application to waters of any salinity.

It is mainly applicable to low ballast ships such as passenger ships, Oil / Chemical Tankers, OSVs (Offshore Support Vessels) and Fishing Vessels.

Bypassing the above process is the so-called 'Bypass Line' where ballast is driven directly from Sea Chests to ballast tanks during ballasting, and respectively from ballast tanks to Overboard where ballast is unloaded during de-ballasting. The need for a bypass can arise when some pumps may not work or depending on the supply we want to have (adjustable pumps or not). It is a quick route for emergency or peculiar situations. In order to achieve this route, it is necessary to have specific valves open which are normally mandatory closed (normal ballasting operation route).

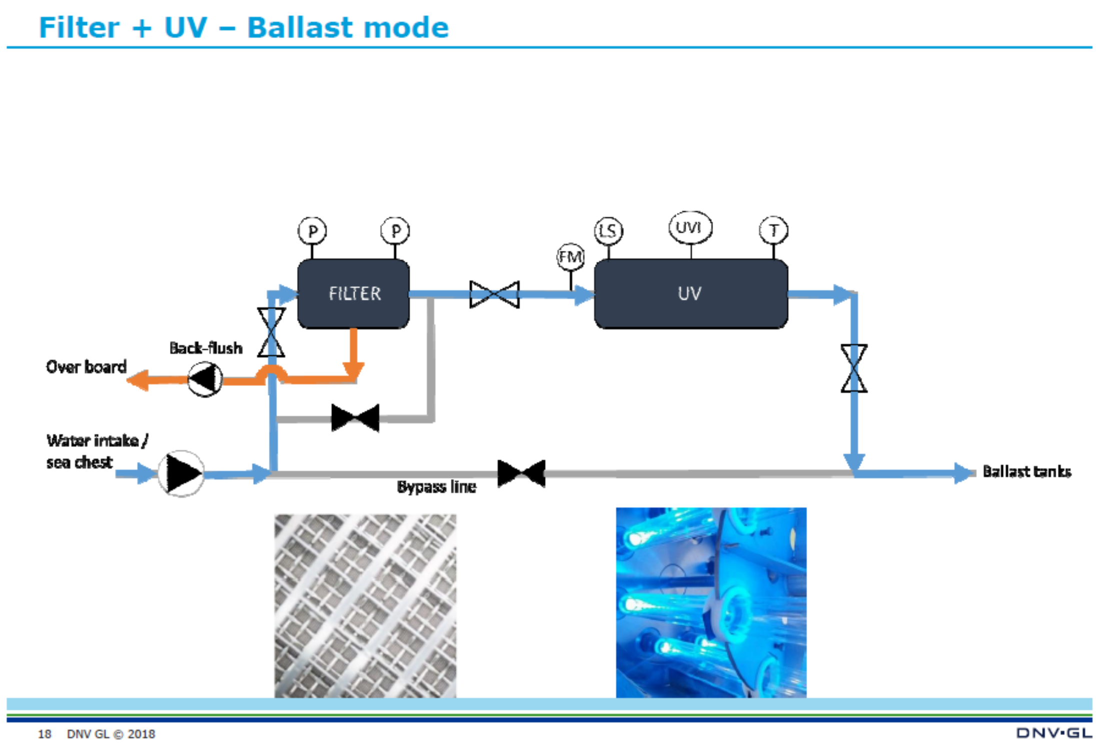

Figure 1: Illustration of the ballasting process using the Filter & UV ballast management system (Tsami, 2018).

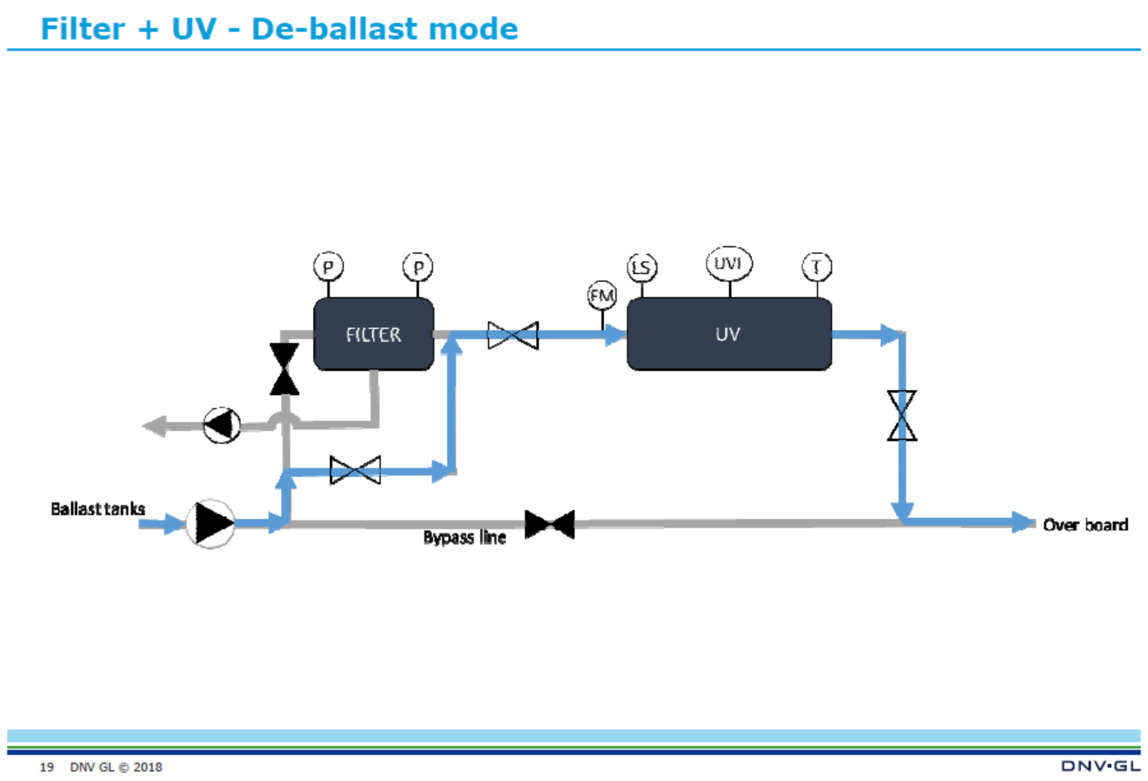

Figure 2: Illustration of the de-ballasting process using the Filter & UV ballast management system (Tsami, 2018).

3.2 Filter and Electrolysis System

According to this system, the ballast water passes through a filter first (this step is sometimes omitted) and then passes to the electrolytic cell where chlorine and hydrogen gas are produced. Finally, it ends up in water ballast tanks, after first going through a TRO mechanism that calculates the ballast concentration in chlorine.

Certain conditions must be met in order for this process to be acceptable and non-toxic:

i. The chlorine content must be less than 0,1 mg / L and
ii. the hydrogen gas produced is dissolved in the atmosphere with a content of up to 4%, not to be considered flammable. Also,
iii. it must be some time before the processed ballast (after the addition of bleach) is in place until the TRO (Total Residual Unit) reaches acceptable levels. This time varies and depends on the initial amount of NaClO introduced.

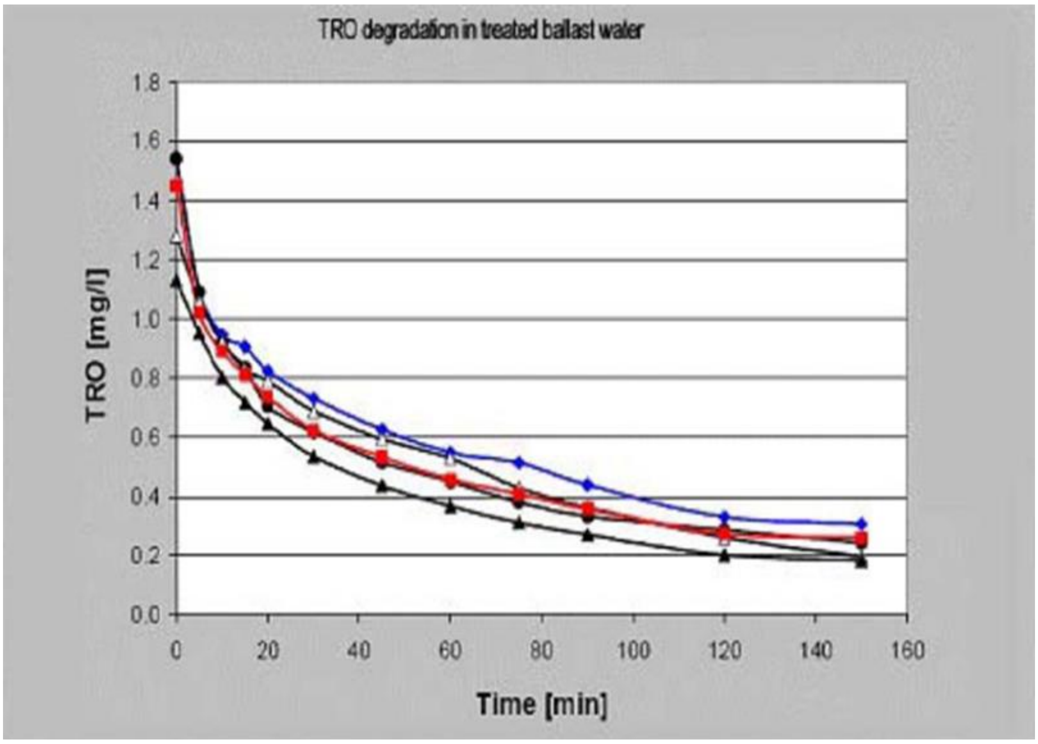

Figure 3: Diagrammatic representation of the change in TRO over time
** Note: The different color curves show the TRO level in different test cycles.

It is mainly applicable to high ballast ships such as Bulk Carriers and Tankers.

- For hydrogen gas there is a safety factor of 60% of the permissible content
- The Factors affecting BWTS by electrolysis are solubility and temperature. For this reason, during ballasting and before electrolysis (after passing through the filter), its salinity is measured, and depending on the result, additional seawater is added with greater salinity through the Spare Saltwater Tank. The temperature is usually raised, where appropriate, with a Heater prior to electrolysis.

There are two systems in the method of marine ballast filtration and electrolysis:
i) *In-line*, ii) *Slip Stream (Side Stream).*

• In line (or full flow)

Under the In-line system, the general arrangement includes the filter -where the ballast passes first- the Spare Saltwater Tank, the electrolytic cell, the ballast tanks and the necessary metering intermediate equipment. In-line systems usually do not exceed the gas hydrogen safety threshold [gas H_2], so they are not measured. The exception is the case where a ballast tank has openings, where it will then absorb oxygen and may be more dangerous and more flammable. Also, heater is not used as described because the temperature in this process is at an appropriate level. The ballasting in-line operation as described is shown in Figure 4.

• Slip Stream (Side Stream)

Under the Slip / Side Stream system, the ballast enters the filter and is then split as follows: 1% of total flow passes through salinity (PSU) and temperature (T) meters and is then connected to the Spare

Saltwater Tank and one Heater where it becomes suitable for processing. It proceeds to the electrolytic cell where it exits along with NaClO and gas [gas] production. Then the content of H_2 dissolved in the atmosphere is measured and if the permissible limit is exceeded, then there is a passage where some of it is removed (Gas Trucks). The remaining 99% does not have this processing but passes through the filter directly to the ballast tanks. At the end of the course of each of the above streams (1% and 99%), the two flows are joined before finally being routed to the ballast tanks, where the processed 1% with the purely filtered 99% are mixed. The ballasting slip stream operation as described is shown in Figure 5.

There is one ballast inlet and three outlets for the electrolytic cell. One outlet is intended for a derivative of the electrolysis process that is neither ballast nor chlorine and turns back, where it is mixed with the new ballast that enters and ends up in ballast tanks. The other outlet corresponds to the amount of chlorine produced which enters the non-electrolyte ballast and ends up in the ballast tank. The third diode is that of gas removed to the atmosphere. During this process some samples are taken in the interim, which end up in TRO meters and then return to the normal flow path.

The de-ballasting process is common to both systems and the flow of the ballast is as follows: from the ballast tanks, directed to the Overboard for unloading at sea, passes through a TRO metric first, which checks whether the amount of chlorine in the ballast is below the permissible limit or not. If it exceeds that, then it passes through the TRO injector where neutralization is done, meaning that the amount of chlorine is reduced. If the limit is not exceeded, the previous process (neutralization) is not necessary. In some cases, gravity de-ballasting may be used as appropriate installation is provided for this function. The de-ballasting operation is shown in Figure 7.

Note: There is a second route from the filter for impurities / microorganisms / substances that are filtered and removed from the ballast. This route ends at the Overboard for unloading at sea.

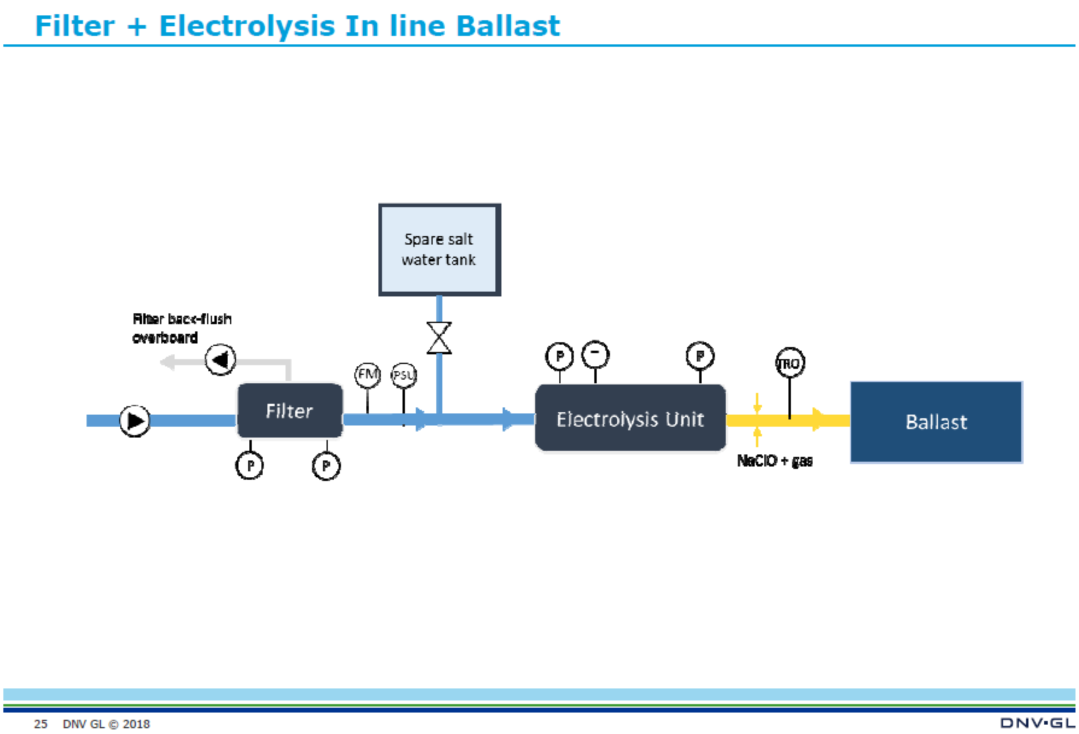

Figure 4: Illustration of the ballasting process using the Filter & Electrolysis in-line ballast management system (Tsami, 2018).

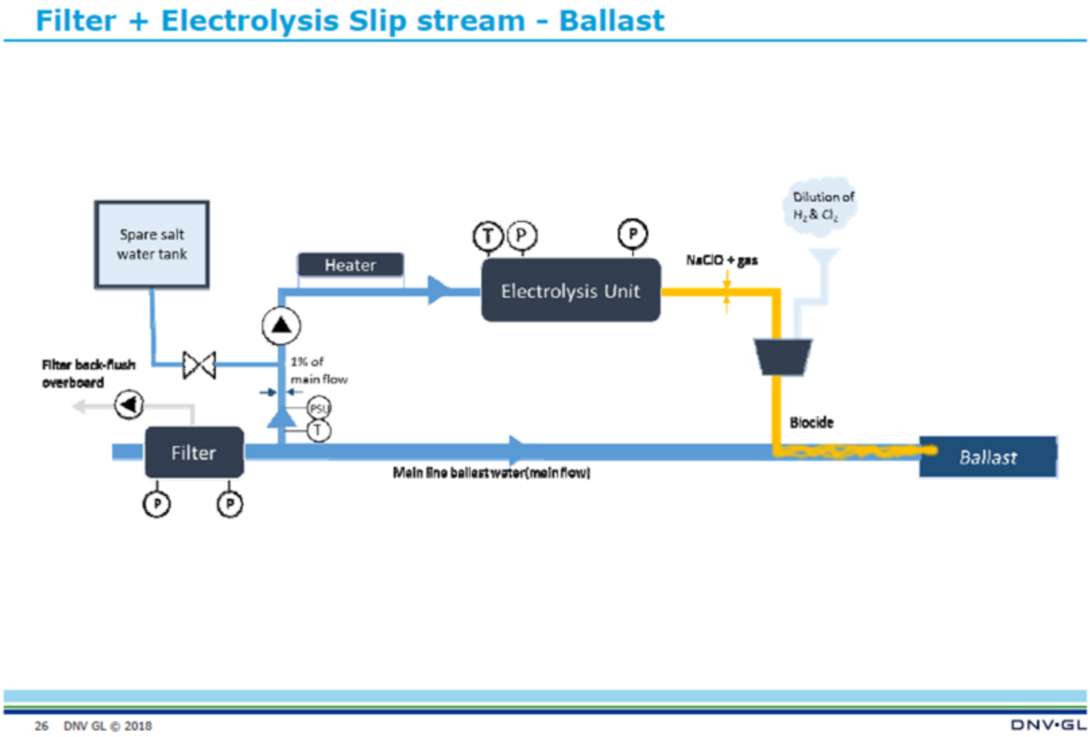

Figure 5: Illustration of the ballasting process using the Filter & Electrolysis slip stream ballast management system (Tsami, 2018).

