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SCHOOL OF ENGINEERING
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COMPARISON OF APPROVED BY IMO TECHNOLOGIES AVAILABLE FOR TREATMENT OF BALLAST WATER ON BOARD VESSELS

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Abstract

The world's fleet is growing continuously in the last few years, using ballast water almost all of the vessels, increasing the risk of spread of invasive species into local environments. This risk has lead the International Maritime Organization to legislate the control and treatment of ballast water to minimize the risks.

For this reason, the International Convention for the Control and Management of Ships' Ballast Water and Sediments has played an essential role for achieving a proper control of the ballasting and de-ballasting process of each vessel. Many Ballast Water Management Systems (BWMS) have been approved that comply with D1 & D2 regulation of IMO. The different treatment systems have clearly reduced ballast water impact but the only way for reducing completely the risk of invasion is to reduce the use of ballast water and to design alternative methods.

The methodology used during the paper consists on a deep explanation of the ballast water impact and a comparison among different treatment systems. The scope of this study is to compare these systems regarding their friendliness to the environment and the efficiency for the vessel. Finally, on the conclusion of this study we will see some different proposals to avoid the use of ballast water.

ΣΥΓΚΡΙΣΗ ΤΩΝ ΕΓΚΕΚΡΙΜΕΝΩΝ ΤΕΧΝΟΛΟΓΙΩΝ ΑΠΟ ΤΟΝ I.M.O. ΓΙΑ ΤΗΝ ΕΠΕΞΕΡΓΑΣΙΑ ΕΡΜΑΤΟΣ ΣΕ ΠΛΟΙΑ

ΣΤΑΜΟΥ ΦΕΙΔΙΑΣ

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Περίληψη

Ο παγκόσμιος στόλος αυξάνεται συνεχώς τα τελευταία χρόνια, μετακινόντας συνεχώς το θαλασσινό νερό αυξάνοντας τον κίνδυνο εξάπλωσης των χωροκατακτητικών ειδών σε ξένα περιβάλλοντα. Ο κίνδυνος εισβολής έχει ωθήσει τον Διεθνή Ναυτιλιακό Οργανισμό (IMO) να νομοθετεί για τον έλεγχο και την επεξεργασία του θαλασσινού νερού έρματος για την ελαχιστοποίηση των κινδύνων.

Για το λόγο αυτό, η Διεθνής Σύμβαση για τον Έλεγχο και τη Διαχείριση του Έρματος των Πλοίων και των ιζημάτων έχουν διαδραματίσει ουσιαστικό ρόλο για την επίτευξη ενός σωστού ελέγχου της διαδικασίας ερματισμού και αποστράγγισης. Μετά τους διάφορους κανονισμούς που περιλαμβάνονται στη σύμβαση (κυρίως τα πρότυπα D-1, D-2), έχουν εγκριθεί πολλά συστήματα διαχείρισης του θαλασσινού έρματος (BWMS). Τα συστήματα διαχείρησης του έρματος βοηθούν μεν στην μείωση της διάδοσης ξένων οργανισμών σε άλλα περιβάλλοντα, αλλά ο μόνος τρόπος να μειωθεί πλήρως ο κίνδυνος εισβολής είναι να μειωθεί η χρήση του έρματος και να σχεδιαστούν εναλλακτικές μέθοδοι. Επομένως, οι διεθνείς οργανισμοί πρέπει να ενεργήσουν για να επιτύχουν τη μείωση της χρήσης του νερού έρματος στο μέλλον και να παρακινήσουν τη ναυτιλιακή βιομηχανία να επενδύσει και να μελετήσει νέο σχεδιασμό πλοίων χωρίς να είναι αναγκαία η χρήση έρματος.

Η μεθοδολογία που χρησιμοποιήθηκε κατά τη διάρκεια της εργασίας συνίσταται σε μια βαθιά θεωρητική εξήγηση του έρματος (συμπεριλαμβανομένης της Σύμβασης Διαχείρισης Υδάτινου Έρματος) και μια σύγκριση μεταξύ διαφορετικών πιστοποιημένων συστημάτων θαλάσσιου έρματος. Ο σκοπός της σύγκρισης είναι να διακρίνει ποιο σύστημα είναι καλύτερο όσον αφορά τη φιλικότητα προς το περιβάλλον και την αποδοτικότητα στην εξόντωση των μικροοργανισμών.

Contents

1 ***Chapter - Introduction to the Water Ballast***

1.1 ***Importance of the Water Ballast on a Vessel***

Shipping carries approximately 80 percent of world trade in volume and more than 70 percent in value (UNCTAD, 2012) and it is characterized as the most cost effective way of transportation. More than ninety percent of the global trade; from fuel and food to construction materials, chemicals and household items – are being transported by vessels. Approximately 50,000 merchant ships sailing at the world's oceans, with a combined tonnage of around 600 million gross tones. Incredible weights that clearly affect to the safety of transportation are able to be carried by new building vessels. Vessels have been designed and constructed to sail and operate safely when they are loaded with cargo but they need additional weight when they are sailing without cargo or when partially laden with cargo in order to ensure appropriate stability and to manage the stresses on the hull.

Stability of the vessels has become more and more important during the years as the maritime industry has seen that the size of vessels have been continuously increasing during decades. For this reason, it is very important when loading-unloading cargo on the vessel, to have a perfect loading manual so as to distribute correctly all the weight on the vessel. Moreover, maritime industry realized that the good distribution of the weights was not enough and new methods were used to ensure the safety of the vessels. One of these methods that are used in order to have a higher control on stability, is the sea water.

Ballast water, is used in vessel's tanks to control her stability, her balance, her draught and her trim. It is water, loaded directly from the sea so as to fill the ballast tanks of the vessel and increase her stability. In earlier days, ships used solid ballast such as metal, rocks and sand (GEF-

UNDP-IMO GloBallast Partnerships and IOI, 2009). But due to technical developments, vessels started to use water since it is much easier to load and discharge and more economical than using solid ballast. Therefore, nowadays the water ballast is really crucial for a vessel in order to operate safely.