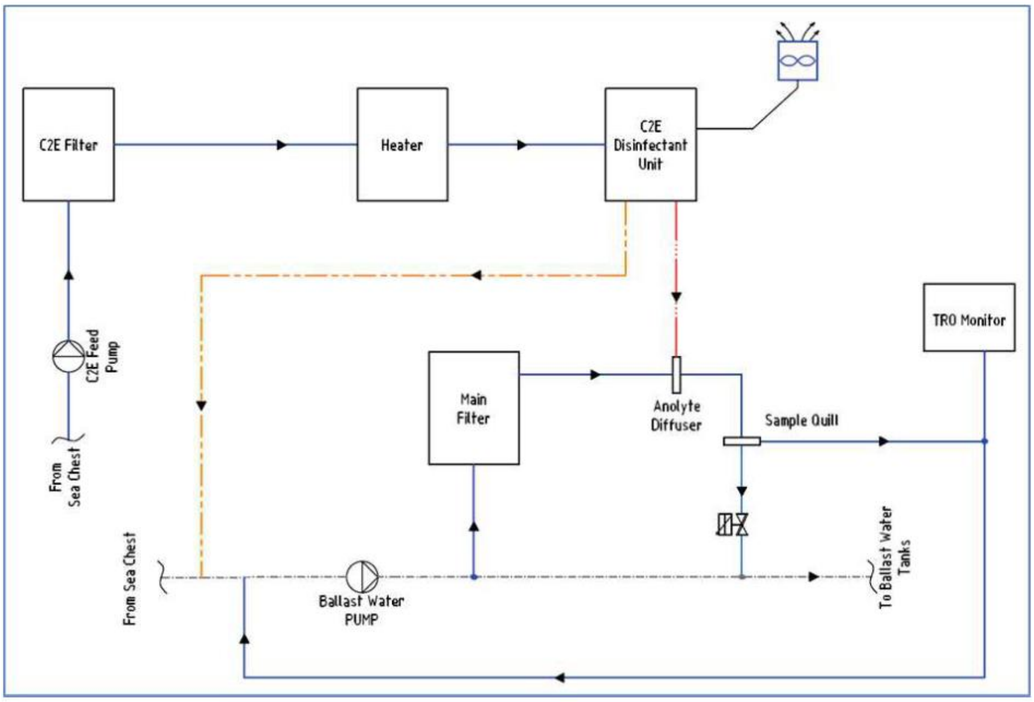

Figure 6: Detailed illustration of the ballasting process using the Filter & Electrolysis Ballast Management System (Tsami, 2018).

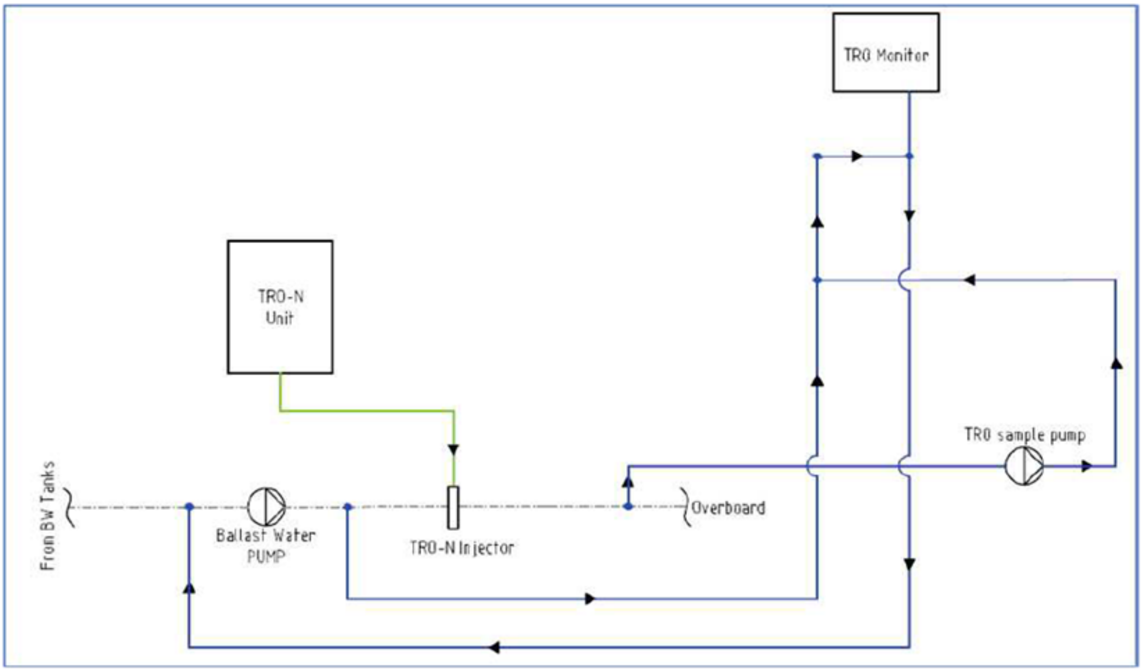

Figure 7: Detailed de-ballasting process using the Filter & Electrolysis Ballast Management System (Tsami, 2018).

The Filter & Electrolysis system also applies to tankers, but with some peculiarities. Due to the nature of the cargo they carry, the area around the cargo tanks is considered a hazardous area and any part of the ship adjacent to them must be properly guarded. In addition, anything (e.g., Ballast) from 'dangerous' to 'safe' areas may not be transferred. For this reason, the marine ballast management system adjacent to the cargo tanks is divided into two areas.

- For the In-line layout there is an imaginary "safety" line that separates the two areas, safe and non-safe, and each has different Sea Chests, filters, pumps and electrolytic cells. The pipes end up on one side to Ballast tanks, and on the other to the Aft Peak Tank. These areas are not internally connected and filter different ballast waters using the same type of system installed in duplicate on board.
- In the Side (Slip) Stream systems the arrangement is as above - with the same equipment respectively - except that there may be an electrolytic cell in the safe area with an injector where it will be connected to a line above the deck, which will take the injected ballast into the hazardous area to be stored in the corresponding ballast tanks adjacent to the cargo tanks. This reduces the cost of equipment, which remains high for this BWTS on Tanker ships.

During ballasting and de-ballasting, a sample of processed ballast is sampled before being stored in tanks or unloaded at the Overboard, and that sample is transferred to a TSU unit to measure its concentration in TRO. Then, depending on the measurement, it is considered whether it’s suitable for discharging or not.

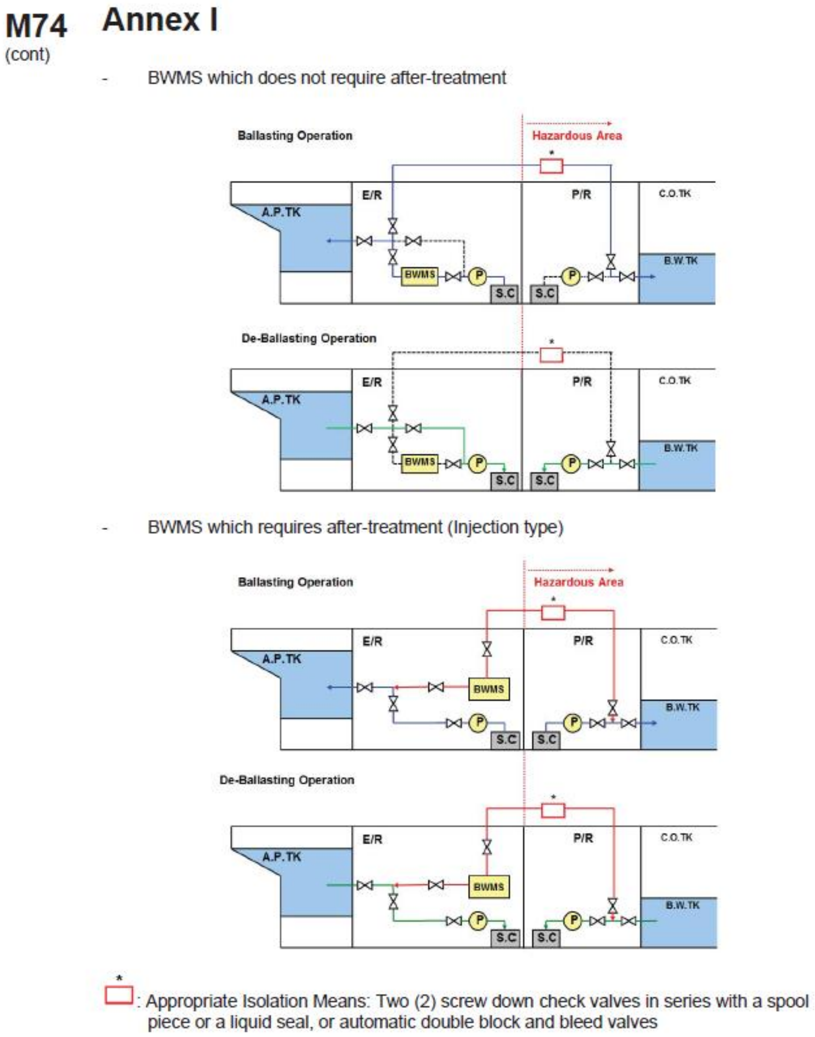

Figure 8: BWTS Filter & Electrolysis system display on tankers (Tsami, 2018).

<u>*Information on some of the BWTS Filter & Electrolysis components:*</u>

• *ANU (Auto Neutralization Unit)*: is the equipment for neutralizing the total residual oxidants remaining in the ballast during unloading. The ANU automatically checks the amount of the neutralizing agent and unloads it into the pipes.

• *TSU (TRO Sensor Unit)*: measures the concentration of TRO in the processed ballast during ballasting and de-ballasting (as well as stripping) processes.

• *GDS (Gas Detection Sensor)*: measures the amount of H_2 gas produced during electrolysis.

• *FMU (Flow Meter Unit)*: measures the rate of ballast flow through the pipes. Flow measurement is used to control the electricity needed.

• *CSU (Conductivity Sensor Unit)*: during ballasting measures ballast conduction and sends this information to the HMI (Human Machine Interface) to control the electricity provided.

• *FTS (Fresh water Temperature Sensor)*: measures the temperature of the cooling fresh water and sends this information to the HMI.

• *EWU (Em Washing Unit)*: rinses the electrode unit with a cleaning agent.

(DNV GL, 2018).

3.3 Chemical Injection

Chemical injection, also called Electro-chlorination injection, is a traditional technique for wastewater disinfection. It can be accomplished through direct injection of chlorine-containing compounds or converting the naturally occurring chlorides in seawater (Cl-). There is the electrolytic chlorination (electrolysis) where an electrical current is applied directly to seawater generating chlorine (Cl_2), sodium hypochlorite (NaOCl), hypobromous acid (HOBr) and other hydroxyl radicals. Electrochlorination requires minimum salinity levels in the ballast water or additional salt would be required. As described before, that method can be either in-line or side-stream. Electrochlorination systems are attractive and provide cost-effective solutions, particularly on existing vessels (i.e., high ballast dependent vessels) when high ballast water capacity, limited space available onboard the vessel, and limited power availability outgrades other choices.

However, electrochlorination beholds some disadvantages as well.

a) These systems lead to higher power demands while an additional DC voltage is required to reach the DC amperage needed to generate the disinfectants when salinity and temperature are low beyond a level.
b) For vessels working in warm marine salinity waters, there are enough sufficient dissolved salts available. For vessels operating in fresh or brackish waters though, and especially in cold climates, electrochlorination technologies show some issues regarding the number of dissolved salts needed for the operation. To compensate for the low salinity levels, the vessels need to include separate tanks onboard for the sole purpose of transferring reserved marine salinity seawater or brine in order for the electrochlorination systems to work properly. For example, sea water can be reserved in the AFT peak tank before entering fresh or brackish waters so that it can be mixed with ballast water being treated. Alternatively, a brine system can be installed onboard which is going to pre-mix commercial salt with water for salinity enhancement of the electrochlorination ballast feedwater.
c) Reserving sea water in the AFT peak tank can be challenging as it is continuously de-ballasted to feed the side-stream EC cells during cargo operations. That could lead to lack of trim control on the vessel while conducting cargo operations.
d) Additionally, heating the side stream system is also a considerable option to improve the effectiveness and efficiency of the side-stream BWMS.

This kind of solutions presuppose the installation of the according equipment, which could be challenging or nearly impossible for some the type of vessels.

A different type of chemical injection coincides with <u>Chlorine Dioxide (ClO_2) Injection.</u> Generating chlorine dioxide has proved to be one of the most effective treatment methods for the elimination of microorganisms in ballast water and it can be created from stored precursor chemicals onboard.

Advantages of this alteration of chemical injection include the difference in the chemical reaction of the two above-mentioned chemical compounds. While chlorine reacts with organic compounds producing undesired disinfection byproducts called DBPs, chlorine dioxide only reacts with living cells and does not produce DBPs. In addition, secondary processing with neutralization agents is not required for that technology. The side stream chemical injection system installation is quite flexible, and it could be used for both port and starboard, forward and APT ballast tanks with a single ClO_2 generator.

Some disadvantages of that chemical injection method can be summarized below:

a) In high ambient temperature conditions, the sensitive stored precursor chemicals might be leaded to fast degradation, therefore vessels following trade routes accompanied by such temperatures might also face issues regarding to that matter. On that case, special storage spaces may need to be provided in order to prolong or maintain the shelf life of the chemicals. However, larger tanks for that purpose increase full tank weights and lightship weight of the vessels and also require proper handling by a specifically trained crew and safety personal protection equipment (PPE).
b) The availability of ClO_2 chemicals at the vessel's trade route destination, as well as the legal provision of the port regarding the handling and refilling of the chemicals and the obligated stay-at-port time are also considerable matters. Several chemical treatments require an extended amount of time at port for chemical replenishment, a serious issue for vessels with shorter trade route than that amount of time.

3.4 Ozone systems

The ozone treatment is an effective disinfection method when is dealing with seawater. Ozone treatment initiates chemical reactions in seawater like in chlorination, which results in the transformation of biocides such as hypobromous acid. In fresh water though, ozone decomposes fast, limiting the production of the required oxidants for the destruction of organisms. In order for that treatment to be effective in seawater, reserved marine salinity water should be provided to mix in a small amount with the ozone injection (Iliopoulos, 2020).

Ballast water treatment method using ozone is considered to be an effective one, however it produces the same disinfection byproducts (DBPs) as the chlorination and electrochlorination methods. When there is excess in TRO, then it is demanding to produce neutralizing chemicals. TRO monitors that are based in wet chemistry, are often used to check the process of the chemical injection during de-ballasting to ensure that the total residual oxidant (TRO) is within the acceptable limits for overboard ballast water discharge.

Ozone treatment methods also beholds some disadvantages:

a) TRO monitors can create issues in BWMS process and therefore, the subsequent use of neutralization chemicals increases the total operating costs.
b) Ozone technology requires taking safety measures as well as the installation of several special safety systems like ozone leaker detectors and low / high oxygen concentration sensors, which in turn increases the total cost as well as the risk of using this technology.
c) The use of ozone could possibly lead to increment of ballast water tank corrosion. Consequently, appropriate piping materials are to be selected in order to avoid corrosion, which could also increase the capital expenses of the BWMS Retrofit (Iliopoulos, 2020).

3.5 Other Technologies (limited information)

Other technologies are sometimes used for ballast water treatment. For example, pasteurization, ultrasonic vibration, cavitation, and vacuum are sometimes used alone or combined with other treatment technologies for some BWMS designs.

With more details, some of the alternative ballast water treatment methods are:

1. Magnetic Field: The magnetic field treatment uses the coagulation[1] technology. Magnetic powder is mixed with the coagulants and added to the ballast water. This leads to the formation of magnetic flocs which includes marine organisms. Magnetic Discs are used to separate these magnetic flocks from the water.

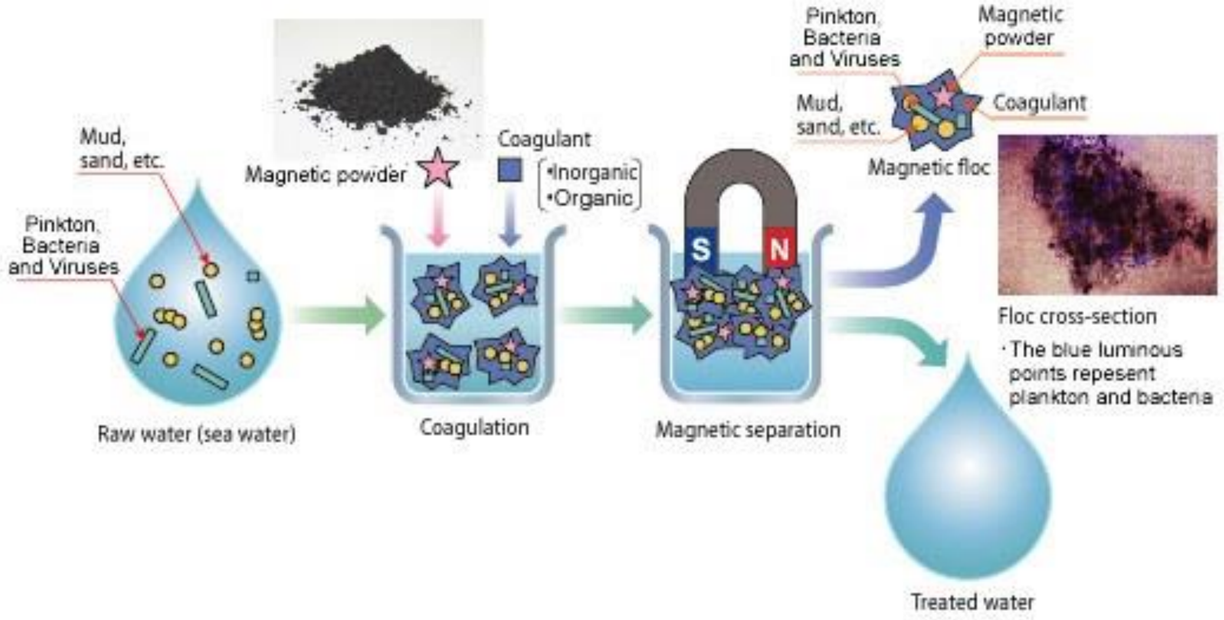

Figure 9: Visualization of Magnetic Field treatment.

2. Heat Treatment: This treatment involves heating the ballast water to reach a temperature that will kill the organisms. A separate heating system can be utilized to heat the ballast water in the tanks, or the ballast water can be used to cool the ship's engine, thus disinfecting the organisms from the heat acquired from the engine. However, such treatment can take a lot of time before the organisms become inactive and would also increase the corrosion in the tanks.

3. Acoustic/ Cavitation or Ultrasonic: Ultrasonic energy is used to produce high energy ultrasound to kill the cells of the organisms in ballast water. Such high-pressure ballast water cavitation techniques are generally used in combination with other systems.

4. Electric Pulse/ Plasma: The electric pulse /plasma for ballast water treatment is still in the development stage. In this system, short bursts of energy are used to kill the organisms in ballast

[1] Coagulation: As most of the physical filtration methods are not able to remove smaller solid particles, the method of coagulation is used prior to the filtration process to join smaller particles together to increase their size. As the size of the particles increase, the efficiency during the above-mentioned filtration processes increases. Such treatment involving coagulation of smaller particles into small flocs is known as flocculation. The flocs settle more quickly and can be removed easily.

water. In the pulse electric field technology, two metal electrodes are used to produce energy pulse in the ballast water at very high-power density and pressure. This energy kills the organisms in the water. In electric plasma technology, high energy pulse is supplied to a mechanism placed in the ballast water, generating a plasma arc and thus killing the organisms. Both these methods are said to have almost the same effect on the organisms (Raunek, 2019).