In a short description, the main reasons for using the ballast on board are the following:

- To control the stability during loading or unloading the cargo on the vessel, depending on the weight distribution.
- To have an extra stability in adverse or foul weather conditions.
- To avoid the stress on the hull.

In general, a ship has to be ballasted on around 30% to 40% of her dead weight tonnage (DWT) in normal ballast condition and 38% to 57% in heavy ballast condition.

It is assumed that in a period of one year, the vessels moves approx... 10 billion tons of Ballast Water.

Ship Type	DWT	Ballast Condition			
		Normal (tonnes)	% of DWT	Heavy (tonnes)	% of DWT
Bulk carrier	250,000	75,000	30	113,000	45
Bulk carrier	150,000	45,000	30	67,000	45
Bulk carrier	70,000	25,000	36	40,000	57
Bulk carrier	35,000	10,000	30	17,000	49
Tanker	100,000	40,000	40	45,000	45
Tanker	40,000	12,000	30	15,000	38
Container	40,000	12,000	30	15,000	38
Container	15,000	5,000	30	n/a	
General cargo	17,000	6,000	35	n/a	
General cargo	8,000	3,000	38	n/a	
Passenger/RORO	3,000	1,000	33	n/a	

Table 1: Representative ballast water capacities

1.2 ***Main Advantages of Ballast Water***

Some of the advantages of the usage of ballast water systems are the following:

1. Reduction of stress on the hull, the provision of transverse stability, mostly during navigation.

2. Improvement of the propulsion of vessel.

3. Increase of maneuverability during navigation.

4. Compensation for weight changes due to differences on cargo levels and due to fuel consumption mostly during navigation (as the change while berthed is insignificant for the stability).

On our days, it is essential for vessels to use ballast water for their safety and there is no other method or technology that can substitute completely the performance of the ballast water.

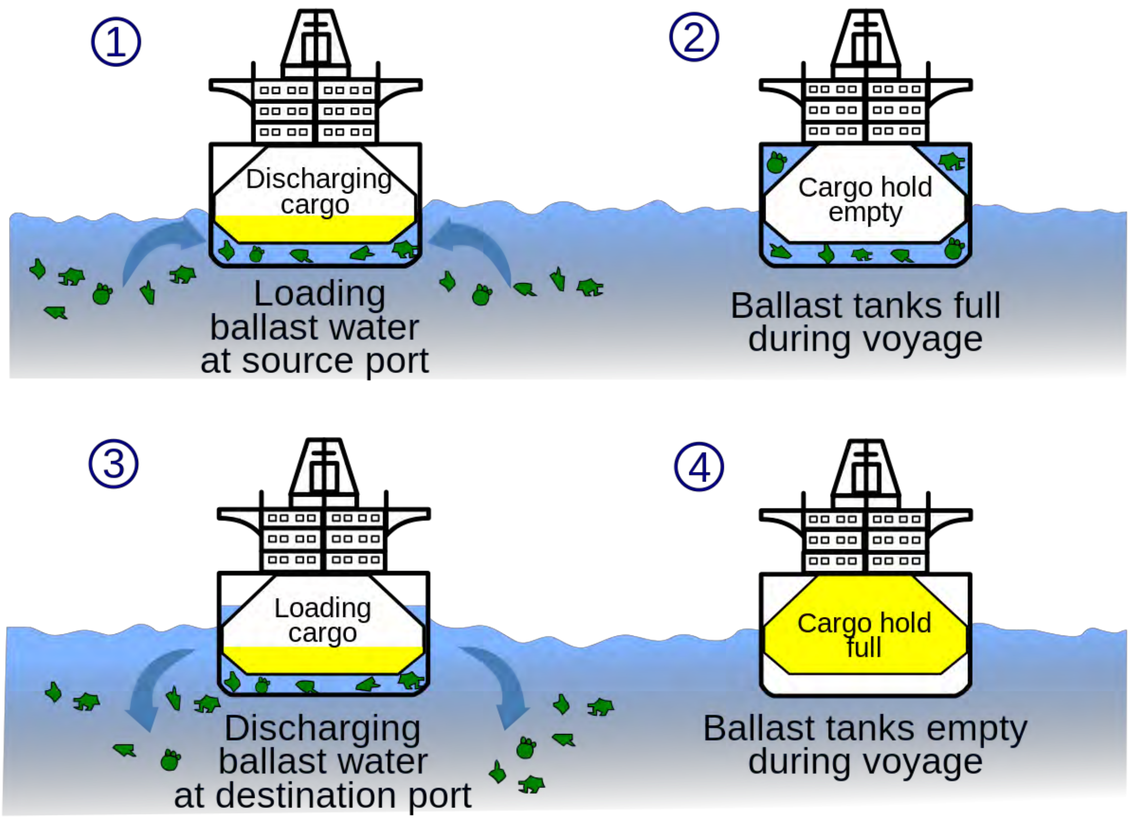


Figure 1 Shows ships' ballast operation cycle in a port where cargo is discharged and de-ballast operation in another port where

cargo is loaded.

1.3 ***Main Disadvantages and Secondary Effects of Ballast Water***

The Water Ballast may be necessary for the safe loading - unloading operation of the vessel; and for a safe sailing but crucial effects may conduct to the environment and to the species living on the seas. This additional weight is necessary in order to bring the vessel to a suitable draft and trim to reduce stresses, and improve stability (GloBallast, Partnerships, The Problem, 2010).

Due to the great expansion of the maritime transportation and due to the increase of the size of the ships and the growth of the volumes, there are too many remarkable problems to the environment. Inevitably, areas that have not been damaged yet, will be affected by the continues growth of bio-invasions. It is assumed that every day ballast water moves approximately 7,000 species around the world (USGS, 2005; GEF et al., 2010). Therefore, shipping is responsible for introductions of marine species as a key vector for movement of species (Cohen & Carlton, 1998; Ruiz et al., 2000a; Hewitt et al., 2004; GEF et al., 2010).