3. 6 Overview of advantages and disadvantages

As a conclusion from all the above information, each technology has its own operational technicalities which emphasizes the differences between them. The table below (Table 5) summarizes the main advantages and disadvantages of the five and most used technologies mentioned above, for a brief comparison and evaluation.

Table 5: Overview of advantages and disadvantages of the five most-used ballast water treatment methods.

Method	*Advantages*	*Disadvantages*
Filter and UV	• Simple application and maintenance. • Low capital cost for small water ballast flow rates due to less auxiliary components required. • Applications to waters of any salinity. • Easier installation and retrofitting, except for the case of oil tanker vessels.	• Ballast water should pass through the UV again during de-ballasting. • Difference between the USCG and IMO in the testing methods to determine the efficacy of the UV-based BWMS. • Higher power consumption, especially for larger water ballast flow rates. • Affected by water transmittance/turbidity. • Larger electric power installation. requirements inside the pump room area, for the case of oil tankers. • Holding time period before de-ballasting of minimum 3 days (72 hours).
Filter and Electrolysis	• Cost-Effective system – especially in high-ballast vessels. • Well established method in other industrial applications • Power efficient, especially for large water ballast flow rates. • Smaller electric power installation requirements inside the pump room area, for the case of oil tankers • Treatment process with electrolysis takes place only during ballasting. During de-ballasting only monitoring and neutralization is required.	• There are several restrictions in the conditions for the process to be safe and accepted. • Hydrogen gas as sub-product will require safe management. Risk assessment is carried out and Class approved solutions are applied for handling hydrogen production. • Spare salt water may be needed. • Temperature raised/Heater could be used => higher cost in use and installation.

Electrochlorination (Similar to Filter and Electrolysis)	• Cost-effective solution • Particularly good for high-ballast vessels.	• Produces DBPs. • Higher power demands with the additional DC voltage required. • In low salinity waters (fresh or brackish) vessels need to include separate tanks carrying reserved marine salinity or brine. • Lack of trim control during cargo operations. • Installation of special equipment => challenging.
Chemical Injection / Chlorination	• Most effective for the elimination of microorganisms. • Does not produce DBPs. • Not requiring neutralization agents. • Flexible system installation and retrofitting. • Not affected by sea water salinity. • Lower capital investment costs.	• Need for special space to protect the chemicals due to degradation in high ambient temperature conditions, which results in the increase of weights and professional handling. • Extended amount of time at port for chemical replenishment. • Higher operational costs. • Safety risks due to the use of the chemicals.
Ozone	• Effective method (like electrochlorination). • Advantageous for handling larger water ballast flow rates. • Smaller electric power installation requirements inside the pump room area, for the case of oil tankers. • Treatment process with electrolysis takes place only during ballasting. During de-ballasting only monitoring and neutralization is required. • Limited piping work in case of retrofitting. • Not affected notably by sea water salinity and temperature.	• Ozone decomposes fast in fresh water. • Produces DBPs. • TRO monitors create issued in BWS process. • Large number of auxiliaries are needed and provided by the manufacturers resulting into complexity in installation, control and maintenance. • Increase operating costs due to higher demands, especially for the case of smaller water ballast flow rates. • Safety measures – risk of using that technology due to the ozone produced which is toxic. • Ballast water tank corrosion. • Only three IMO type approved manufacturers for that technology, while none USCG type approval has been granted yet.

4. BALLAST WATER TREATMENT TECHNOLOGIES IN DIFFERENT TYPES OF VESSELS

In order to comply with the ballast water regulations, ship-owners have to choose the right BWMS to install on a vessel. The criteria for that choice are numerous and cover any possible aspect for a new and important installation, covering the demands of the ship on ballast water along with the impact of the system on the ship operations and the balancing cost of the installation.

Regarding the above, a ship-owner or operator needs to evaluate the following factors:

1. Vessel type.
2. Maximum and minimum flow rate during ballasting and de-ballasting.
3. Ballast water capacity of the vessel and the required amount of space.
4. Ballast water needs of the vessel.
5. Flexible positioning of the components of the system.
6. Cooperation with the rest of the vessel's systems.
7. Certified and safe / validation for safety.
8. Valid certification and the according certificates.
9. Availability of consumables, spare parts and support (service).
10. Operating cost.
11. Availability of the system and delivery time.
12. Validation that the chosen system contains the right amount of capacity to cover the ballast water supply of the vessel.
13. Electricity consumption.
14. Chemical substances required, consumption rate and availability in ports.
15. Health and safety measurements (working environment, handling and storage of chemicals).
16. Protection systems for normal and emergency operation.
17. Requirements for training on the safe use, monitoring and regulation of the system.
18. Statement of the effects of treated ballast water on ballast tank coatings - including copies of relevant studies supporting such claims.

The above list of factors constitutes a full research that will result into the final choice of the BWM system appropriate for a vessel. However, basic steps can be followed in order to facilitate that research.

Retrofits

Retrofits are ballast water treatment systems that are installed on an already operating vessel. Installing such a system on an existing vessel is typically more complicated than on a new-build. Ballast water treatment was not considered during the original construction of most vessels, and as a result, there is no dedicated space for the new system. This means that the installation needs to be adapted to existing circumstances on board. High flexibility, thorough preparation and strong cooperation from all partners are all necessary for a successful retrofit installation as it affects many onboard systems, each of which has its own specific considerations. A retrofit is not simply the installation of new equipment, but the addition of a complete system that will demand a new way of managing ballast water. The typical dockyard timeframe for a retrofit is two weeks, and any delay means lost income for the vessel owner (ABS, 2019).

Poor retrofit planning or selecting a BWMS with incompatible system design limitation (SDL) could result in consequences such as:

• Noncompliant ballast discharges requiring another retrofit for replacement with a suitable BWMS.

• Possible deviations from planned routes and loss of charter opportunities due to inability to meet the discharge standards or severe vessel voyage restrictions.

• Fees or criminal penalties and Port State detentions that could damage the reputation of the vessel owners and operators.

• Delays during cargo operations and possible restrictions by some ports.

• Additional delays to conduct contingency measures to regain compliance (possibly at lay berth, loitering, or slow steaming *en route* while conducting ballast water exchange etc.).

• Increased operating expenses and higher life-cycle costs.

• Off-hire periods making charter retention problematic.

• Commercial and financial losses including early scrapping of a vessel in lieu of a second retrofit.

Considering though the new Guidelines, most vessels needed a ballast water treatment system retrofit to be installed, therefore the necessity of a wise choice of such a system. Below listed are the most important parameters affecting the decision-making process.

4.1 General parameters

A virtual conference about ballast water management was held by the BS group where the main points discussed were the below:

• How to choose the right BWMS for ships?
• How to deal with technical challenges during the BWT such as power supply, salinity, tank stripping etc.
• What is the best guideline of retrofit installations for BWMS?
• What are the essentials of the Ballast Water Management Plan?

Many professionals in different aspects around the BWMS gave insightful information and tips for ship-owners (BS Group Webinar, 2020).

Derived from that useful presentation are below presented the general parameters that play a part in the selection process of the best fitted BWTS.

- Ship Type and characteristics

According to the ship type, vessels can be divided into two categories regarding their needs in ballast water:

High ballast dependent ships, such as tankers and bulkers,
Low ballast dependent ships, such as containerships, general cargo ships and cruise ships.
The determination of whether a ship has a high or low ballast dependency is based upon the ballast demands, such as the maximum amount of discharge at any one port, pump capacities and maximum ballast flow rates.

High ballast vessels usually have to ballast in a specific time period to facilitate the port turnaround times. These operations can take up to 12, 18 or even 24 hours usually. On the other hand, for low ballast vessels have smaller ballast capacities and therefore the pumps don’t need to handle ballast operations regularly. Also, in order to adjust the lining or heel, the ballast is transferred from one tank to another instead of filling a tank when unloading cargo.

- Size of the vessel and Installation Space Required

For newbuilding vessels, the BWMS size and weight can be accommodated, though for the existing ones the size is a very important challenge. The common space requirements can vary from a few to more than 25 m² for a small BWMS (i.e., TRC of 200 m^3/h) and more than 50 m² for larger systems (i.e., TRC of 4,000 m^3/h). Most BWMS models increase in size as ballast capacity increases but the increased size may not be linear. An important space consideration is the changes to the vessel's ballast piping. New branch lines or bypasses that shall be installed can lead to large diameter piping with large elbows and tee fittings can require much additional installation space. For example, in full flow Electrolysis or UV-based systems with filtration, the installation can be complicated due to the additional space required for the large piping revisions, while side-stream EC or chemical dosing systems can reduce these piping revisions.

Last but not least, check for maintenance space requirements is also important. The BWTS components that could be opened for removal of replacement might need extra space around the installed system. Also, an additional chemical storage space and safeguards can be mandatory for some systems which could result in additional footprint and weight considerations for the BWMS.

- Power demand and Energy Consumption

The power demand of a ballast water treatment system is a high importance factor that any ship-owner should take into consideration before choosing the appropriate system for a vessel, especially for retrofit systems. The total consumption of a system is calculated by its typical power demand, the water conditions, rated TRC, the probable or actual flow rates as well as the total ballast water treated –or re-treated for some technologies-. For BWTS using chemical dosing of active substances, the chemical costs are also included.

For newbuilding vessels, the system is engineered into the vessel as a component during the vessel's design. The designer considers the space and power requirements from the beginning, which makes the final installation relatively easy, while for retrofits the vessel needs to have enough available power to meet the maximum power demands of the BWM System. That can lead to the need of using all three auxiliary engines/ generators which can be a challenge for a vessel: overuse of the power of the engine and the possibility of one engine/generator ton not be available or out of commission. A ballast water treatment system may be operating in reduced power option, only for several times. Overall, for newbuilding vessels the possibilities for a system adapting the vessel are normally large, so the choice of ballast water treatment system is less consequential from an installation perspective, even if the cost and complexity may vary.

For the chemical injection systems, the need for power supply is low (approx. 30kW) and not being affected by water parameters, while other systems such as UVs, Electrochlorination and Electrolysis are more demanding.

- Salinity

The water salinity affects the treatment systems which are based on Electrochlorination (Electrolysis or Electrocatalysis). According to the approved systems, the lower salinity at which a BWTS can operate is 0.85PSU. The majority of the BWTS are keeping salt water or brine in a tank onboard (usually the APT) for injection so the salinity can be adjusted to the acceptable level. Therefore, the BWTS based on active substances work well for vessels operating in brackish or marine waters when enough salinity is available. For vessels operating in freshwater or low salinity brackish water, the system might not operate properly and so affecting the BWMS performance.

- <u>Tank Stripping</u>

Single treatment technologies do not affect the stripping operation however, the design of any new pipe to accommodate TRO sensors and neutralizing agent injection should be designed carefully without compromising suction or pressure. Both-way treatment technologies such as UV, may pose challenges in stripping operation due to pressure or suction loss from the passage of the water from the UV reactor and the piping involved.

- <u>Footprint and dry-weight</u>

Footprint and dry-weight of the installed BWMS are key aspects for BWMS selection. Vessels with larger ballast water treatment rated capacities, such as high ballast dependent vessels, would typically result in larger BWMS. Due to limited space onboard an existing vessel, selection of a BWMS with small footprint or suitable for installation in smaller spaces on the vessel is important.

Total dry-weight and operating weight of the BWMS is also an important aspect of the BWMS retrofit, particularly since additional weight onboard the vessel cause cargo displacement and affect the vessel's trim and stability and could result in structural modifications.

- <u>Trading Pattern</u>

The trading pattern of a vessel along with the number of round trips per year, is a major factor affecting almost all the above considerations when choosing a treatment system. It can affect the salinity depending on the waters that is operating, the power demand required per trip and the number of trips per year, as well as the maintenance and repair of the system that is contingent on the ports visited by the vessel and the availability of spare parts and other necessities of the system.

As an example, especially for the chemical injection treatment systems, is that, depending on the vessel trade routes the vessel might experience a possibility of high ambient temperature conditions which could result in the accelerated degradation of the stored precursor chemicals (i.e., sensitive to high temperatures) and that itself leads to a lot of extra requirements for the vessel and the system. Another issue would be availability of the treatment chemicals at the vessel's trade route destination. Some cargo terminals require extended in-port periods at lay berths for chemical replenishment.

4.2 Containerships

The typical Panamax containerships carry ballast in the double bottom and are equipped with wings used to maintain stability as well as control trim and list. Usually, post-Panamax sized vessels are larger so they have much more flexible ballasting options and can often avoid port discharge through careful planning. Usually, the containership's ballast system does not have the capability to transfer ballast between tanks. As a result, ballast water is discharged to the sea when tanks are de-ballasted even though new ballast water may be brought into other tanks to reach the desired load condition. If possible, ballast adjustments are made at sea prior to arriving, in anticipation of the expected loads, or after departing the port. Some ballasting may be necessary during container loading and unloading operations (Hurley *et al*, 2001).

A common and preferable choice is the UV-based, full-flow electrolysis system for a containership. There are no hazardous space complications, and the engine room (although not usually spacious) has available room for the machinery. There are no significant equipment installation issues.

4.3 Bulk Carriers

Bulk carriers, one of the largest segments of the merchant shipping fleet, are highly ballast-dependent. Some of these bulk carriers, possessing Topside Water Ballast Tanks not connected to the Bottom Side Water Ballast Tanks and which often de-ballast directly overboard by gravity discharge, complicate BWMS selection. For these vessels, the selection of a suitable BWMS requires additional considerations. Topside tank gravity discharge operations are incompatible with most IMO and USCG type approved BWMS (David, 2015).

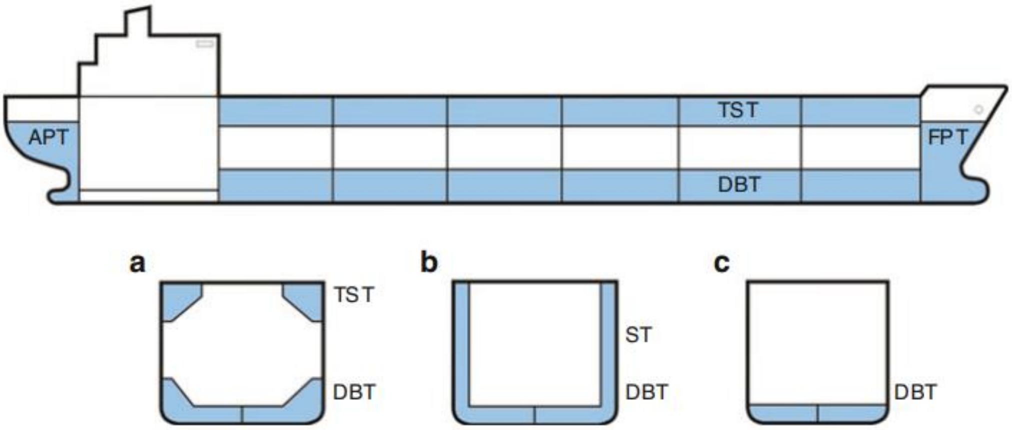

*Figure 10: Ballast tanks on: (**a**) most bulk carriers, (**b**) tankers, container vessels. And some newest bulk carriers, and (**c**) Ro-Ro and general cargo vessels. (APT after peak tank, DBT double bottom tanks, FPT forepeak tank, ST side tanks, TST topside tanks or upper wing tanks).*

UV-based treatment systems are not usually a wise choice for bulk carriers due to the main operating principle of that technology. These systems require re-treatment by UV during discharge and most active substance based BWMS require neutralization (mandatory for compliance with the type approval certificate requirements) before discharging overboard. Retreatment process requires the topside tanks ballast water to be re-routed back to the bottom side ballast tanks or ballast headers to perform retreatment during de-ballasting, therefore it is nor effective neither appropriate for this kind of vessels. Selecting a BWMS that does not require secondary treatment and that allows overboard discharge of the topside tank ballast water or installation of a dedicated BWMS for the topside tanks, constitutes of an excellent alternative option for bulk carriers however, this might increase the capital and operating expenses due to additional equipment and associated components.

Chlorine Dioxide (ClO_2) Injection method is an option. Since no secondary treatment or neutralization is required during de-ballasting operations, this treatment technology is compatible with bulk carriers' topside tanks configurations requiring gravity discharge overboard. Similarly, the Filter and Electrolysis could be an effective combination for treating ballast water in bulk carriers.

4.4 Tankers

Tanker ballasting operations are characterized by moving large volumes of ballast each trip. The ship must have a minimum draft when not carrying cargo to control hull stresses, provide good seakeeping and maneuvering, and provide propeller submergence. Pumps and valves are controlled by the ballast control system, which is part of cargo control (Hurley *et al*, 2001).

“Gravitating” ballast is an important component of the ship’s ballasting operations. Gravitating is allowing water to flow into or out of the tanks using the head differential between the tank level and the outside water level, and not using pumps. The ability to gravitate reduces the owner’s cost because of reduced pump operating time and provides simpler and more efficient operations for the crew.

Equipment installation in almost all tankers, is complicated because the ballast piping, pumps and valves are all located in the pump room, which is a hazardous area. The pump room also happens to be the most crowded, densely packed space on the vessel. In addition, it is probably not possible to install a UV unit in that space because it would introduce electrical equipment and its wiring in a hazardous area. Electrical equipment in hazardous areas is not allowed unless “essential for operation purposes.” The electrical equipment that can be allowed in the pump room must be intrinsically safe, and so far, an intrinsically safe UV unit is not available. If a UV-based treatment system is to be used in a tankers vessel, then there can be some potential solutions to overcome the above issue (Hurley *et al*, 2001):

1. Route the ballast piping out of the pump room up into a small UV unit compartment accessible from the engine room and install the UV unit in that space (Figure 11).
2. Continue in the development of an intrinsically safe unit and also gain acceptance from the regulatory bodies (Classification society, etc.) that the unit is essential for operation purposes. (i.e., certification as explosion proof and intrinsically safe).
3. Drop the UV unit and proceed with other alternatives.

While the first option is the best and a very effective one, it is not easy to accomplish given the pump room space arrangements and physical size of the piping. Also, there are still potential regulatory problems as the ballast piping could be considered to pass through spaces where sources of ignition are present. Additionally, the internal piping may also have oil vapors when dry. This problem can be addressed by installing a flow sensor on the piping that does not allow the UV unit to be energized unless the pipe is full of flowing ballast water. The aft ballast systems are much easier to install because the components can all be in the spacious engine-rooms, and not be subject to the space and hazardous location constraints of the pump room.