It is a common view that the transportation of unwanted organisms due to ships' ballasting procedures has jeopardized many of the earth's natural ecosystems. Successful invasions have been well documented, including the European zebra mussel in the US Great Lakes, Japanese dinoflagellates in Australia, and the North American comb jellyfish in the Black Sea (Hallegraeff 1993, Nalepa & Schloesser 1993, Ascherson 1996). Mills et al. (1993) noted only to the Great Lakes of North America more than 140 alien species have been introduced.

Recently updates to these data shown that the reported transportation rate of the invasions has increased over the past 200 yr, and that most reported invasive species are members of the Crustacea and Mollusca. It has also been reported that in the US, more invasive species are present along the Pacific Coast than along the Atlantic and Gulf Coasts (Ruiz et al. 2000a). There has also been some indication that microorganisms (pathogenic bacteria) may be spread due to ships' ballasting operations. For example Ruiz et al. (2000b) have measured Vibrio cholerae in planktonic samples collected from ships. Microorganisms associated with marine diseases may also be transported via ballast, and Harvell et al. (2000) have documented several new marine diseases. The diversity and the abundance of the species that including in ballast water has been examined through various studies world-wide (e.g. Galil and Hu¨lsmann, 1997; Zhang and Dickman, 1999; Ruiz et al., 2000).

1.3.1 Ecological Problems

When the vessel pump-in ballast water, for filling her tanks on the port 'A', the water that gets into the tanks is loaded from the area that the vessel is passing the specific moment. The vessel will de-ballast this ballast water, to another port where she will be for loading cargo. Therefore, multitude of species that entered the ballast tanks on the port 'A' such as bacteria, microbes, eggs, small invertebrates, cysts and larvae of many different species, will discharged to the port 'B'.

In case these species achieve to survive in the environment where they will be discharged, they may reproduce and their population will be increased in areas that they have never been established. If their survival will be achieved, then the species will be reproductive and they will be made invasive species that will compete with the native ones and many times they will become a plague for this new environment.

In order to have a glance of the amount of sea water that is being used by vessels, it is assumed that around the world, about 10 billion tons of ballast water is being carried out world per year, which signifies that every hour of the day, a total of 7000 thousand species being transported.

It was in 1903 in the North Sea when the first invasive species were recognized, when there was a spreading of the Asian phytoplankton algae Odontella. The first time that the ecological problem occurred by ballast water was studied was in 1970s and it was In 1980s, Australia and Canada experienced problems caused by invasive species and brought their concerns to the International

Maritime Organization's (IMO's) Marine Environment Protection Committee (MEPC). The International Convention for the Control and Management of Ships' Ballast Water and Sediments (i.e., the Ballast Water Management (BWM) Convention) was a result of the above mentioned actions.

Nowadays, ship-owners and management companies, have been forged to meet regulations and requirements concerning the ballast water operation of the vessel.

1.3.2 Economic Problems

Economic effects are also occurred due to the invasive species. It is obvious that the food industry is the most affected economic parameter (reduction in fisheries) but apart from this, there are economic losses associated to the affection of ships hulls (fouling). The tourism and the recreational areas are also affected indirectly due to this phenomenon. Finally, it needs to be taken into consideration the money that have been used for the control or the prevention of the invasive species, the eradication of them and the costs of a water ballast treatment to be installed on board in order to reduce the impact on the environment.

1.3.3 Health Problems

Humans are definitely connected with the oceans and the all the seas and rivers around the world. Species that human is eating may occur problems in his health.

Moreover, it is to be considered that humans are used to the bacteria that exists at the areas where they normally live. Many health problems, for example with the digestive system may be caused due to the exhibition of the human body to bacteria that it is not used to.

1.4 ***Some Examples of Invasive Species***

Invasive aquatic species means a species, which may pose threats to human, animal and plant life, economic and cultural activities, and the aquatic environment (IMO, 2011).

1.4.1 Asian Kelp (Undaria Pinnatifida)

The normal geographic area that the kelp Undaria pinnatifida, may be found, is Japan, Korea and in some areas of China, but it has been found to grow up to 7 m depth over a 4 km stretch of the shoreline of Wellington Harbour, New Zealand. It was announced that in August 1987, some sporophytes were up to 1.3 m tall with fully developed sporophylls. Within the last 9 years, evidence proves that Japanese fishing vessels have carried Undaria to New Zealand. This is the second record of Undaria being inadvertently introduced to shores beyond Asia, and it is the first record of its occurrence in the Southern Hemisphere. (Cameron H. Hay & Penelope A. Luckens (1987) (https://www.tandfonline.com/doi/abs/10.1080/0028825X.1987.10410079)

1.4.2 Cholera (Vibrio Cholerae)

Especially in port areas that have been polluted with sewage water and the sanitation is poor, there are breeding ground cholera bacteria. These cholera bacteria, being attaché zooplanktons and other platonic animals especially in countries with tropical climate. By this way, these cholera bacteria may be inserted through the ballast water in ballast tanks and to be transmitted in areas around the world. If ingested in drinking water, strains O1 and O139 of the bacteria can cause cholera in humans.

It was in 1991 and 1992, when toxigenic Vibrio cholera O1, serotype Inaba, biotype El Tor, was recovered from nonpotable (ballast, bilge, and sewage) water from five cargo vessels in areas of the U.S. Gulf of Mexico. From these five vessels, the four of them, had taken on ballast water in cholera-infected countries; the fifth took on ballast in a no infected country. Isolates examined by pulsed-field gel electrophoresis were indistinguishable from the Latin American epidemic strain, C6707; however, they differed significantly from the endemic Gulf Coast strain (VRL 1984), the sixth-pandemic strain (569-B), and a V. cholera non-O1 strain isolated from a ship arriving from a foreign port. Further to the above, food and Drug administration, forced US Coast Guard to request from captains and agents of the vessel to exchange the ballast water in high seas before enter US. (https://aem.asm.org/content/60/7/2597.short)

1.4.3 European Green Crab (Carcinus Maenas)

Another one specie which colonize in Australia is the European green crab, which has found its way from its original habitat in the north-east Atlantic Ocean and Baltic Sea to the Antipodes, South Africa, South America and both the Atlantic and Pacific coasts of North America. The green crab is a carnivore that preys upon clams, mussels, oysters, and gastropods. It was introduced in US at 1950's and due to the fact that it prays on scallops and on commercially important shellfish, it has caused in American fishing industry millions of dollars. Besides from preying on native species, the European green crab is able to outcompete them for food, and can reproduce in high volumes.

Figure 2European Green Crab - source: https://www.vichighmarine.ca/european-green-crab/

1.4.4 North Pacific Sea star (Asterias Amurensis)

This specie is native to, North China, Japan and far eastern Russia, is capable to be survive in many temperature salinity ranges. In the period of July till October, the female may carry almost 20 million eggs, which live as planktonic larvae for 180 days. The north pacific sea star, has been introduced to south-eastern Australia and Tasmania, from vessel's ballast water. The port of Melbourne is port in Australia, serving a lot of vessels, coming from Far East. This creature has caused a serious problem in Australia, because it is eating the eggs of the endangered hand fish. The sea star will eat a wide range of prey and has the potential for ecological and economic harm in its introduced range.

Figure 3 ***The Killer Shrimp - source:*** *https://www.thinglink.com/scene/789523271463731201*

1.4.5 Killer Shrimp

Dikerogammarus Villosus, as it is the scientific name, is a very small creature but it is really wild. I t's origin place is in Eastern Europe in the Black Sea.

It and its nasty cousin Dikerogammarus haemobaphes, are only about 2-3cm long, but Hugh MacIsaac, a scientist and professor of biology at the University of Windsor who specializes in invasive species, said the small bottom-dwelling shrimp apparently attack anything their size or even bigger, including small fish.

When a cabal was dug in order to unite the Rhine Rivers with Western Europe in order to accommodate shipping and the popular river cruises, this alien species got access to Western Europe. Most probably due to ballast water of the vessels, this shrimp has been found in United Kingdom in 2010.

Figure 4 ***North Pacific Seastar - source:*** *https://www.rcinet.ca/en/2014/11/19/beware-the-killer-shrimp/*

1.4.6 Geographic Risk

Depending on the geographic region and the country, the risk of irruption of a foreign species may vary. In order to ‘’predict’’ which geographic areas may have the biggest concentration of invasive species, we should have in mind some factors such as:

- Harbors that draw vessels concentration at most.

- How different or how similar are the origin and the destination port, concerning the environment.

- Level of invasive species already living in a specific region provoking a habitat disturbance.

- The difference of the salinity and the temperature of the water between the destination and the origin seas.

Taking into consideration all the above, when a vessel sails from it's a port to another with very similar seawater characteristic, then there is a high opportunity of spreading invasive species. The risk of the invasion, depends on the common characteristics of the sea water between the two areas. This risk is being reduced when the characteristics defers and may be disappear when they are totally different. For example, there is very likely for an invasive species to be spread if it is pumped into the vessel in Baltic Sea and de-ballasted in the Pacific Coast due to the water condition similarities (both of them have cold water). On the other hand, the possibilities of spreading a specie ballasted in the Baltic Sea and de-ballasted in the tropics is very low as the likelihood of surveying are not too many.

In Figure 5, we may found the reported number of already known harmful-alien species of the North hemisphere. We can observe that where more harmful alien species can be found is the Mediterranean Sea, West Coast of the United States, water from around Great Britain and the islands of the North Pacific (Hawaii).

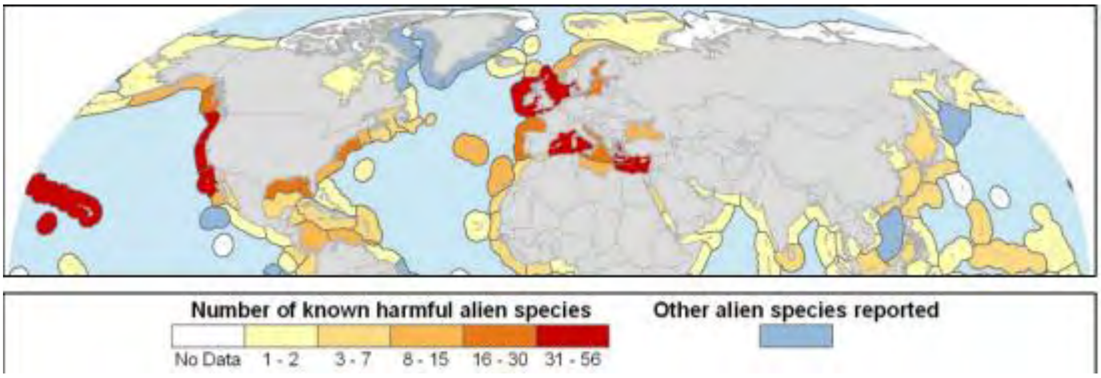


Figure 5Number of known harmful alien species. - Source: http://www.imo.org/en/OurWork/Environment/MajorProjects/Documents/EBRD%20BWM_Infrastructure_Investment_Guidance.pdf

The Mediterranean Sea, has common water characteristics (warm temperature and same salinity) with Black Sea or the Caspian Sea and therefore there is a high possibility of spreading alien species if the vessel ballast water from the first area and de-ballast the water to the other areas. When comparing seas with cold waters with warmer seas such as Baltic Sea and Pacific coast or the tropics, the possibility of spreading alien species, is being minimized a lot. Due to the high difference at the temperature the risk is very low when the water comes from the Arctic to the Mediterranean Sea since the organisms will die naturally without to be treated.

The risk profile of the Mediterranean Sea that, as we have seen, has a big number of known harmful alien species is the following (8):

- Too many vessels at a very small (refer to dimension) Sea
- Too many fishermen on this area.
- Due to not treated or bad treatment of the grey water, the quality of the seawater is extremely lower than years ago.
- Overfishing is threatening the biodiversity of marine ecosystems and the habitat of local species has been reduced.

As a conclusion of the above, it is essential for the Mediterranean Sea the port state control to carry out strict inspections on the vessels in order to check if the ballast water is being treated or not. Otherwise it may occur a high risk of the appearance of new invasive species at the local environment.