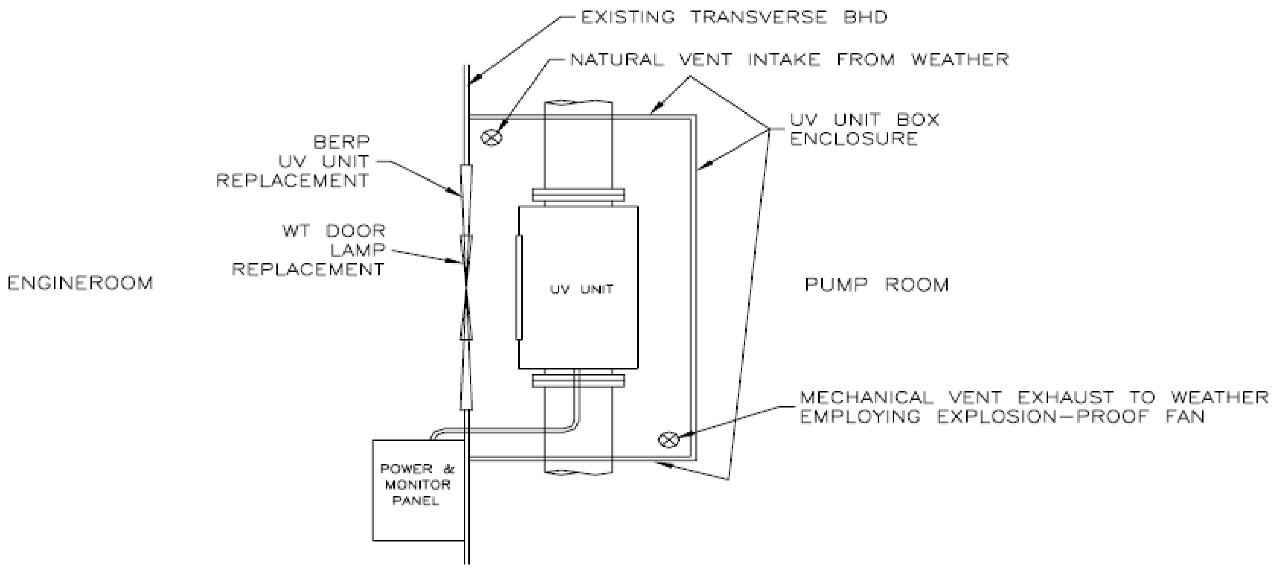

Figure 11: Alternate UV unit Location (Option 1).

Electrolysis system in a tanker vessel can be challenging as well. Some of the technologies can be provided as explosion-proof products[2], but there is a cost factor for this. The generation of hydrogen by the electrolytic technologies is not considered an issue, provided the gas is vented and diluted with air to safe levels, but it is still a concern.

The chemical treatment system is the simplest and least-cost installation and requires very minor storage facilities and tank volume however, it requires approval of all regulatory bodies (federal, state and local) before discharge of the chemical is accepted, and that regulatory approval process may be long.

Generally, the process of electro-chlorination generates hydrogen and chlorine gases that are both explosive and toxic. Mixtures of hydrogen and chlorine have a wider range of flammability than mixtures of either gas with air. Many vessels have overcome the potential hazard by installing/ upgrading existing ventilation systems to ensure that gases created are sufficiently diluted and removed safely (gas monitoring systems are also incorporated).

4.5 Chemical Tankers

Similar to the tankers vessels, a chemical tanker vessel faces multiple issues in the decision of the treatment system operating onboard because of the hazardous areas and danger in explosion that lies on that. An important criterion of technique is the existence of gas-proof insulation on BWTS devices. Gas-proof standard is a prerequisite for dangerous cargo carriers (i.e., oil tankers, chemical tankers).

The most common technologies used in chemical tankers are the combination of Filter and Ultraviolet radiation (UV), as well as the Filter and Electrolysis treatment. Side-stream system functions like the first option for UV units in tanker vessels, as described in the subchapter 4.4, and is the most preferable solution also for chemical tankers using that treatment technology.

[2] Explosion proof applies to an apparatus enclosed in a case that is capable of withstanding a gas or vapor explosion. It means that, should there be an explosion, it will be contained within an enclosure (NFPA, 2020).

4.5.1 Conclusion/ comments for Tankers/ Gas Carriers:

If a ballast tank is located in a hazardous area (tankers, LNG carriers, LPG carries, Chemical tankers etc.), then sampling and dozing pipes are to be in a non-hazardous area located within a gas tight enclosure and equipped with gas detectors, sensors of water leakage and automatic shut-down (Venetsanou, 2017). Also:

- BWTS is to be in a Hazardous area (pump room), considering the following:
  Measures in a hazardous area:
  1) Special considerations according to Class Rules, SOLAS and IEC 60092-502 (1999)
  2) An interlock for disallowing maintenance on the BWMS when it is energized
  3) An Interlock with the pump room ventilation
  4) The BWMS is to be earthed to the metal hull
  5) An interlock such that any detection of hydrocarbon gas will immediately shut down the BWMS
  6) The circuit feeding the BWMS is to be monitored continuously for ground faults and is to give an audible and visual alarm
  7) All cables, other than those of intrinsically safe circuits are to be sheathed with a non-metallic impervious sheath
  8) The failure of pressurization where applicable for certified safe type components of a BWMS is to result in the shutdown of the power supply of the BWMS
  9) The BWMS shutdown device and power supply are to be located outside the pump room space

- BWTS is to be in a non-hazardous area (more than 2,4m above deck) considering the following:
  Measures in the Non-hazardous Area:
  1) A remote operable valve is to be installed in the ballast piping leading to the ballast tanks
  2) Remote operable valve the ballast water pump and the BWMS are to be automatically shut down in the case of loss of power or detection of flammable and/or toxic vapors, in the ballast tanks
  3) The ballast water piping penetrations are to be watertight.

4.6 BWTS Operational Experience by Technology Analysis

Based on a survey (ABS, 2019) of 483 vessels covering a wide category of vessel-types (bulk carriers, containers, tankers, LNG carriers, gas carriers, general cargo carriers, product carriers, vehicle carriers and heavy load carriers), the below diagrams can be considered representative of the market, as well as a reference for conclusions on the different types of technologies, their use and the difficulties faced.

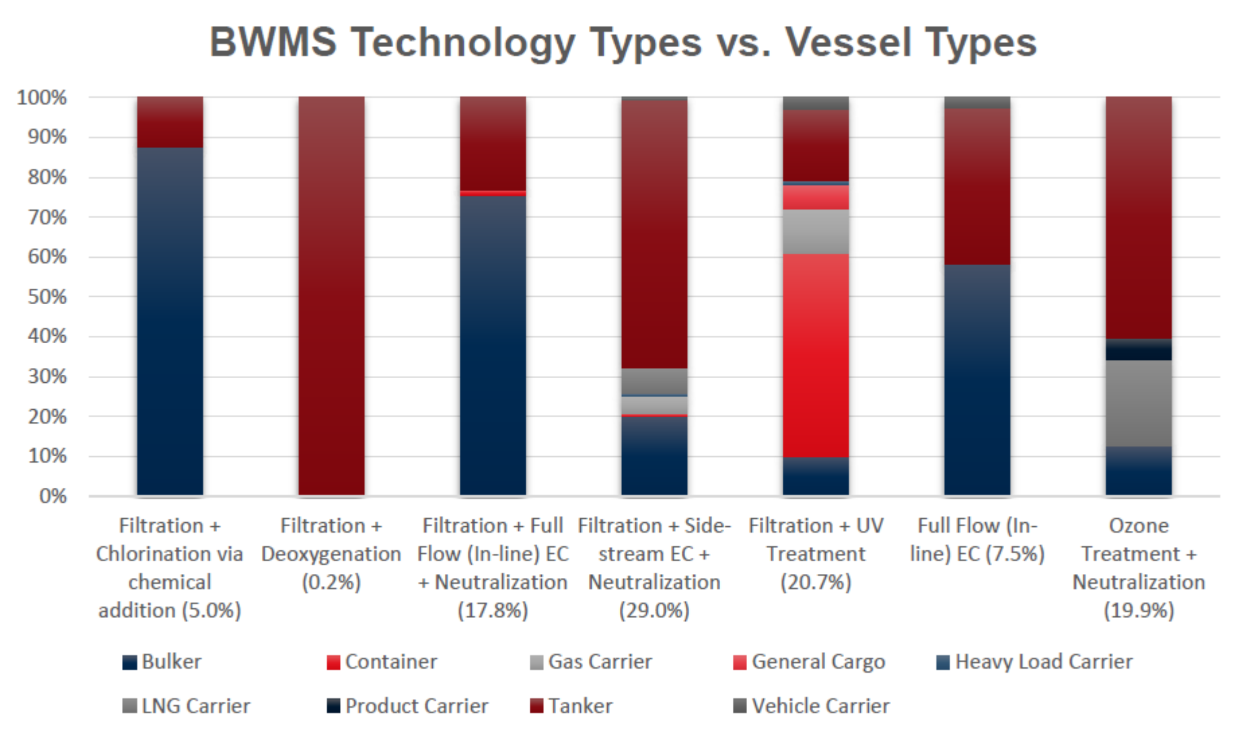

Figure 12: BWTS Technology Types vs. Vessel Types.

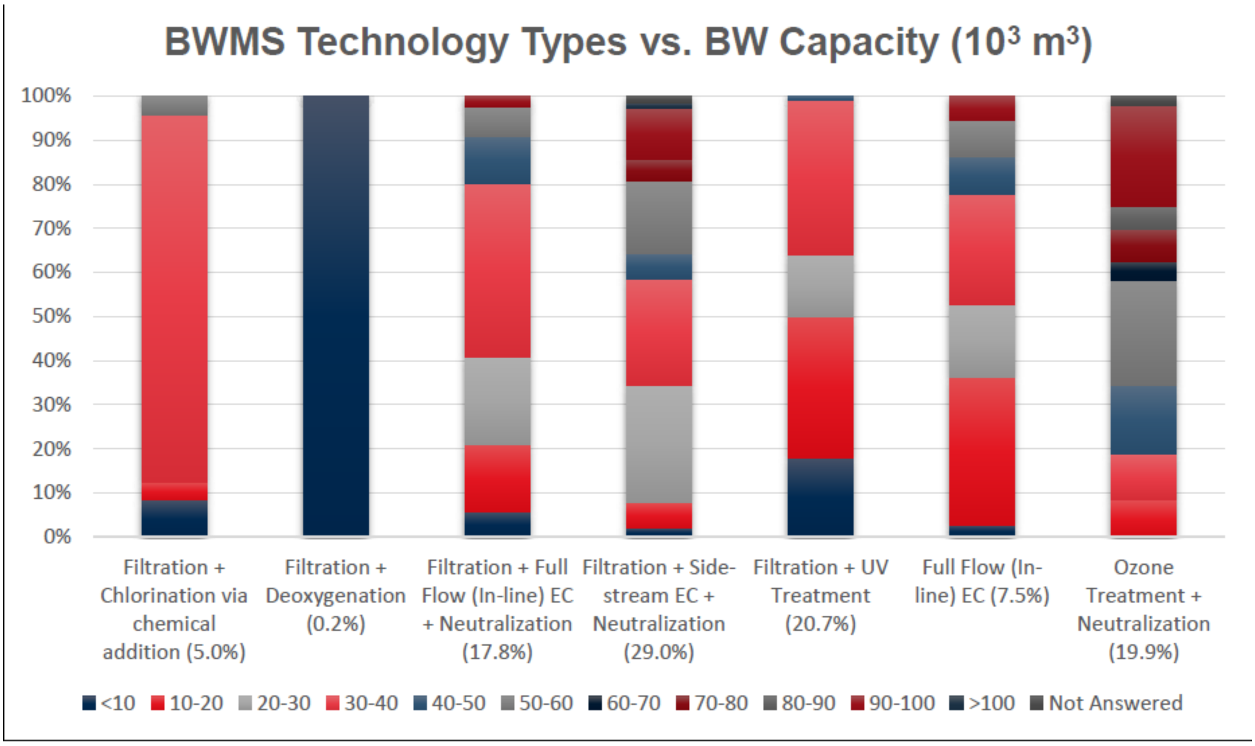

Figure 13: BWMS Technology Types vs BW Capacity (10 m^3).

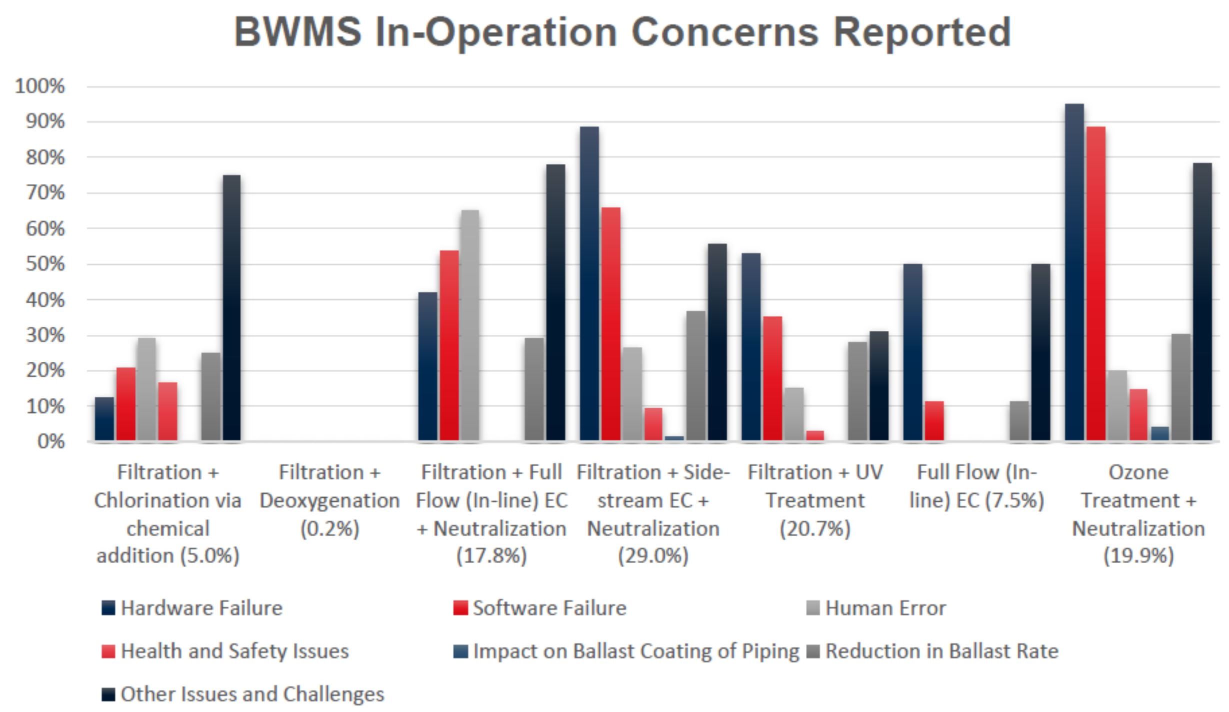

Figure 14: BWMS In-Operation Concerns Reported.

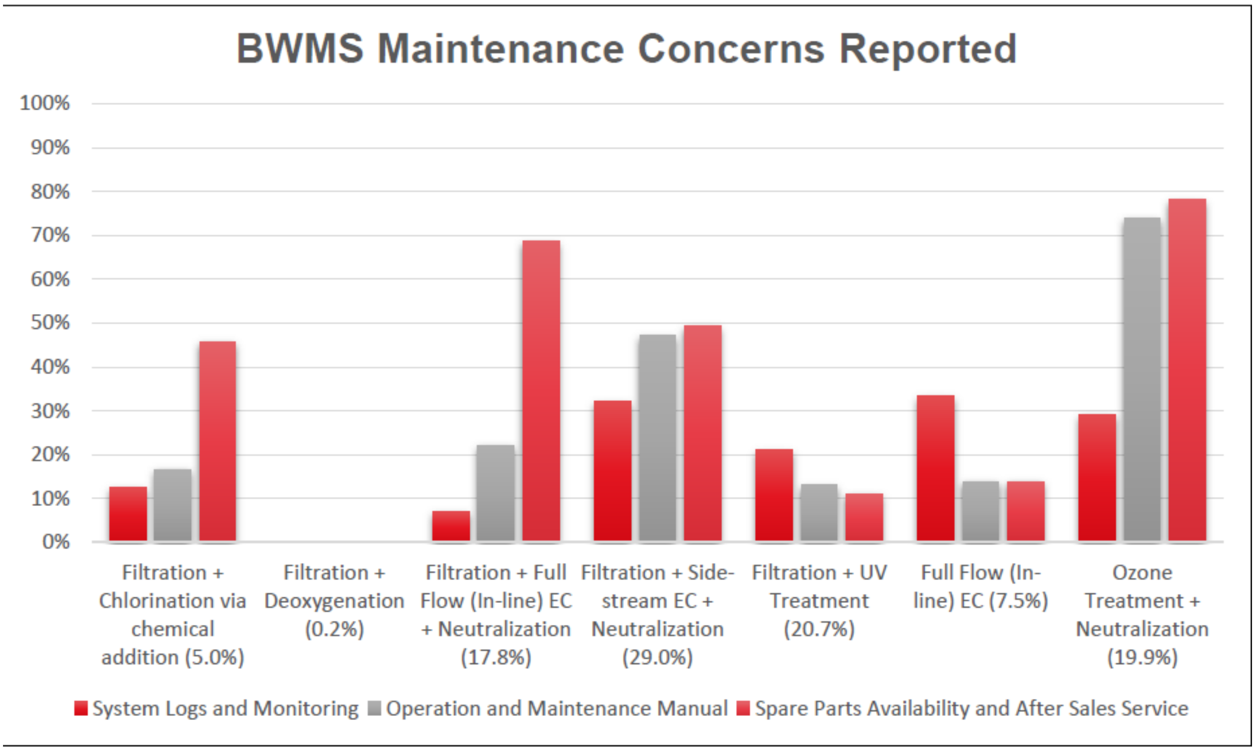

Figure 15: BWMS Maintenance Concerns Reported

5. COMPARATIVE ASSESSMENT ON THE BALLAST WATER TREATMENT SYSTEMS OF TWO SISTER BULK CARRIERS

Two Bulk Carriers, and sister vessels, with different ballast water treatment systems were chosen for this comparative assessment referring to the installation challenges, effectiveness of each system and operating aspects.

The definition of *sister vessels* refers to two or more vessels of the same class or of virtually identical design (IMO, 2005). Such vessels share a nearly identical hull and superstructure layout, similar size, and roughly comparable features and equipment.

The reference vessels are the Bulk Carriers *Vessel A* and *Vessel B*.

5.1 Ballast Water Treatment Systems Description

The main characteristics of the Vessels A are given in *Table 6*.

Vessel A

Length	292.62 m
Breadth	45 m
Depth	24.8 m
Draft Scantling	18.3 m
Gross Tonnage	92744 t
DWT	179221.4 t
Ballast Capacity	145665.7 m^3
Year of Build	2010
Maker	Maker A

Table 6: Vessel's A details.

The installed system in the *Vessel A* is a BWTS (Maker A BWTS Installation Specification, 2020) which applies established chlorine dioxide (ClO_2) technology to oxidize and disinfect aquatic invasive species (AIS). It is a two-step treatment process: incoming ballast water is pumped onboard as usual (through the sea chest/sea filter) via the ship's ballast pumps. Ballast water then passes through the first step of treatment process, the automatic cleaning filter to reduce sediment and prevent larger organisms from entering the ballast tanks. The second step is generation and injection of ClO_2 into the incoming ballast water line. A small quantity of filtered ballast water is directed to the treatment system, where it is mixed with generated ClO_2 and it is injected into the incoming ballast water flow to achieve a 4.25 mg/L (ppm) dose in the total ballast water flow. The 4.25 mg/L (ppm) injection concentration set point is used to calculate the required chemical pump speed. There is a direct relationship between the chemical pump speed and the rate of ClO_2 production (kg/hr).

The main principle of that system is that once chlorine dioxide is transported through organism cell walls, it leads to cell inactivation and organism death while also disrupting vital cell functions. The treatment occurs only during the ballast uptake operation and it is not needed, either by ClO_2 or neutralization chemicals, at the time of ballast water discharge. The treated ballast water is held in ballast tanks and it is not considered corrosive or known to have negative effects on ballast tank coatings or vessel piping and pumping systems. Prior to discharging treated ballast water, the ClO_2 residual must be verified using the appropriate analytical device supplied with the BWTS. The time required for residual ClO_2 to reach the Maximum Allowable Discharge Concentration (MADC) of 0.2 mg/L (ppm) varies and may require more than 72 hours, depending upon water quality. The treated ballast water must be confirmed to have a ClO_2 content of ≤0.2 mg/L (ppm) by two representative, independent samples before discharge.

As of the Vessel B, its main characteristics are given in *Table 7*.

Vessel B	
Length	292 m
Breadth	45 m
Depth	24.8 m
Draft Scantling	18.3 m
Gross Tonnage	92715 t
DWT	179234.2 t
Ballast Capacity	145611.7 m^3
Year of Build	2010
Maker	Maker B

Table 7: Vessel's B details.

The installed system in the *Vessel B* is a treatment system (Maker B, BWTS, 2019) for ballast water (Model Maker B BWTS FIT 1x3000) which combines a filter with an electrolytic cell. During ballasting, the incoming/ upcoming water goes through filtration, to remove particles and organisms larger than 40 microns. The filtered water then enters the electrolytic cell. The remaining viable organisms are eliminated with in situ production of chlorine up to 6 mg/L (TRO) from advanced electrolytic cells. Using an active substance that is produced by the method of electrolysis any danger of re-growth is eliminated. During de-ballasting, the system is by-passed and the water can be discharged directly overboard after neutralization.

5.2 Installation of BWTS

For the *Vessel A* using filtration combined with chemical injection, the two (2) main ballast filters are installed in the engine room (lower level – *Figure 16*) as it is considered a non-hazardous space, and the ClO_2 Generator and chemical storage tanks are installed into a designed deckhouse located on starboard-side of the B-deck, at a non-hazardous space as well (*Figure 17*).

Generally, in chemical injection treatment systems, the chemical storage tanks must be installed in a dedicated space, preferably located on or above the main deck. An option is to install them into a dedicated space below main deck. Therefore, in all installations, this space must be designed and constructed in accordance with vessel class and flag requirements. Additionally, it is suggested to ensure proper clearance is provided in the area of electrical enclosure openings.

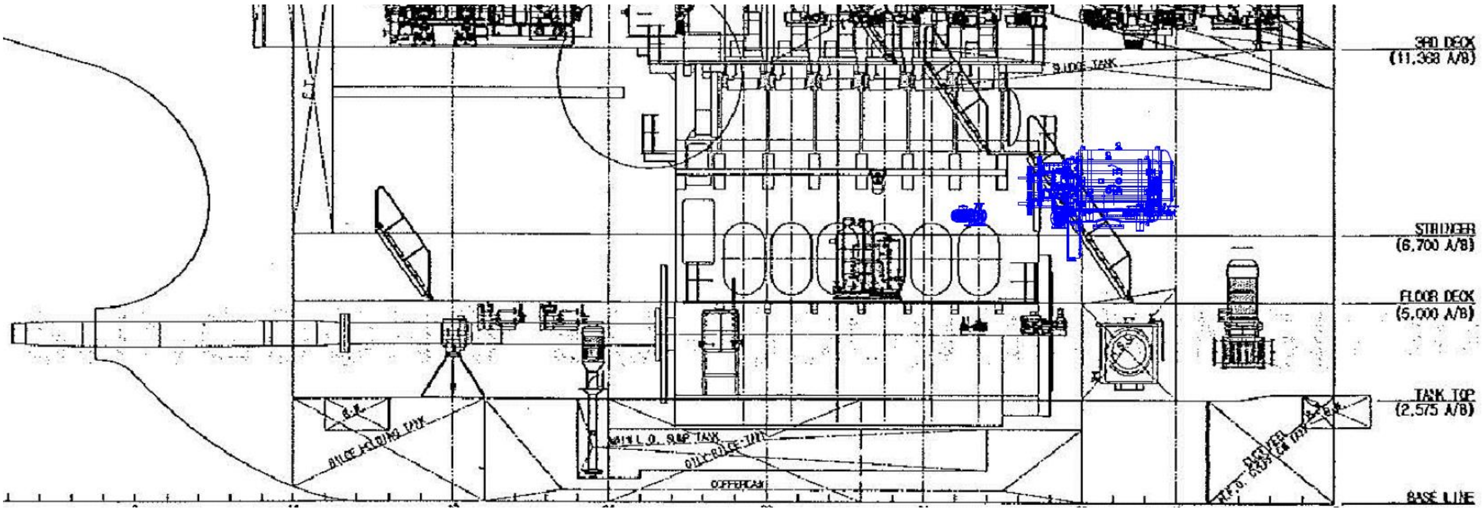

Figure 16: Port elevation (looking port) of BWTS filtration installation in the engine room, Vessel A.

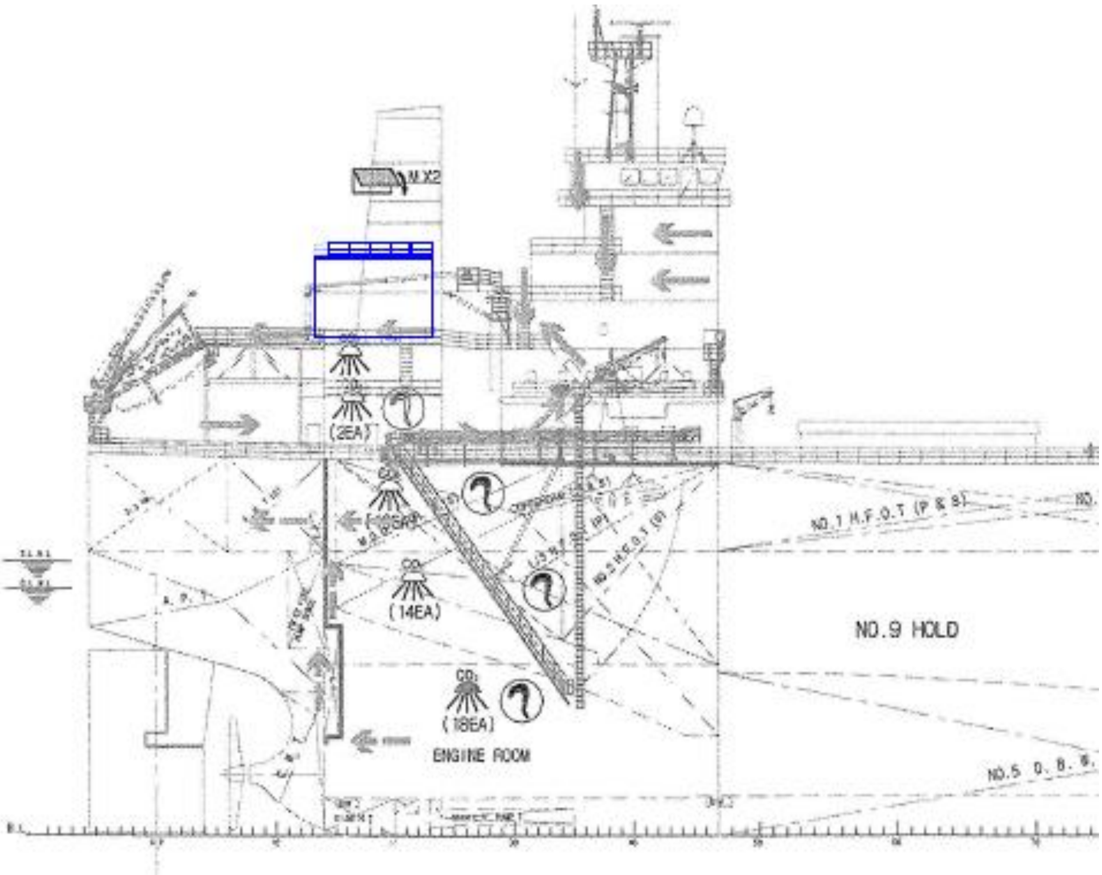

Figure 17: BWTS Chemical Storage Tanks Location, Elevation View B-Deck, Vessel A.

Regarding the *Vessel B*, the ballast water treatment system must be securely installed on a stable, horizontal surface, in a dry, spacious and well-ventilated position. There should be sufficient space for operation and maintenance. Therefore, the treatment equipment which includes a filter and three (3) electrolyzers (electrochemical cells) used for the electrochlorination, is installed entirely in the engine room (*Figure 18*).

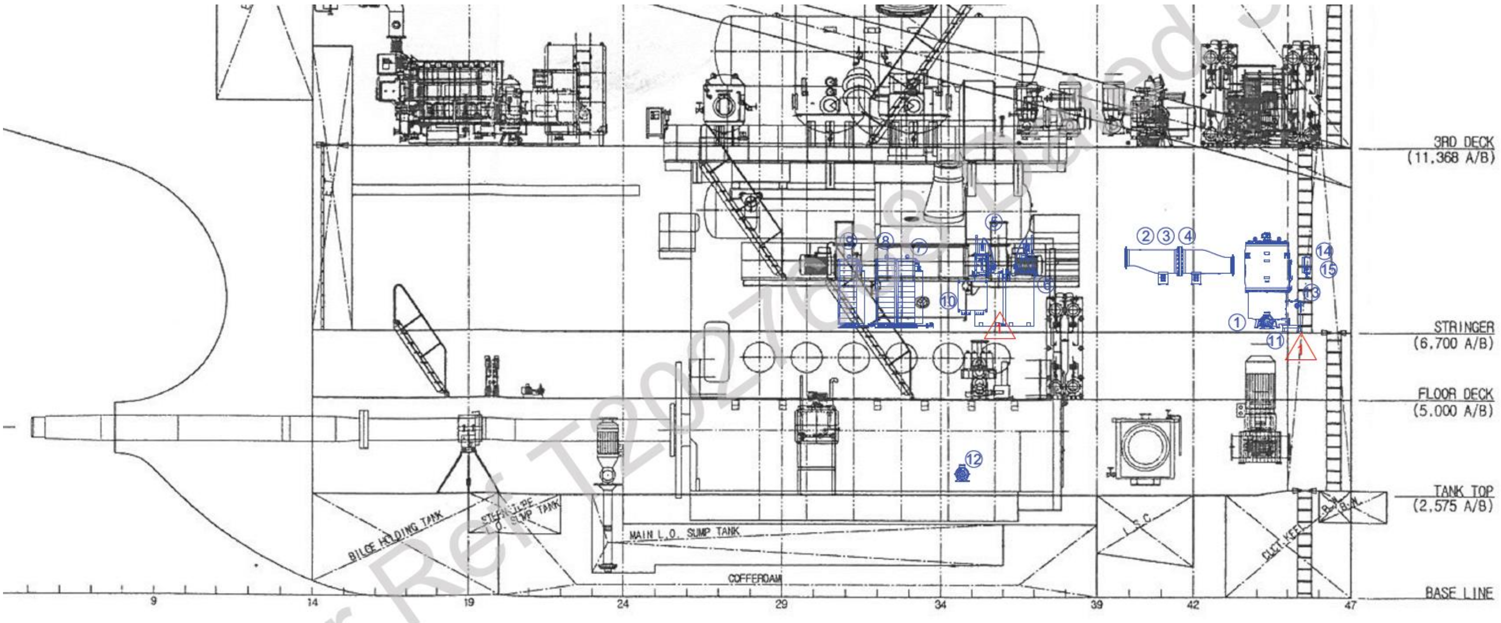

Figure 18: Starboard elevation of BWTS installation in the engine room, Vessel B.

Filter and (2), (3), (4): Electrolytic cells.

5.3 General Arrangement of the BWTS and Main Ballast Operations.

In the general arrangement of the Water Ballast System the pipes, pumps, valves, tanks etc. are shown as to indicate the route of the water ballast during the two main operations: i) *ballasting* and ii) *de-ballasting*.

There are two conditions in which the treatment system is operating:

1. Normal condition, and
2. Emergency condition. In this case the treatment operation stops, bypass valve opens, and an alarm is activated.

As an example, in the below figures the route of the ballast water is highlighted for both ballasting and de-ballasting operation (*Figure 19* & *Figure 20*) applied for the *Vessel B*. The location of all these drawings is the engine room.

5.3.1 Ballasting Operation

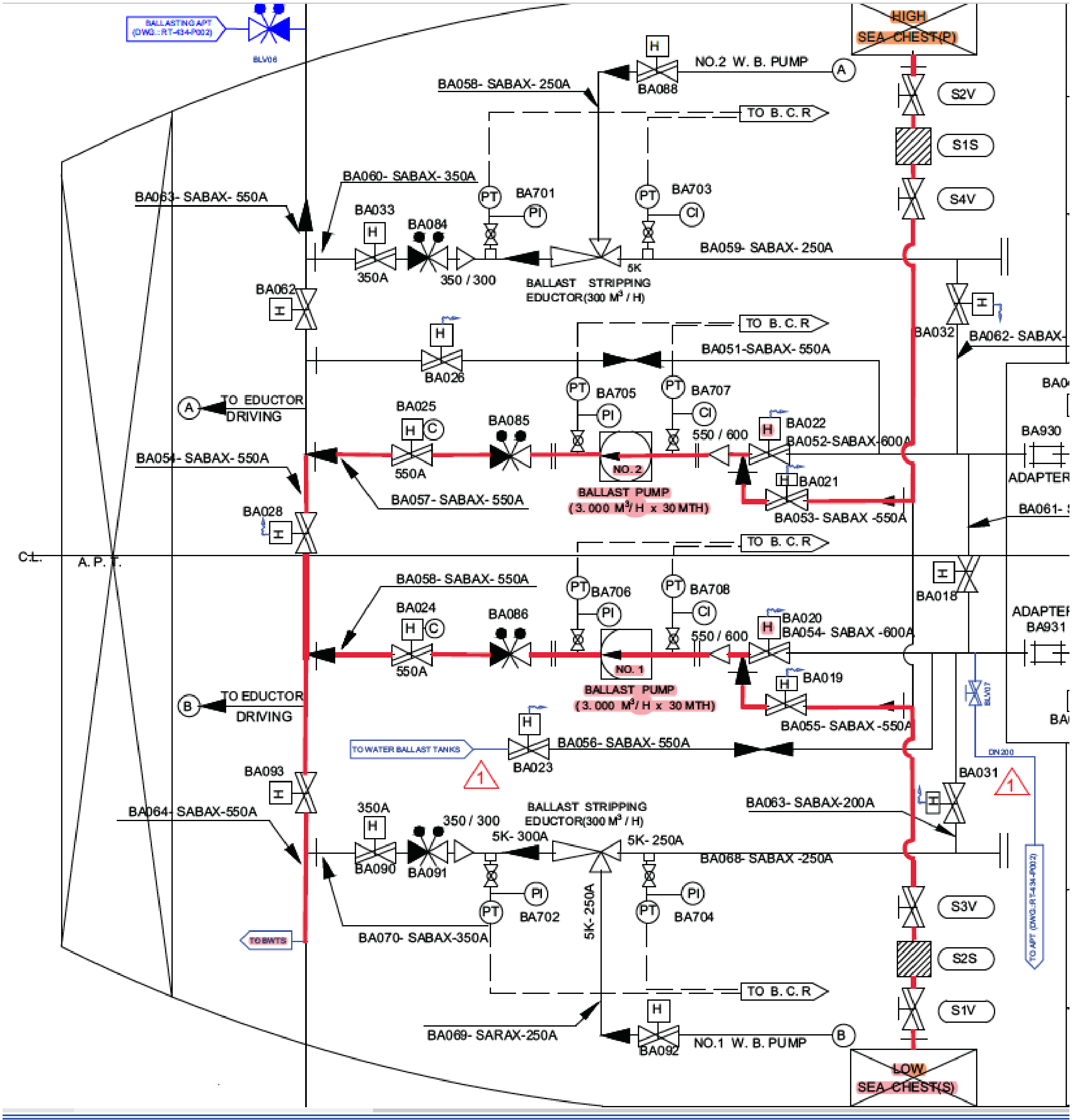

Figure 19: Water Ballast System arrangement – Ballasting operation part I, Vessel B.

During the ballasting operation, the ballast water enters the ship through the sea chests available on each side of the hull (High Sea chest on the port side and Low Sea chest in the starboard side according to the drawing in Figure 19). Through the pipe-route highlighted in **red** in the Figure 19, the water flows through the two large ballast pumps No.1 and No. 2 (3,000 m^3/h each) and then it is headed towards the place indicating “*TO BWTS*” where the treatment equipment is located (Figure 20). The two highlighted valves (H) just before the two ballast pumps respectively, are used to monitor whether the ballast water will go through the treatment system or bypass that and go straight to the ballast tanks and then sends a signal to the control panel. If the second case is true, then an alarm is activated.