2 ***Chapter - Imo Regulation about The Ballast Water Treatment***

2.1 International Regulation

As we already discuss above, ballast water which is being transferred by the vessels has been identified as the greatest means of organisms transfer between geographically separated sea areas (Rigby and Taylor, 1999; Humphrey, 2008; Amoaka-Atta and Hicks, 2002). It is estimated that more than 3,000 species of species and plants are being transferred on a daily basis around the world in ballast water (NRC, 1996) and every nine weeks there is at least one foreign marine species is introduced into a new environment (Akeh, et al.,2005).

The Ballast Water Management Convention or BWM Convention (full name International convention for the Control and Management of Ships' Ballast Water and Sediments, 2004) is a treaty adopted by the International Maritime Organization (IMO) in order to help prevent the spread of potentially harmful aquatic organisms and pathogens in ships' ballast water.

Initial researches had proposed management of ballast water with precautionary practices (Carlton et al., 1995).

All the vessels worldwide are forced to manage and treat their ballast water so that alien species, microorganisms and pathogens to be removed from the water that will be discharged to another geographic location, from 8 September 2017. With this strict measures, the spread of the alien species and organisms will be prevented. IMO is the United Nations specialized agency responsible to develop global standards for vessel’s safety and security and for the protection of the marine environment and the atmosphere from any harmful impacts of shipping.

IMO has introduced two standards of ballast water management (D-1 & D-2).

According to the D1 standard the vessels have to exchange their ballast sea water in open seas 200 miles (ideally) away from coastal areas and at least 200 meters deep waters. When this exchange take place, the survival species will be much fewer and the vessels will not release harmful species when they de-ballast the sea water to another port.

The D-2 standard specifies the maximum amount of viable organisms allowed to be discharged, including specified indicator microbes harmful to human health.

From the date that this regulation of BWM Convention got into force all the new building vessels have to comply with the D-2 standard and all the vessels to comply with D-1.

Since 8 September 2019 all the vessels globally should comply with D2 standard which means that the already in use vessels that do not have treatment system should install.

At the Marine Environment Protection Committee (MEPC) all the IMO Member Governments, have agreed an implementation timetable for already in use vessels, which will be linked to the ship's International Oil Pollution Prevention Certificate (IOPPC) renewal survey.

Since 8 September 2017, all new building vessels should comply with the D-2 standard and all the ships must have:

1. A ballast water management plan;

2. A ballast water record book; and

3. An International Ballast Water Management Certificate.

➢ Existing ships must meet at least the D-1 (ballast water exchange) standard; they may also choose to install a ballast water management system or otherwise meet the D-2 (discharge) standard but this is not mandatory until the corresponding compliance date.

It is assumed that, more than 50,000 vessels need to be equipped with BWTS (IMO, 2010) and BWTS production and shipyard capacities may become a bottleneck. The convention was adopted in February 2004 and, once ratified, will require all vessels to manage their ballast water (IMO, 2005).

2.2 IOPPC Renewal Survey

2.2.1 After 8 September 2019

A vessel which is undergoing a renewal survey linked to the ship's International Oil Pollution Prevention Certificate after the date of 8 September 2019 must meet D-2 standard by the date of this renewal survey.

2.2.2 IOPPC Renewal Survey between 8 September 2017 And 8 September 2019

If the previous IOPPC renewal survey was between 8 September 2014 and 8 September 2017, then the ship must comply with D-2 standard by this renewal survey.

If the previous IOPPC renewal survey was before 8 September 2014, then the ship can wait until the next renewal survey (which will be after 8 September 2019).

In case that the vessel doesn’t have an IOPPC renewal survey, then she should comply with the D2 standard at a date determined by its flag State, but not later than 8 September 2024.

2.2.3 Difference between The D-1 And D-2 Standards?

While D1 standard requires only the ballast water exchange, D-2 specifies which is the maximum amount of viable organisms that the vessel may discharge during de-ballast operation, including also microbes specified harmful to human health.

- According to D1 standard, the vessel should exchange far away from the coast a minimum presentence of 95% of the total ballast capacity of the vessel’s sea water.
- According to D2 standard the vessel should discharge *less than*:

1. 10 viable organisms per cubic meter, greater than or equal to 50 micrometers in minimum dimension;

2. 10 viable organisms per milliliter which are between 10 micrometers and 50 micrometers in minimum dimension;

3. 1 colony-forming unit (cfu) per 100 milliliters of Toxicogenic Vibrio cholerae;

4. 250 cfu per 100 milliliters of Escherichia coli; and

5. 100 cfu per 100 milliliters of Intestinal Enterococci.

2.3 Is it possible for the authorities to check the compliance?

States cannot ratify the BWM Convention due to lack of enforcement methods, thus there has been significant discussion concerning the development of BW sampling guidance (Elliott, 2013). Port State control in any port or terminal of a Party to the BWM Convention may check this compliance. The inspectors may request for the approved by classification society or the flag of the vessel Ballast Water Management Plan, request for a valid certificate which should be kept onboard inspection of the ballast water record book which shall be updated in each operation and a sampling of the ship's ballast water, carried out in accordance with the *Guidelines for ballast water sampling* (G2).

The time which is required in order to analyze the sampling of the ballast water cannot be used for an unduly delay of the operation or departure of the vessel.

Moreover, it is necessary for the vessel to carry a copy of the Type Approval Certificate of the installed BWTS on board all times (MOF, 2013).

2.4 How Are Ballast Water Management Systems Approved?

There is a D3 Regulation of the Convention which covers approval requirements for ballast water management systems.

Ballast water management systems must be approved by the Administration taking into account IMO Guidelines.

2.5 Why did it take so long for the treaty to enter into force?

Entry into force of the treaty was dependent on enough ratifications by States. It is fair to say that suitable ballast water management systems were not immediately available and guidelines to support the BWM convention needed to be developed. But these issues have now been addressed.

To support ratification by States as well as research and innovation, IMO executed the Global Environment Facility (GEF) - United Nations Development Programme (UNDP) -IMO GloBallast Partnerships Programme (2000-2017). This successful project focused in particular on assisting developing countries to reduce the transfer of harmful aquatic organisms and pathogens in ships' ballast water and implement the BWM Convention.

The BWM Convention stipulated that it would enter into force 12 months after ratification by a minimum of 30 States, representing 35% of world merchant shipping tonnage. Those criteria were reached on 8 September 2016, hence the entry into force on 8 September 2017. as at September 2017, the treaty has been ratified by more than 60 countries, representing more than 70% of world merchant shipping tonnage.

3 ***Chapter Technologies for Ballast Treatment***

3.1 Introduction To Bwm Systems

There are too many Ballast Water Treatment technologies worldwide that comply with the IMO regulation and many different systems that may be used on board in order to comply D2 standard and avoid pollution.

The most important factors that have to be taken into consideration during the selection period of the future installed BWTS are the following:

- Safety of the crew.
- Friendliness with the environment - capability to minimize the percentage of organisms in ballast water.
- CAPEX (capital expenses) of the system
- OPEX (operational expenses) of the system
- Installation cost of the system
- Easy to be installed.
- Space on board in collaboration with the footprint of the system.

According to the above factors, ship owners decides which is the most preferable system to satisfy their demands.

Several methodologies that seek to remove or render harmless organisms in ballast water while in tanks and on ships are in development or being piloted. This includes mechanical treatment (e.g., filter or cyclonic separation), physical treatment (e.g., ultraviolet, ultrasound, or heat treatment), chemical treatment (e.g., the use of disinfectants or biocides), and biological treatment, or a combination of these (Tamelander et al. 2010).

The following types of ballast water treatment technologies exist globally.

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

3.2 Variety of Treatment Methods and Vendors

Treatment methods can be divided into physical and chemical methods. Filtration, UV-radiation, cavitation, pressure vacuum and heat, among others, are physical methods. Chemical methods include (but are not limited to) chlorination, electro chlorination and ozonation. Each method has its pros and cons.

The footprint, operational costs and need for spare parts and maintenance will differ between different methods. The methods can be seen as compromises; the goal is not to find absolutely best solution, but a solution that best fits the current situation.

The main concern for the ship owner is to find a BWTS that fulfils the rules of the IMO and flag authorities as well as ship- specific requirements including the water characteristics where it is operated. The selected system should also be cost efficient and the operating the system should not cause problems for the ship's existing systems or require extra efforts from the ship's crew.

3.2.1 Physical Separation or Filtration Systems

Systems that do not use chemicals and by sedimentation / filtration separate the solid parts, are called systems of physical separation or filtration systems. By this method, the biggest solid particles is getting filtered and the water is getting cleaner before it will get discharged to another geographic location. When the particles get separated from the water, they are being discharged before the vessel's departure; in the same location that the ballast water was pumped into the vessel.

3.2.2 Hydro Cyclone

The hydro clone is using the centrifugal force in order separate the solid practices from the ballast water. It is characterized as an easy to install system since it doesn't have moving parts at all, as it is a static system.

Hydro cloning is a cost-effective alternative to filtration (Taylor and Rigby, 2001). Despite the particles removals similar to filtration, the efficiency is much lower (Parsons, 2003). Larger particles is difficult to be removed (Parsons and Harkins, 2002) since hydro cloning depends on the density difference between the organisms to be removed and the fluid in which it is carried. The biggest disadvantage is that they are not so efficient since in the most cases, hydro clones cannot separate too small practices from the ballast water.

Figure 6 Hydro cyclone process. - Source: http://www.fonte.se/Ballast-water-treatment.html

3.2.3 Screens

The screens are another one solution which seems to be an eco-friendly solution since there is no use of toxic chemicals. When using fixed or movable screens as a method to treat the ballast water, then the system is very efficient for solid larger than 50μm particles which can be discharged directly overboard through the use of a back flushing pump.

Unfortunately, the screens cannot stand alone in a ballast water treatment system since they cannot meet all the requirements of the IMO standards.

Figure 7screen filter: http://www.cross.com.gr/wp-content/uploads/2012/05/Filtersafe-1.png

3.2.4 Media filters:

In order to separate micro organizations for typical organism sizes ranging from 25-50μm (Taylor and Rigby, 2001), filtration is the simplest way. Due to the fact that they can remove solids and organisms of lower than 1μm in addition with other physical treatment methods that can remove larger then 50μm, media filters are being very effective. For the marine environment the crumb rubber filters are highly recommended due to their smallest size.

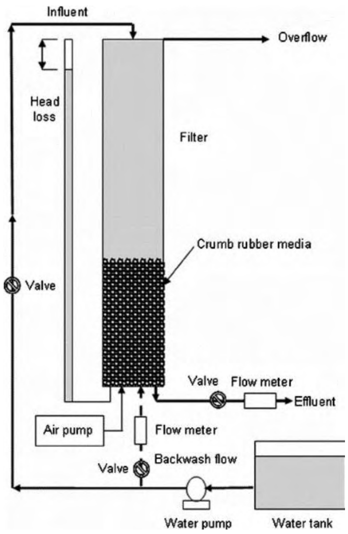


Figure 8 Screen filter: *https://www.researchgate.net/figure/Experimental-setup-of-the-crumb-rubber-filter_fig1_245336809*

3.2.5 Coagulation:

Coagulation as method cannot stand alone on a vessel. This method is being used in order to merge together all the smallest particles of the ballast water, making bigger particles which would be easier to be removed by a filtration process. These bigger particles are being called flocs as the process is calls flocculation. In order to be used on a vessel, the need to be installed together with a filter and an additional tank for this process. Due to the above requirements, coagulation is difficult to be installed due to their demand for a big free space.