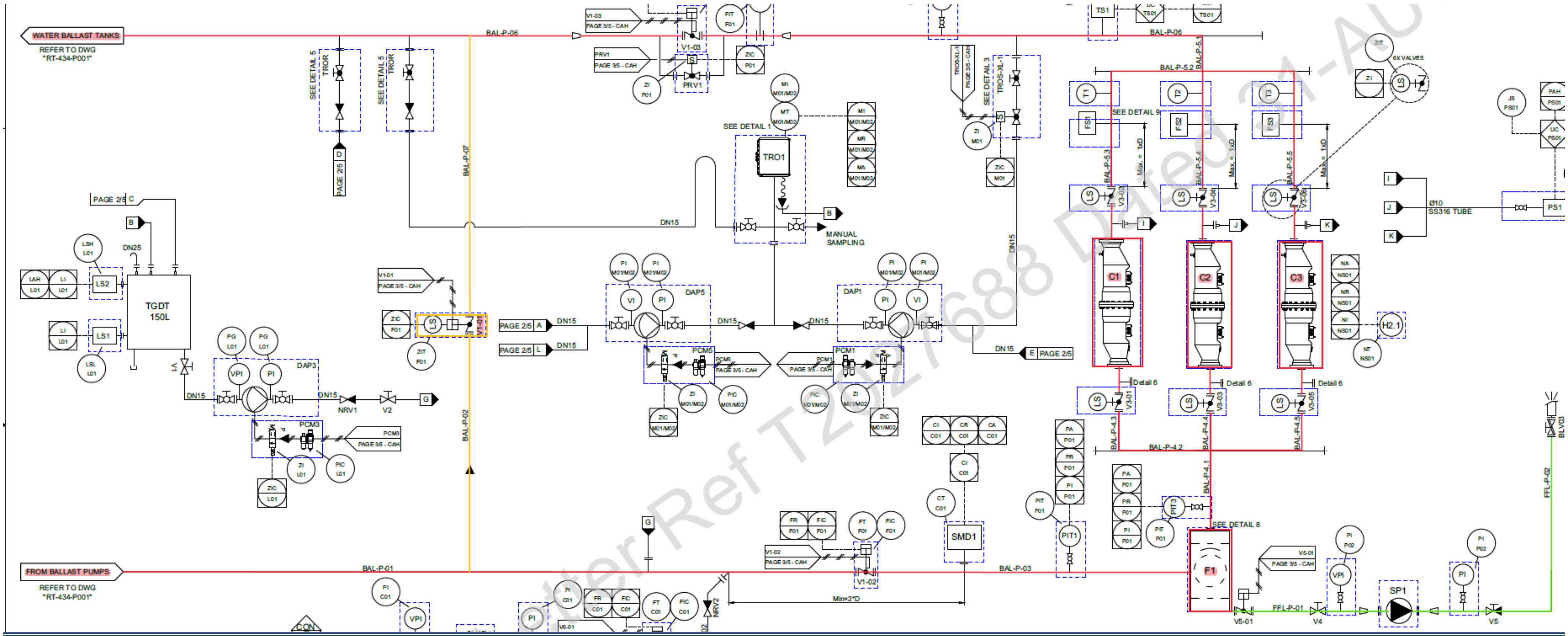

Figure 20: Water Ballast System arrangement – Ballasting operation part II, Vessel B. Three different routes: red, yellow and green.

The connection at the “*TO BWTS*” point is indicated in the Figure 20, where the piping diagram of the treatment system is shown. The route for the normal ballasting operation is again highlighted in **red**. The ballast water first goes through filtration (filter “F1”), to remove the larger particles and organisms. Then the filtered water enters the electrolytic cell where the remaining viable organisms are eliminated. In total, there are three electrolytic cells (C1, C2, C3). After that, the last destination is the water ballast tanks of the vessel.

Note: On cells’ outlet a pressure switch is installed to send signal -critical alarm- to vessel’s control module when inlet pressure is >5 bar as well as a temperature switch installed to send signal -critical alarm- to vessel’s control module when outlet temperature >40°C.

The **yellow** route (*Figure 20*) is a bypass route applied in the emergency condition. It can be used when a critical alarm has been activated, when the treatment system is not working or has reached a high temperature and cannot operate normally and any other emergency situation that may occur.

The **green** route (*Figure 20*) is basically for when the filter is clogged. In that case, the water flows in the opposite direction helping to clean the filter and then gets discharged. After the filter is sufficiently cleaned, the ballasting operation can normally take place with the ballast water following the red route.

In order to start the ballast mode, it is very important to follow several steps such as to proceed in the proper valve arrangement from the sea-chests’ piping to the ballast tanks’ piping, make sure that all the necessary pumps for the ballast operation are working, and the valves responsible for discharge are closed.

5.3.2 De-ballasting Operation

The de-ballasting operation is simpler. Highlighted in **red** (*Figure 21*), the route of the (treated) ballast water consists of going from the ballast tanks where it was previously stored, to the large ballast pumps and then, after going through the neutralizing agent tank and the TRO monitor, it is discharged in the open sea, outside of the vessel (Overboard). In the below drawing (Figure 18) the red lines indicate the above-mentioned path for the example of only the pump No. 2 and the discharge point (overboard) in the port side. The same is applied for the pump No. 1 and the overboard in the starboard side, respectively.

The **orange** line is for the last part of the de-ballasting operation. When most of the ballast water has been pumped out of the ballast tanks, the remaining small amount cannot be “reached” from the large pumps. Therefore, the “ballast stripping eductor”, working in only 300m^3/h, can trace that small amount of water and pump it out of the tanks, ending again to the overboard (meeting the red line, *Figure 21*).

During de-ballasting the BWTS is by-passed, and only the neutralizing and sampling stages are operating. Sample is taken to check if the remaining TRO concentration exceeds maximum allowable discharge amount, in which case the neutralizing agent is injected. A second sample is taken to confirm that TRO levels are below the previous allowable amount, otherwise the quantity of the neutralizing agent which is injected increases.

To start the de-ballasting mode, the operator must arrange the ballast piping valves in such way that the flow of the ballast water is directed from the ballast tanks, to the ballast pump – one or both ballast pumps may be operating - and then to overboard for discharge.

When it is time to terminate the de-ballast operation, the ballast pumps that are being used need to be the first ones to stop working and then the pump's valves responsible for the discharge.

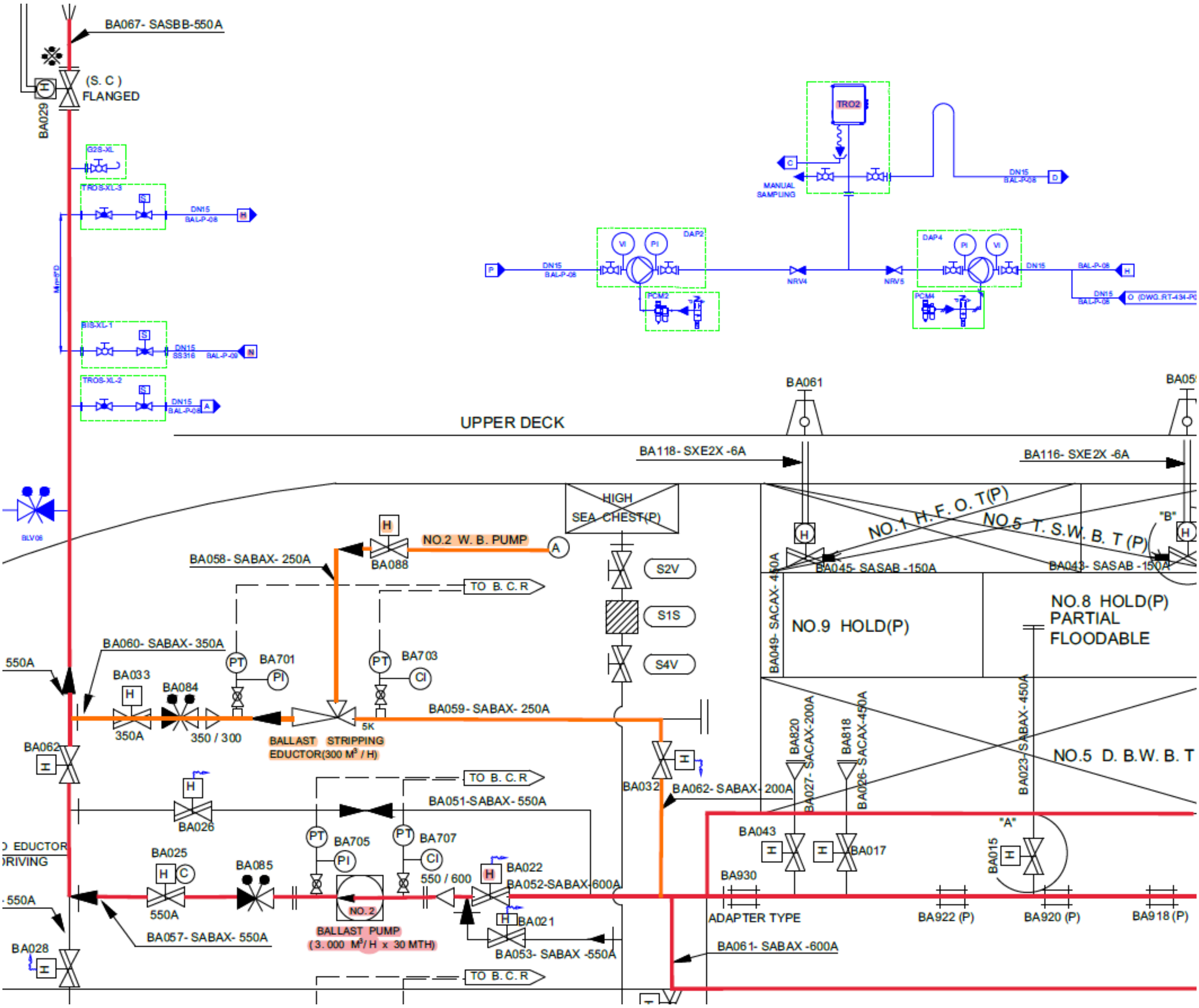

Figure 21: Water Ballast System arrangement – De-ballasting operation, Vessel B

5. 4 Hazard Identification

It is extremely important to evaluate the potential hazards of installing and operating the BWTS equipment onboard of the vessels. This consists of checking if the BWTS is physically integrating and connecting to a vessel, the potential for ballast tank corrosion or coating failure, hazards associated with chemical storage and use, as well as fire and/or explosion hazards. The possible risks are linked with different processes of the treatment system, as enumerated below (Maker A, 2020).

Integration:

I. Complete or partial inability to operate vessel ballast system that may cause malfunction of BWTS regarding the electrical control or mechanical failure. The potential consequences could be the non-ability to complete treated ballasting and commercial operation, as well as regulatory and environmental consequences. The provision of a manual BWTS by-pass switch or a mechanical valve to isolate the BWTS in the event of such a malfunction, would consist of a possible and effective solution.

II. Structural failure coming from improper design and engineering and/or inaccurate information from the ship-owner/ operator/ shipyard. Therefore, it is very important to ensure structural integrity and vibration impacts are considered in the system design and engineering.

III. Power overload or loss of vessel power. No mitigation measure available except for a very thorough consideration of the power demand during the initial design review.

IV. Pressure drops across BWTS filter due to water quality and leading to reduced ballast water flow rate. This has an impact on the vessel's commercial operations, and it demands proper design of the system and incorporated controls to respond to process variation.

V. Release of ClO_2 solution due to plastic pipe failure. Some potential causes for that are the improper pipe assembly, material selection, mechanical damage or leaking mechanical joints. All pipe sections should be pressure tested carefully – especially on open deck and high traffic areas to be provided with physical protection-, the material compatibility verified, all flanged mechanical joints outside of containment to be provided with spray shield and drip trays.

Corrosion:

I. Corrosion of ballast tanks and/ or ballast failure can be caused by storage of treated ballast water in the ballast tanks. However, seawater bears no significant difference in corrosion compared with seawater treated with ClO_2 in the quantity used in the BWTS.

II. Use of dissimilar/ incompatible materials potentially leads to elevated corrosion risk at physical connection points of BWTS.

Chemical Storage and use:

I. Accidental chemical release. Numerous are the potential causes for that hazard:
   a) Incident such as collision/ allusion grounding etc. not related to BWTS.
   b) Chemical storage tank, delivery pipe, gasket, flange, or valve failure. And,
   c) Accident during chemical resupply operations.

The consequences are very serious. Humans can be exposed due to the chemical contact, impacts on the aquatic environment if the chemical content is released into harbor during resupply, as well as property damage on the vessel. Therefore, the mitigation measures are accordingly:

a) Proper design, engineering and materials construction.
b) Chemical storage tanks should have some secondary containment units designed to hold the whole tank capacity.
c) Secondary containment units and generator cabinet equipped with liquid detection sensors.
d) Automatic isolation valves on the chemical tanks in event of liquid detection system alarm.
e) Chemical tank isolation valves in closed position when BWTS is idle.
f) Perform leak tests during BWTS commissioning.
g) Pipe length from secondary containment to generator cabinet is minimized.
h) BWTS space to be ventilated.
i) Vessel crew training towards chemical risks.

Also, there are several physical hazards such as elevated noise levels where hearing protection is required, moving parts during the BWTS operation i.e., the filter cleaning suction pump (can cause injuries such as crushing or cuts) and electrical discharge because of the high voltage of the BWTS. An additional physical hazard for the chemical injection treatment systems can be the chemical contact during the BWTS maintenance or repairs (such as sulfuric acid, chlorine dioxide solution) that can cause personal injury and that require proper training procedure along with a lot of safety precautions.

5.5 Comparative Evaluation

The selection of a ballast water treatment system is not approached from a single point of view. It is a complicated process that can differ between ship-owners. The comparative assessment in discussion at this chapter, consists of a perfect example for that as both systems installed in the sister vessels could be sufficiently functional. However, the two ship-owners did not choose the same treatment system.

Summarizing the different factors involved, the selection of a BWTS is based on the following parameters:

- From owners' point of view: cost and reliability, capital cost, familiarization of crew pools and overall reputation of one system.
- From designer's point of view: empty space in vessel in order to fit the ballast water treatment system, power consumption and pump arrangement.

Therefore, the main differences between the two treatment systems mainly conduct to the technical details, as well as the cost evaluation, the most essential criteria for the decision-making process.

Regarding the technical details, the pros and cons of the two technologies (due to the different manufacturer and the nature of the treatment) are presented in Table 8 and Table 9.

VESSEL A

PROS	• No filtration on discharge. • Use of filter on uptake eliminates larger organisms, reduces total organism/biomass to kill and reduces maximum sediment size allowing improved active substances effectiveness thus reducing the energy consumption. • Reduced complexity of installed system. • No salinity, turbidity/UV transmittance operational challenges. • No neutralization chemicals required. • Easier installation on vessels with cargo pump rooms or hazardous cargo areas. • Treated freshwater (<1 PSU) is allowed for discharge in US water (refer to USCG approval).
CONS	• Filtration on intake - consideration required for effects to ballast pump flow reduction and added differential pressure. • Filter components mechanical reliability. • Use of filter requires additional maintenance with increased component replacement costs through life cycle. • Clogging of filter beyond self-cleaning capability can interrupt operations. • Filter back-flushing impacts ballast water throughout extending ballasting operations. • Additional handling and storage of hazardous chemicals-personnel PPE and training considerations. • Supply and storage of treatment chemicals - availability where required at routing destinations. • Storage capacity/added weight vs. resupply frequency cost considerations. • Chemicals spill preparations and emergency procedures for exposure required. • USCG limit: 24 hours minimum hold time. May cause delays before treated ballast water can be discharged.

Table 8: Pros and Cons of Filtration and Chemical Injection Treatment System (ABS, Maker A BWMS Information Sheet, 2019).

VESSEL B

PROS	• No filtration on discharge. • Use of filter or cyclone separator on uptake eliminates larger organisms, reduces total organism/ biomass to kill and reduces maximum sediment size allowing improved active substance effectiveness thus reducing the energy consumption. • Sediments in the ballast tanks may be reduced due to filtration. • Original models provide residual disinfectant in ballast tanks that consequently provide additional protection against organism regrowth. • Lower TRO and reduced power requirements. • No minimum hold time for USCG compliance.

CONS	• Filtration or cyclone separator on intake - considerations required for effects to ballast pump flow reduction with added differential pressure. • Differential pressure for cyclone separator must be considered for pump sizing. • Filter components mechanical reliability. • Use of filter requires additional maintenance with increased component replacement costs through life cycle. • Clogging of filter self-cleaning capability can interrupt operations. • Filter back-flushing impacts ballast water throughout ballasting operations. • Generation of hazardous gases. • Maintenance and replacement costs of electrodes may be disinfectant. • Active substances - increased potential for corrosion. • Significant centralized DC power supply - waste heat removal required. • Neutralization required - additional chemical storage and handling. Additional maintenance on the TRO monitor sub-assemblies. • Provision for storage of TRO sampling water or piping connection to return to the ballast tanks. • Increased power required for low salinity/low temperature ballasting ports.

Table 9: Pros and Cons of Filtration and Electrolysis Treatment System (ABS, Maker B BWMS Information Sheet, 2019).

Some advantages are common for the two vessels since both are using filtration as part of the treatment, such as the elimination of the larger organisms and the reduction of the energy consumption due to the use of filter and the need not to filter while de-ballasting. However, there common disadvantages as well, for example both systems require additional maintenance with extra costs for component replacement due to the use of filter. Also, both the filter itself might cause interruptions to the ballasting operation as it might clog.

The installation challenges that a vessel with BWTS using *filtration along with chemical injection* could face, are (ABS, 2019):

1. Space needed in engine room area.
2. Location of panels.
3. By-pass arrangements.
4. Components maintenance footprint.

While for a vessel using BWTS with *filtration along with electrolysis*, the installation challenges could be (ABS, 2019):

1. Footprint (limited access to maintenance space).
2. Modification to existing pipe work and additional space required for equipment installation.
3. Procurement of small items for the system.
4. Interface with existing onboard system.
5. To retrofit and locate the components in existing arrangement in pump room and Engine room.
6. For Aft Peak tanks, the BWTS is placed beside the fire pump in the Engine room bottom platform.
7. This system does not allow ballasting / de-ballasting by gravity, it requires using the ballast pumps throughout the ballasting/de-ballasting operation.

8. Does not work below 0.9 PSU salinity (fresh water). Salt water has to be stored in the Aft Peak tank to allow system to be fed with salt water (1% saltwater flow is required), hence increasing salinity above 0.9psu before the system becomes operational.

The cost evaluation is another very important factor, especially from the ship-owner's perspective. The installation plus the operating costs of the BWTS is considered to play a significant role when choosing the proper system for a vessel. For the two vessels in discussion, the **operating costs per ballast operation are greater for the case of the *Vessel A* than the *Vessel B*.**

With more details:

- Vessel A
  - Considered high for the amount of chemicals to be used.
  - Operating expenses (OPEX) cost higher than budgeted due to chemical consumption slightly higher than design.
  - OPEX is higher due to chemical consumption.
  - Low energy consumption.
  - Heavily relied on chemicals (both treatment and neutralizer) and for short voyages the chemicals consumption might increase the vessel's expenses.
  - Additional costs for the construction of the specially designed deckhouse.