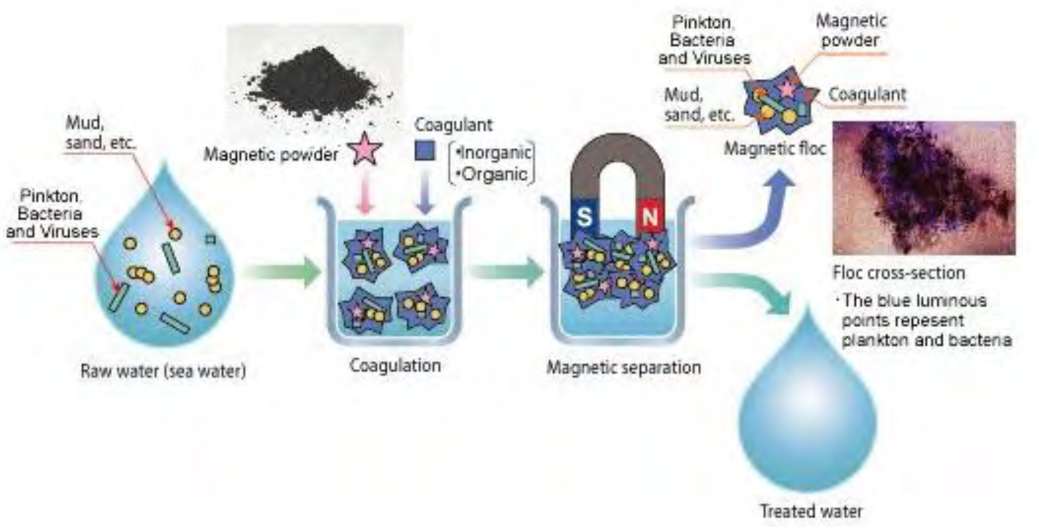


Figure 9 Coagulation process: https://www.marineinsight.com/tech/how-ballast-water-treatment-system-works/

3.2.6 Ballast Water Treatment System Using Chemical Disinfection

Chemicals are being used in order to remove alien species from the water ballast that has been ballasted on the vessel. Normally they divided in two categories of biocides that are being used in order to act as disinfectants:

1. Oxidizing
2. Non-oxidizing

At this point we have to mention that the biocides that are being used for the treatment of ballast water have been tested to be very effective against the marine microorganisms and not to be toxic against the nature.

How effective, or not the chemicals are, is related with their fundamental actions: alteration of protoplasm/organism DNA or RNA, damage of the cell of the wall and by abortion of the enzyme activity (Tsolaki and Diamadopoulos, 2009).

The most preferable of the chemical disinfection methods, is the chlorination. From Sodium Hypochlorite, the chlorine is possible to be generated and this is a very effective method in potable water systems. Ballast water tests that have been performed when using hypochlorite, have shown that Bacteria have been eliminated at 85.2 % for *Escherichia Coli* and 99.85% for anaerobic bacteria have been recorded (Zhang et al., 2003). A lot of systems are using electrolysis of the salty water in order to produce Chlorine and Sodium. Such a system may succeed efficiency of 99% results for bacteria, phytoplankton and mesoplankton (Matousek et al., 2006). Unfortunately, the effectiveness of Chlorine depends on a lot of factors such as reaction time, residual Chlorine and temperature (Tsolaki and Diamadopoulos, 2009) as also pH level (Armstrong, 1997). There is a possibility of a post treatment at high residual levels of Chlorine and toxic by-products (Rigby and Taylor, 2000; Bolch and Hallegraeff, 1993; Rigby et al., 1993).

Another oxidizing chemical, Chlorine-di-oxide tests have recorded 98% organism removal (Bolch and Hallegraeff, 1993). Residual levels of Chlorine-di-oxide have to decline prior to discharge and would safely require 24 hours (Lloyds' Register, 2010)

3.2.7 Oxidizing Biocides

By using oxidizing biocides, this method of chemical injection, uses disinfectants that destroy nucleic acids and cell membranes. Some of the most common oxidizing biocides are the following:

- Chlorine: this is a very dangerous chemical which when it sprayed into the ballast water, it will destroy all the species that will get in contact with. In order to have an idea about who toxic; chlorine would be, it may cause a lot of health issues also to the human so as to cause a cancer or burn the skin.

- Ozone gas: by using this biocide, bubbles are being released into the ballast water in order to destroy the microorganisms. The most important issue by using ozone gas is that it is extremely toxic for the environment and the human health.

- Peracetic acid and hydrogen peroxide: These oxidizing biocides are also being used in order to destroy marine micro organizations.

3.2.8 Non-Oxidizing biocides

Non Oxidizing biocides, unfortunately need many days in order to act against the micro organization. This means that the ballast water has to be for a long period inside the ballast tanks in order to act completely the non oxidizing biocides. This obviously means that if the vessel makes short distances voyages, the ballast cannot be treated completely. Main example of non-oxidizing biocide is the" SeaKleen", a mixture of Vitamin K3, bisulfite and naphthoquinone. The disadvantage of the "SeaKleen" is that it is not approved if it has a correct effect on the different species that can be found in the ballast sea water.

3.2.9 Magnetic field treatment

The magnetic field treatment, is getting into force, once the coagulation process is being performed. Using magnetic powder mixed which is getting mixed with the coagulants inside the ballast water, leading to the formation of big size particles including the marine organisms that we need to remove. After this solid creation, using magnetic plates, these big size particles are being separated from the ballast water.

3.2.10 Electric Pulse and Plasma Treatment

Electric pulse systems are being characterized as easy to be installed systems, they have a low capital cost and they are also environmentally friendly. Both methods it seems to have same results and the fact that they are environmental friendly is the most common advantage of this method.

By the use of electric pulse, during ballasting operation, pulses are used in order to extinguish the micro organization. Due to the two metal electrodes, high power may be generated and transmitted in the ballast water being able to be transmitted in different sea water pressure and density.

By the generation of a plasma arc inside the ballast water, the electric plasma treats the sea water which is ballasted in the vessel. The most important disadvantages of both methods, are that this technology needs a further research in order to be installed on a vessel and the crew should be properly trained.

3.2.11 Deoxygenation

This method kills the microorganisms by asphyxiation. Using inert gases such as nitrogen, this method reduces the level of the oxygen inside the ballast tanks affecting not only the asphyxiation of the microorganisms but also avoiding the corrosion inside the ballast tanks.

This method is being characterized as a green method since it is very environmental friendly and it is one of the most cost effective solutions for the ship owner since it requires very short modifications on the vessel in order to be installed.

A really very important advantage is that the corrosion levels in Ballast tanks are being reduced due to reduce of oxygen (Tamburri et al., 2002).