- Vessel B

  - OPEX are derived from the DG additional kW/hrs. for operating the system (DG additional fuel costs), the TRO sensor measurement reagents and neutralization chemical costs.
  - Relatively low cost for the installation.
  - Extremely high-power consumption.
  - Only requires some chemicals consumption.
  - Hidden OPEX due to delays and extended stays at cargo terminals (caused by extreme flow cutbacks impacting on ballasting and cargo operations).

Both vessels have had the BWT systems **retrofitted**, which can be a challenge in general for a vessel due to the modifications required for the installation of the system, as well as the costs included. For new building vessels, a ballast water treatment system is mandatory and therefore part of the general arrangement plan of the ship from before being built.

5.6 Conclusion

Subject to this chapter is the comparative assessment between two ballast water treatment systems that were installed in a couple of sister vessels. The two sister bulk carriers are under different management and one owner chose to install the technology with filtration and chemical injection as the treatment to the ballast water, while the other one chose filtration with electrolysis. Both technologies are suitable and very commonly used for bulk carriers but are still dissimilar. This case presents the technical, economical and other details that make these treatment systems differ and therefore come to a selection point whose criteria vary between ship-owners.

As a conclusion of this study, both treatment systems are very often chosen for Bulk Carriers because the installation is quite smooth and the effectiveness is high. A great factor on the above is the waters where the vessel is operating because of the prevailing regulations and the chemical state of the waters i.e., the salinity of the water and the temperature.
Derived from the entire study as well as many discussions with the designer companies of these two systems, a comparison table of the overall differences and similarities (technical details, cost, consumption etc.) is presented in Table 10.

Table 10: Comparison table of the two technologies.

Filter and Chemical Injection (Vessel A)	***Filter and Electrolysis (Vessel B)***
Filter maintenance is costly.	Filter maintenance is costly.
Extra cost for the construction of the extra chemical storage compartment.	Extra cost for the isolation of the BWTS in the engine room.
No special ventilation system just for the BWTS.	Special ventilation system just for the BWTS.
The installation of the extra chemical storage compartment is a wise choice for that vessel because if it was chosen to be installed in the engine room, it would be mandatory to isolate it from the other parts and the steering gear room would “break” in two.	Requires a lot of space in the engine room.
Simple and automatic system in operation.	Simplicity in operation.
Dangerous but controllable (with proper training, precautions etc.).	Low danger involved.
Contains only a few compartments: Two (2) filters, two (2) pumps and one chemical compartment.	Compartments contained: One (1) filter, two (2) pumps, two (2) TROs and three (3) electrolytic cells.
After the chemical injection and the required holding time of the treated water inside the tanks, the discharge is immediate without any prior mandatory measurement.	After the electrolysis treatment and before the discharge, TRO measurement and sampling are mandatory.
Top side tanks can be not connected to the double bottom tanks therefore it is not required to check the ballast water before discharging since the treated water can be directly stored there.	TRO involved therefore top side tanks cannot be isolated, instead they have to be connected with the main system which leads to additional cost along with a lot of construction work for the connection piping installation.
Chemical consumables purchase.	No chemical consumables required.
Very low energy consumption required.	Extremely high energy consumption due to the electrolytic cells and the great power demand.

- ✓ A personal suggestion for the ship-owners would be the choice of the *Filtration and Chemical Injection* system for its <u>simplicity and effectiveness</u> for that type of vessel. Discussing with the designer engineers and the ones completing the review, the main reason I would choose the chemical injection system over the electrolysis one, would be its adaptability in the vessel, though both of them turned out to be really efficient for both Bulk carriers. The budget would be a major factor for the owning company in the decision-making process, but a retrofit BWTS is also a big challenge for vessels who are already operating and have to comply with the new regulations in a specific timeframe. Therefore, the chemical injection system proves to be more flexible regarding that, since it does not require extra installation space in the engine room by giving the owner the option of the additional chemical storage tank in the deck of the vessel. An area with low danger involved, and additionally, one that can be easily modified and used for various purposes since it is a –technically- free space.

6. OWNER'S PERSPECTIVE

6.1 Selection of BWTS maker

After choosing the most appropriate ballast water treatment system for a vessel, the ship-owner shall proceed with the selection of BWTS maker. Quite often, the available makers along with the costs associated are affecting the decision of which treatment system is suitable for the ship concerned.

Each and every BWTS maker on the market should be qualified and type approved according to the IMO G8 Guidelines. It should be noted that the development of BWMS is a very dynamic market with newly proposed BWMS appearing almost on a monthly basis. For some BWMS it is difficult to follow their development as some systems were renamed during the certification process.

In Appendix B there is a table of BWMS manufacturers in alphabetical order, commercial names of their BWMS, technologies used and available web pages (last accessed April 2015). Type approved BWMS are shown with grey shading (updated after David and Gollasch 2015, IMO 2015).

6.2 Selection of Designer

The selection of the BWMS should be based on a decision hierarchy developed by the owners and managers during the feasibility study and not created during the proposal reviews. A ship visit to conduct a preliminary onboard survey (2D tape measurements) should also be included in the proposal. This can help determine that the pre-selected BWMS will fit in the spaces available and potentially provide some installation options. This is important for existing vessels limited installation space.

Once the 2D preliminary onboard survey is completed, the ship owners and managers should start requesting technical and installation proposals from reputable Naval Architect/Marine Engineering companies and third-party installation contractors with extensive experience. To provide full support (i.e., urgent request to revise design that occurs during equipment installation, prompt onsite attendance to address any conflicts with the existing vessel onboard systems, etc.), it is important to engage a responsible and reliable Naval Architect or Marine Engineer and installation contractor with good knowledge and experience for the installation, operation and maintenance of BWMS. Previous experience and successful installations can be beneficial. Credibility of each potential Naval Architect or Marine Engineer and installer should be reviewed.

A 3D model design would be requested, and it can be converted into a detailed engineering drawing to show all structural foundations, pipes and pipe fittings, controls and automation, other machinery and electrical components required for the installation of the BWMS (ABS, 2019).

6.3 Class and Flag Approval

The classification society is required to:

i. Review and approve the vessel's plans, drawings and operational manuals prior to the installation.
ii. Conduct an engineering review and approval of the installation design.
iii. Include an engineering review of hull plans showing foundation and attachments to vessel's structure for each component of the BWMS. These plans are to clearly indicate the scantlings and welding details (the specific list of required drawings and documentation required for approval might vary between different class societies).
iv. Review of the machinery plans showing the installation of the BWMS on the vessel including location, piping and electrical details, drawings, general arrangement and layout, and installation and equipment plans. They also have to include applicable arrangements for hazardous areas.
v. Review a safety risk assessment specific to the installed BWMS to be installed and for the specific type of vessel under consideration to address the risk to the vessel and its crew is also to be conducted before the installation of the BWMS, so that any mitigation measures identified during the assessment study could be applied before or during the BWMS installation. This safety assessment is to be reviewed by the class society to confirm the adequacy of the proposed arrangement and the relevant information resulting from the safety assessment is to be documented in the vessel's BWMP.

It is important to first obtain Class and Flag approvals before beginning the retrofit in order to avoid costly rework that affects the installation schedule. Another major advice is to start the BWMS fabrication after the completion of the design and approval phase. Retrofit project plans based on experience gained during new-build BWMS installations tend to overlap design and BWMS manufacturing phases. This is acceptable for new-build projects where the ship designers will accommodate the BWMS installation spaces and power demand, but it can be detrimental for retrofit projects.

6.4 Available Shipyards

It is very important to choose a shipyard with practical retrofit experience for installation of the BWMS, because retrofitting is a particularly high challenge for the ship-owners and because some shipyards have limited or no practical retrofit experience. Another issue could be that some shipyards might be more familiar and have the practical experience with the installation of the selected BWMS technologies while other may have little or no experience at all with the different treatment technologies.

In general, the ship-owner along with the shipyard should review the data for the test conditions (i.e., salinity, water temperature, UV intensity, etc.) to ensure the BWMS was tested in conditions important to the ship's planned operations. For example, ships that ballast and de-ballast freshwater should verify that the BWMS was tested in freshwater and that the BWMS is approved for operation in freshwater.

6.5 Timeline

The BW Management Convention amendments to the implementation schedule (regulation B-3) of ballast water management for ships required to comply with the D-2 biological standard (Ballast Water Performance Standards) were adopted by the IMO Committee with resolution MEPC (72) (MEPC.297(72), 2018). These amendments to regulation B-3 of the BWM Convention, which entered into force on *13th of October 2019*, require ships constructed <u>on or after</u> 08 September 2017 to comply with the D-2 biological standard upon their delivery. Ships constructed <u>before</u> 08 September 2017 are to comply with the D-2 standard at the first MARPOL IOPP renewal survey completed on or after:

• 08 September 2019 (reg B-3/10.1.1); or

• 08 September 2017, in the event a MARPOL IOPP renewal survey is completed during the period on or after 08 September 2014 and prior to 08 September 2017 (reg B-3/10.1.2).

Below is a schedule for the easy understanding of the above-mentioned timelines:

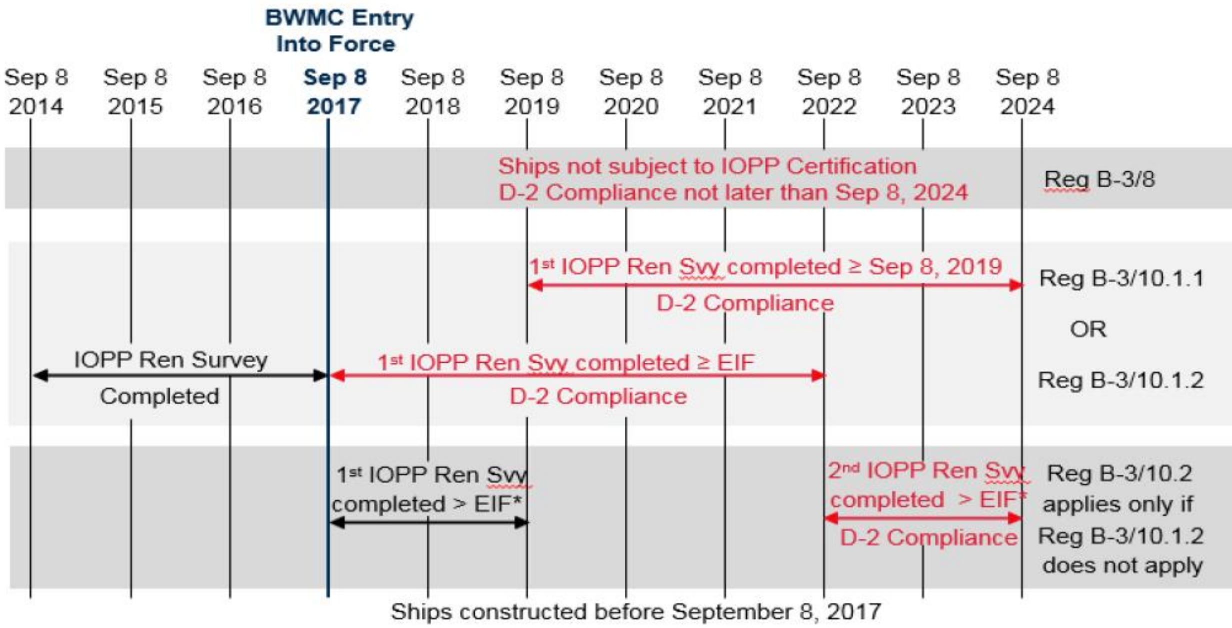

Table 11: Adopted D-2 Implementation Schedule

- If the IOPP Renewal survey was not completed during the period on or after 08 September 2014 and prior to 08 September 2017 (per reg B-3/10.1.2), then compliance with the D-2 standard is required at the *second* MARPOL IOPP renewal survey after September 8, 2017. This is allowed only if the first MARPOL IOPP renewal survey after 08 September 2017 is completed prior to 08 September 2019 and a MARPOL IOPP renewal survey was not completed during the period on or after 08 September 2014 and prior to 08 September 2017 (reg B-3/10.2).

  Note that the ship has to comply with at least the D-1 (Ballast Water Exchange) standard on/after 08 September 2017 -until the D-2 compliance date-, regardless of the vessel's D-2 implementation date. A ballast water record book is required to be maintained on board at all times and the ballast water management to be performed according to the approved ballast water management plan.

- For ships constructed before 08 September 2017 which are not subjected to the MARPOL IOPP renewal survey (Oil tanker of less than 150 GRT and every ship other than Oil tankers of less than 400 GRT), are to be D-2 compliance no later than 08 September 2024 (reg B-3/8).

Well Planned Timeline

It is important to start planning at least 24 months before the IMO or USCG BWM compliance date, whichever is earlier. This allows some extra time for successful project completion.

-Determining the vessel's compliance date early in the process can allow ship-owners to anticipate project completion deadlines.

-It allows ship owners to make an informed economic decision: If investing in a BWMS installation is the best compliant method for the vessel, especially for vessels that are close to their service life.

- Planning helps prevent making a wrong BWMS selection where a second BWMS retrofit might be required to achieve compliance with regulations.

- Allow additional time for an in-depth analysis of different BWM treatment technologies, pre-selection of the most suitable BWMS, analyzing various vendor sustainability and support capabilities, selecting suitable installation locations (i.e., on the vessel and the shipyard), and some additional time for unexpected situations that would require rework or repairs to be conducted.

- Contingencies for any missing, damaged or broken components or sub-assemblies, and additional time to make repairs or shipping of replacement components should be included in the installation planning process to prevent the vessel from returning to service after the retrofit

6.6 Prediction of Contingency Measures/ BWMP

A ship-specific ballast water management plan (BWMP) should be provided with the installation of the BWMS and it should include the latest information for operational, maintenance, safety and repair instructions. All the stakeholders are participating in the development of the BWMP and its updates.

Clear contingency measures are recommended for the BWMP as well as clear plans for action for the crew in the event of a malfunction or inoperable BWMS. The Master and crew should practice contingency measures to validate the feasibility of the BWMP.

Examples of contingency measures may include conducting sequential ballast water exchange plus treatment during re-ballasting to alleviate water quality issues that may be encountered in some ports (for example low UVT or salinity for electro-chlorination based BWMS, high silt and sediment that affect filters, etc.). Performing BWE in lieu of treatment may be considered the last resort in the event of failure of the BWMS. However, the acceptability of BWE only is subject to the approval by the port state and Flag administrations, especially if followed by BWT to regain compliant ballast water. The BWMP should provide detailed instructions for contacting port state control (ABS, 2019).

Some contingency measures may include, according to the relevant guidelines:

• Practical measures in the case a ship is unable to manage ballast water in accordance with its approved ballast water management plan

- Discharge to another vessel or shore facility
- Managing all or part of the ballast water in a method acceptable to the port
- BWE as agreed by the ship and port state, <u>or</u>
- Other operational actions (e.g., modifying sailing, internal transfer or the retention of ballast water on board the ship).

7. Conclusions

7. 1 Goals and general conclusions

The present diploma thesis introduces the issue that arises from the transfer of microorganisms and pathogens through the water used as ballast in the ships along with the need for the ballast water treatment systems. The most used and effective available ballast water treatment technologies are:

- Filtration
- Electrolysis
- Chemical Injection
- UV (Ultraviolet)

Almost all the BWT systems use a combination of the below i.e., Filtration with UV. Their effectiveness lies exactly in the utilization of both separation and disinfectant methods. The attributes of separation come from the usage of the filter, while the disinfectant properties are provided by the rest of them (i.e., electrolysis, ultraviolet radiation etc.).

Furthermore, the most important part of this project is the organized presentation of all the criteria involved in the decision-making process of an appropriate ballast water treatment system for a vessel. Dividing these factors in relevant categories and explaining all of them with details, the goal is for a ship-owner to examine all the possibilities and alternative choices that may be suitable and to come across the best one. The factors that play a critical role are:

- Ship type and characteristics
- Size and installation space required
- Power demand and energy consumption
- Salinity
- Retrofitted system or not. Retrofits have proven to be the biggest challenge for a ship-owner because they require careful planning and handling.

Moreover, a description of where the theoretical part of the project meets the practical aspect is given with a comparative evaluation between two existing sister Bulk carriers that belong to different ship-owners and that ended up operating with different ballast water treatment systems. The purpose of this assessment is to examine closely the treatment operation, spot the details that individualize them, and explore the choices a ship-owner can have. One vessel is using Filtration with Chemical Injection and the other is using Filtration with Electrolysis. Highlighting the most important details, the Filtration with Chemical Injection treatment system is a better choice for a Bulk Carrier.

In addition, it is of much importance to highlight the procedure prior to the installation that is mandatory and crucial for the selection of a treatment system as well. The maker that constructs the treatment system and applies it to the vessel, the designer responsible for the engineering drawings, the available shipyard that the installation will be completed, all of these have significant value for the effectiveness of the system itself as well as the financial aspect. On top of that, an effective collaboration between the owning company, the vessel's classification society and the marine technical office is necessary for the completion of the project according to the timeline.

In conclusion, the decision-making process for the appropriate selection of a ballast water treatment system for a vessel, is a greatly complicated procedure that requires a great knowledge of the operating details and potential of the technologies available, the regulations applied as well as the properties and attributes of the vessel itself. It also required an early and organized planning, a thorough research for the appropriate maker, designer, shipyard and a smooth cooperation between them. Not all the technologies fit for all the vessels, but at the same time a vessel doesn't have only one option for a ballast water treatment system.

7.2 Suggestions for future work

The purpose of this diploma thesis is to familiarize the ship-owners with the regulations applied for the ballast water management and assist in the selection of the appropriate treatment system highlighting all the factors involved and the step that need to be taken. There is an adequate amount of available technologies for the treatment of the ballast water, providing in that way a variety of choices to the ship-owners. However, each one of them have vulnerabilities and downsides, while some of them are not sufficiently functional, and therefore not mostly used.

At last, the importance of the issue of BWTS for the maritime industry leaves space for further relative studies. Some suggestions are given for further research and improvement in the field of ballast water management:

- Continuous improvement of the widely used technologies to eliminate the disadvantages and improve the effectiveness.
- Minimize the volume of the installation and space required (preferably for retrofits).
- The shipyards should expand their expertise to fit most treatment technologies' installations.
- Research for new ballast water treatment options and/or utilization of the existing technologies that are not widely used (i.e., heat treatment).
- Financial feasibility study of the BWTS retrofit in cases of older vessels.
- Investigation of alternative solutions (e.g., ballast treatment to be held at port).

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- Lloyd's Register | Sahan Abeysekara, Principal Specialist
- Peterson Vessel Performance Centre | Paul Jacob Bins, Founder and Managing Director
- Optimarin | Jurrien Baretta, Technical Sales Manager
- PSB & CO S.A | Gregory Papadakis, Managing Director

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ANNEX 2

RESOLUTION MEPC.297(72)
(adopted on 13 April 2018)

AMENDMENTS TO THE INTERNATIONAL CONVENTION FOR THE CONTROL AND MANAGEMENT OF SHIPS' BALLAST WATER AND SEDIMENTS, 2004

Amendments to regulation B-3

(Implementation schedule of ballast water management for ships)

…

Section B – Management and control requirements for ships

Regulation B-3 – Ballast water management for ships

1 The text of regulation B-3 is replaced with the following:

"1 A ship constructed before 2009:

.1 with a ballast water capacity of between 1,500 and 5,000 cubic metres, inclusive, shall conduct ballast water management that at least meets the standard described in regulation D-1 or regulation D-2 until the renewal survey described in paragraph 10, after which time it shall at least meet the standard described in regulation D-2;

.2 with a ballast water capacity of less than 1,500 or greater than 5,000 cubic metres shall conduct ballast water management that at least meets the standard described in regulation D-1 or regulation D-2 until the renewal survey described in paragraph 10, after which time it shall at least meet the standard described in regulation D-2.

2 A ship constructed in or after 2009 and before 8 September 2017 with a ballast water capacity of less than 5,000 cubic metres shall conduct ballast water management that at least meets the standard described in regulation D-2 from the date of the renewal survey described in paragraph 10.

3 A ship constructed in or after 2009, but before 2012, with a ballast water capacity of 5,000 cubic metres or more shall conduct ballast water management in accordance with paragraph 1.2.

4 A ship constructed in or after 2012 and before 8 September 2017 with a ballast water capacity of 5,000 cubic metres or more shall conduct ballast water management that at least meets the standard described in regulation D-2 from the date of the renewal survey described in paragraph 10.

5 A ship constructed on or after 8 September 2017 shall conduct ballast water management that at least meets the standard described in regulation D-2.

6 The requirements of this regulation do not apply to ships that discharge ballast water to a reception facility designed taking into account the Guidelines developed by the Organization for such facilities.

7 Other methods of ballast water management may also be accepted as alternatives to the requirements described in paragraphs 1 to 5 and paragraph 8, provided that such methods ensure at least the same level of protection to the environment, human health, property or resources, and are approved in principle by the Committee.

8 A ship constructed before 8 September 2017 to which the renewal survey described in paragraph 10 does not apply, shall conduct ballast water management that at least meets the standard described in regulation D-2 from the date decided by the Administration, but not later than 8 September 2024.

9 A ship subject to paragraphs 2, 4 or 8 will be required to comply with either regulation D-1 or regulation D-2, until such time as it is required to comply with regulation D-2.

10 Notwithstanding regulation E-1.1.2, the renewal survey referred to in paragraphs 1.1, 1.2, 2 and 4 is:

.1 the first renewal survey, as determined by the Committee, on or after 8 September 2017 if:

.1 this survey is completed on or after 8 September 2019; or

.2 a renewal survey is completed on or after 8 September 2014 but prior to 8 September 2017; and

.2 the second renewal survey, as determined by the Committee,1 on or after 8 September 2017 if the first renewal survey on or after 8 September 2017 is completed prior to 8 September 2019, provided that the conditions of paragraph 10.1.2 are not met."

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APPENDIX B

BWMS manufacturers and technologies used as of 2016

Nr.	Manufacturer	System name	Pre-treatment	Treat ment	Residual control	Web site
1	21st Century Shipbuilding Co., Ltd	ARA Ballast (old: BlueOceanGuardian)	Filtration	Plasma + UV	-	-
2	Ahead Ocean Technology (Dalian) Co., Ltd.	AHEAD	Filtration	UV	-	http://aheadocean.en.ec21.com/Products--8727817.html
3	Akballast	Akballast	Filtration	UV	-	-
4	Alfa Laval Tumba AB	PureBallast (2.0, 2.0 Ex)	Filtration	UV + TiO_2	-	www.alfalaval.com
5	AquaEng Co. Ltd.	AquaStar (and Ex)	Smart pipe unit	Electrolysis/electrochlorination	Sodium thiosulphate	www.aquaeng.kr
6	atg UV Technology (ATG Willand)	-	Filtration	UV	-	www.atguv.com
7	ATLAS-DANMARK	ATLAS-DANMARK ABTS	Filtration	Electrochemical (Anolyte)	-	www.atlas-danmark.com
8	Auramarine	CrystalBallast	Filtration	UV	-	www.auramarine.com/news/auramarine-_new_challenger_in_the_market_for_ballast_water_treatment_systems
9	Azienda Chimica Genovese	ECOLCELL BTs	Filtration	Electrolysis/Electrochlorination	Sodium thiosulphate	-
10	BAWAC Systems Pte. Ltd.	BAWAC	Filtration	UV	-	http://www.gensysgroup.com/products/modularized-systems/bawac.html

Nr.	Manufacturer	System name	Pre-treatment	Treatment	Residual control	Web site
11	Bawat	Bawat BWTS	-	Inert gas+heat / De-oxygenation and pasteurisation	-	http://www.bawat.dk/
12	Bio-UV	Bio-SEA	Filtration	UV	-	-
13	Brillyant Marine	-	-	Electric pulse	-	www.brillyantinc.com
14	Cathelco Group	Cathelco BWTS A2	Filtration	UV		www.cathelco.com
15	China Ocean Shipping Company (COSCO)	Blue Ocean Shield	Hydrocyclone + Filtration	UV	-	www.cosco.com/en
16	CLARCOR Company	PF-BWF	Filtration			http://www.pecofacet.com/
17	Coldharbour Marine	Coldharbour BWT	-	Deoxigenation	-	www.coldharbourmarine.com
18	Dalian Maritime University	DMU OH BWMS	Filtration	hydroxyl radicals, ozone and hydrogen peroxide	Sodium thiosulphate	-
19	DESMI Ocean Guard AS	OxyClean	Filtration	Ozonation+UV	-	www.desmioceanguard.com
20	Dow Chemical Pacific (Singapore) Pte Ltd.	Dow-Pinnacle BWMS	Filtration	Ozonation	Sodium thiosulphate (optional)	-
21	Ecochlor Inc	Ecochlor	Filtration	Chlorination (ClO_2)	-	www.ecochlor.com
22	Ecologiq	BallaClean	Filtration	Electrolysis/Electrochlorination	-	www.ecologiq.us
23	Ecomarine Technology Research Association & Sumitomo Electric Industries Ltd.	Ecomarine Management System	Filtration	UV		-
24	Electrichlor Inc	Electrichlor	Filtration	Electrolysis/Electrochlorination	-	www.electrichlor.com
25	Elite Marine Ballast Water Treatment System Corp – China	Seascape	Filtration	UV		
26	EltronWaterSystems	PeroxEgen	-	Chemical injection (Hydrogen Peroxide)	-	www.eltronwater.com, www.eltronresearch.com

Nr.	Manufacturer	System name	Pre-treatment	Treatment	Residual control	Web site
27	Environmental Technologies Inc	ETI	Filtration	Ozonation+Ultrasound	-	www.tlmcos.com
28	Envirotech and Consultany PTE ltd.	BlueSeas BWMS	Filtration (microsized strainer)	Electrolysis/Electrochlorination	Sodium thiosulphate	-
29	Envirotech and Consultany PTE ltd.	BlueWorld BWMS	Filtration (microsized strainer)	Chemical injection	Sodium thiosulphate	-
30	Erma First SA	Erma First BWMS	Hydrocyclone+filtration	Electrolysis/Electrochlorination	Sodium bisulphite	www.ermafirst.com
31	Evonik Industries AG	Evonik Ballast Water Treatment System with PERACLEAN® OCEAN	Filtration	Electrolysis/Electrochlorination		-
32	Evoqua Water Technologies, LLC (old: Siemens)	SeaCURE (old: SiCURE)	Filtration	Electrolysis/Electrochlorination	Sodium sulphite (optional)	-
33	Exeno Yamamizu Corporation / Panasonic Environmental Systems & Engineering Co., Ltd.	ATPS-BLUE sys	-	Electrolysis/Electrochlorination		
34	GEA Westfalia (old: Aquaworx ATC GmbH)	BallastMaster ultraV 250 (old: AquaTriComb)	Filtration	UV + ultrasound	-	http://www.westfalia-separator.com
35	Hamworthy	Aquarius UV	Filtration	UV	-	-
36	Hamworthy	Aquarius EC	Filtration	Electrolysis/Electrochlorination	Sodium bisulphite	-
37	Hanla IMS Co. Ltd.	EcoGuardian	Filtration	Electrolysis/Electrochlorination	Sodium thiosulphate	-
38	Headway Technology	OceanGuard, HMT-	Filtration	Electrolysis/Electrochlorination+U	Sodium thiosulphate	www.headwaytech.com/en/fist.asp

Nr.	Manufacturer	System name	Pre-treatment	Treat ment	Residual control	Web site
	Co. Ltd.	100F to 4000F		ltrasonic treatment (EUT)	(optional)	
39	Hi Tech Marine Pty Ltd.	Ballast water disinfection	-	Heating	-	www.htmarine.com.au
40	Hitachi	ClearBallast	Filtration	Flocculation (magnetic particles)	-	www.hitachi.com
41	HWASEUNG R&A Co. Ltd.	HS-Ballast	-	Electrolysis/Electrochlorination	Sodium thiosulphate	-
42	HyCa Technologies Pvt. Ltd.	HyCator	Filtration	Electrolysis/Electrochlorination	Sodium thiosulphate	-
43	Hyde Marine Inc-Hyde Guardian	Hyde Guardian Gold	Filtration	UV	-	www.hydemarine.com
44	Hyundai Heavy Industries	EcoBallast	Filtration	UV	-	http://english.hhi.co.kr
45	Hyundai Heavy Industries	HiBallast (and Ex)	Filtration	Electrolysis/Electrochlorination	Sodium thiosulphate	http://english.hhi.co.kr
46	JFE Engineering Corporation	JFE BallastAce BWMS (uses TG Ballastcleaner)	Filtration	Chlorination+Residual Clorine+Cavitation (TG BallastCleaner)	Sodium sulphite (TG Environmentalguard)	www.jfe-eng.co.jp/en
47	JFE Engineering Corporation	JFE BallastAce BWMS (uses NEO-CHLOR MARINE)	Filtration	Chemical injection (Neo-Chlor Marine)	Sodium sulphite	www.jfe-eng.co.jp/en
48	Jiangsu Nanji Machinery Company, Ltd. – China	NiBallast	Filtration	Deoxygenation		http://en.jsnj.com/index.html
49	Jiujiang Precision Measuring Technology Research Institute	OceanDoctor	Filtration	UV+Photocatalytic reaction	-	-
50	Kadalneer Technologies Pte. Ltd.	VARUNA	Filtration	Electrolysis/Electrochlorination	+	

Nr.	Manufacturer	System name	Pre-treatment	Treat ment	Residual control	Web site
51	KALF Engineering Pte. Ltd	ElysisGuard	Filtration	Electrolysis/Electrochlorination	+	http://www.kalf.sg/Research.aspx
52	Kashiwa Kuraray Co.Ltd.	Microfade	Filtration	Chlorination (Cl_2)	Sodium sulphite	www.kuraray.co.jp
53	Katayama Chemical Inc.	Sky-System using PeracleanOcean	-	PeracleanOcean	Sodium sulphite	-
54	Knutsen Ballastvann AS	KBAL	-	Vacuum+UV	-	-
55	Korea Top Marine (KT Marine) Co. Ltd.	MARINOMATE (old: KTM-BWMS (Plankill pipe))	Plankill pipe	Electrolysis/Electrochlorination	Sodium thiosulphate	-
56	Kurita Water Industries Ltd	KURITA BWMS	-	Chemical injection		http://www.kurita.co.jp/english/
57	Kwang San Co. Ltd.	En-Ballast	Filtration	Electrolysis/Electrochlorination	Sodium thiosulphate	-
58	La Rossa Internacional Consultoria e Serviços Lda.	BALMECA	Filtration	Electrolysis/Electrochlorination		
59	Mahle NFV GmbH	Ocean Protection System OPS-250	Filtration	UV	-	www.nfv-gmbh.de
60	Malin Group	Cleanship Solutions (CSS)		Portable BWT system		http://malingroup.co.uk/csssub/
61	Marenco Technology Group Inc.	Marenco BWTS	Filtration	UV	-	www.marencogroup.com
62	Maritime Solutions Inc.	-	Filtration	UV	-	www.maritimesolutionsinc.com
63	MH Systems Inc.	MH Systems BWTS	-	Deoxigenation	-	www.mhsystemscorp.com
64	Mitsui Engineering & Shipbuilding	FineBallast® OZ (Special Pipe SP-Hybrid)	-	Ozonation+Cavitation	Activated carbon	www.mes.co.jp/english

Nr.	Manufacturer	System name	Pre-treatment	Treat ment	Residual control	Web site
65	Mitsui Engineering & Shipbuilding	FineBallast® MF (Special Pipe SP-Hybrid)	Filtration	(Membrane filtration)		www.mes.co.jp/english
66	MIURA CO. LTD.	MIURA	Filtration	UV		http://www.miuraz.co.jp/en/network/w-net.html
67	MMC Green Technology AS	MMC	Filtration	UV	-	-
68	NEI Treatment Systems LLC	Venturi Oxygen System (VOS) 2500-101	-	Cavitation+Deoxigenation	-	www.nei-marine.com
69	NK Company	NK-03 BlueBallast	-	Ozonation	Sodium thiosulphate	http://nk-eng.nkcf.com
70	NK Company	NK-Cl BlueBallast	-	Sodium dichloroisocyanurate	Sodium thiosulphate	http://nk-eng.nkcf.com
71	Nutech 03	Mark III	-	Ozonation	-	www.nutech-o3.com
72	Oceansaver AS (MetaFil AS)	OceanSaver	Filtration	Cavitation+Electrolysis/Electrochlorination+Deoxigenation	Sodium thiosulphate	www.oceansaver.com
73	Oceansaver AS (MetaFil AS)	OceanSaver (with optional N2 supersaturation)	Filtration	Cavitation+Electrolysis/Electrochlorination(+optional deoxigenation)	Sodium thiosulphate	www.oceansaver.com
74	Optimarin AS	OptiMarin Ballast System OBS/ Optimarin Ballast System EX	Filtration	UV	-	www.optimarin.com
75	Panasia Co. Ltd.	GloEn-Patrol	Filtration	UV	-	www.pan-asia.co.kr
76	Panasia Co. Ltd.	GloEn-Saver	Filtration	Electrolysis/Electrochlorination	Sodium thiosulphate	-
77	Qwater	-	Filtration	Ultrasound	-	www.qwatercorp.com
78	REDOX Maritime Technologies (RMT) AS	REDOX AS	Filtration	Ozonation+UV	Sodium thiosulphate	-
79	RWO GmbH Marine Water Technology	CleanBallast	Filtration	Electrochlorination+OH	Substance unknown	www.rwo.de

Nr.	Manufacturer	System name	Pre-treatment	Treat ment	Residual control	Web site
802	SAMKUN CENTURY Co. Ltd. (old: 21st Century Shipbuilding Co. Ltd)	ARA PLASMA (old: Blue Ocean Guardian BOG)	Filtration	Plasma+UV		http://samkun.en.ec21.com/ARA_Plasma_Ballast_Water_Treatment--6933481_6933484.html
81	Samsung Heavy Industries	PuriMar/ Purimar 2.0/ Neo-Purimar	Filtration	Electrolysis/Electrochlorination	Sodium thiosulphate	http://www.shi.samsung.co.kr/Eng/product/digital_prd01.aspx
82	Sea Knight Corporation	-	-	Chemical injection+ Deoxigenation+bioaugmentation	-	www.seaknight.net
83	Sea Reliance Marine Services	-	Filtration	UV	-	http://seareliance.com
84	Seair	-	Filtration	Ozonation	-	www.seair.ca
85	Sembcorp	Semb-Eco	Filtration	UV including LED-UV	-	-
86	Severn Trent De Nora	BalPure	optional	Electrolysis/Electrochlorination+Residual Clorine	Sodium bisulphite, Sodium sulphite or Sodium thiosulphate	www.severntrentservices.com/denora
87	Shanghai Cyeco Environmental Technology Co. Ltd.	Cyeco-B200-6000	Filtration	UV	-	-
88	Shanghai Hengyuan Marine Equipment. Co. Ltd.	HY-BWMS	Filtration	UV		
89	Shanghai Jiazhou Environmental Mechanical & Electrical Co. Ltd.	BALWAT	Filtration	UV		
90	SPO System	Special Pipe Hybrid BWMS with PeracleanOcean	-	Cavitation+PeracleanOcean	-	-
91	Sincerus	Sincerus maritime	Filtration	Electrolysis/Electrochlorination	-	www.sincerus.de/en/
92	Sumitomo Electric	SEI BWMS	Filtration	UV		

Nr.	Manufacturer	System name	Pre-treatment	Treat ment	Residual control	Web site
	Industries Ltd.					
93	SUNBO Industries Co. Ltd.	Blue Zone	-	Ozonation	Thiosulphate	-
94	Sunrui Corrosion and Fouling Control Company (Sunrui CFCC)	BalClor BWMS (Sunrui BWMS)	Filtration	Electrolysis/Electrochlorination	Sodium thiosulphate	www.sunrui.net
95	STX Metal Co. Ltd.	Smart Ballast	-	Electrolysis/Electrochlorination	Sodium thiosulphate	www.stxmetal.co.kr
96	Techcross	ElectroCleen System ECS (ECS-HYCHLOR, ECS-HYCHEM, ECS-HYBRID)	Filtration	Electrolysis/Electrochlorination	Sodium thiosulphate	www.techcross.net/eng_main
97	The Ship Stability Research Centre (SSRC), University of Strathclyde	ClearBal	-	Brilliant Green & cetyltrimethyl ammonium bromide	Detoxifiction system based on ion exchange (Amberlite XAD-7)	www.sumobrain.com/patents/wipo/Ballast-water-treatment-system/WO2010086604.html
98	Titan	RT SAFEBALLAST (KLOROGEN®-BW)	Filtration	Electrolysis/Electrochlorination		
99	Trojan	Trojan-UV Marinex	Filtration	UV	-	http://trojanuv.com/
100	Van Oord B.V.	VO-BWMS	-	Drinking water+chlorine	Sodium bisulphite	-
101	Vitamar	Seakleen	Filtration	Seakleen	-	
102	Wuxi Brightsky Electronic Co. Ltd.	BSKY	Filtration	UV	-	-
103	Yixing PACT environmental Technology/Co. Ltd.	PACT Marine	Filtration	UV	-	http://www.pactchina.com/
104	Zhejiang Yingpeng Marine Equipment Manufacturer Co. Ltd	YP-BWMS	Filtration	UV	-	