The only disadvantage of the method is that two to four days are required in order to asphyxiate the species which is not convenient for the vessels that require fewer days for a short voyage.

3.2.12 Heat treatment

The heat treatment of ballast water has been widely advocated as a possible treatment regime based on theoretical (Bolch and Hallegraeff, 1993; Hallegraeff et al., 1997; Mountfort et al., 1999) and laboratory/small scale trials (Rigby et al., 1999; Mountfort et al., 2001).

In case sustaining a temperature range of 35o – 45o C ensures elimination of organisms Heat treatment is projected as an effective method in earlier studies (NRC Report, 1996; Rigby and Taylor, 2000).

The ballast water is being supplied to the heat treatment system using the fire pump and fire main. The water is being heated in two heat exchangers, where the pre-heater increased the temperature to 40–45 C and the second heat exchanger increased it to the test temperature required for the particular trial using steam from the ship's boiler. The target is to reach the desire temperature till all the micro organizations to be killed. The mortality of the species has been proven if for extended periods the temperatures are sustained (Quilez-Badia et al., 2008).

The biggest advantage of this method is that as a heater, the existing boiler of the vessel may be used but the thermal duty of the boiler has to be checked during the engineering study.

From the opposite, the biggest disadvantages of this method is the time needed for the treatment and the corrosion that may occur to the ballast tanks.

3.2.13 Ultra-violet Treatment method

In combination with a filter, UV lamps are being installed on the vessel and the water is being treated by the UV reactor both at ballasting and de-ballasting operation. The UV-C rays can destroy the DNA of the micro organizations and as a result of this they cannot be reproduced inside the ballast tanks.

The main advantage of this method is that it is an environmental friendly solution and can work indifferent salinities but the biggest disadvantage is that may not work properly when the vessel is in mud waters where it is difficult for the UV to penetrate into the organisms that contains the ballast water.

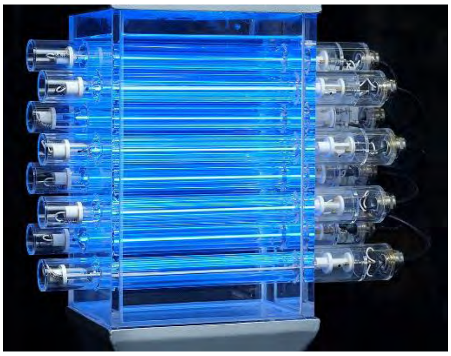


Figure 10 UV reactor: https://www.eta-uv.com/en/applications/environmental-technology/

3.2.14 Cavitation or Ultrasonic treatment

The way that the cavitation or ultrasonic treatment works, is by using acoustic signals in order to kill the bacteria who lives in the sea water. In order to kill them, ultrasonic energy is being transferred to the sea water, producing high energy ultrasound that kills the cells of the microorganisms. The main disadvantage of this method is that it cannot be applied only by it shelf but needs also another one method to be combined with. Of course the main advantage is that there is no use of chemicals which may be harmful to the environment.

3.3 Remarks on Ballast Water treatment system on vessels

Having a glance on the technology variety of treatment systems technologies that exists worldwide in order to kill the bacteria and the micro organizations a vessel ballast on board at the cargo unloading port, we need to say that almost none of the above technologies can stand alone as a treatment method.

In most of the cases, it is used 2 different technologies and together may achieve the maximum efficiency in order to clean the ballast sea water. The variety of the methods uses filtration (or another type of physical separation) to collaborate with on board in order to kill the micro organizations.

4. ***Chapter - Methodology of a New BWTS Retrofit installation Project***

4.1 Retrofit Project

In order to comply with D2 standard, all the existing vessels need to install a Ballast Water Treatment System. A BWTS retrofit, includes various phases i.e. evaluating solutions and the selection of suitable system, design, installation, including prefabrication and commissioning.

Design includes system integration design and installation or detail design. Between the two design phases there is normally the classification society approval.

The result of the feasibility study, the first phase of a BWTS retrofit, provides a shortlist for the best alternatives for each vessel. The selection for the shortlist is based on several technical and economic criteria. Different systems, methods and vendors are compared. Also the footprint of the required equipment and operational aspects such as water quality, total ballast volume and ballasting cycles per year are considered. 3D scanning is performed and 3D models of different systems are modelled into a point cloud, which is produced via 3D scanning. BWTS usually require space for maintenance and repairs. Sufficient space reservations for maintenance can be verified with 3D design. The final selection is made from the shortlisted alternatives according to normal commercial negotiations and decisions.

Design starts with updating the relevant system diagrams. Possible clashes with other systems or pipes need to be identified as early as possible, therefore accurate design methods are preferred. Laser scanning is a proven tool for creating an accurate starting point for design which is preferably done in 3D. The later clashes are identified, the greater is the impact on the schedule and costs. Another important issue is the hauling plan. The system components are large, and hauling may not be possible via normal routes.

After system diagrams and other drawings are sent for class approval, the design regarding installation and pre- fabrication is started. Detail design has a significant effect on the successful installation and completion of the retrofit project. The better and more careful the design, the less time is spent at the yard or in the dry-dock, where the installation is normally done. Optimal design is essential for minimum off-hire and the successful and timely completion of the installation.

4.2 Criteria for Selecting the Best Solution

Each ship can be compared to fingerprints; even if they look alike, there are several differences that make each ship and fingerprint unique. The ship's size, age, type, ballast water capacity and ballast pump(s) capacity, and ballasting frequency are issues to consider when choosing the best alternative. The ship's route, including water characteristics and the length of voyage, also have an influence.

Machinery spaces on ships are normally used efficiently, which means that there is minimal extra space, if any, available. It is likely that the BWTS is installed in machinery spaces such as engine rooms. The electrical capacity may be limited and there is no surplus for all types of BWTS. Therefore, updating the electric balance calculations is essential to ensure compliance of the selected BWTS.

Another concern is the pressure drop as a result of the increased pipe meters and components. That might lead to a need to modify or even replace ballast pumps to keep the ballasting capacity as initially required.

Some vendors set numeral limits for water characteristics such as salinity or Ultraviolet Violet Transmittance. The responsibility for fulfilling the IMO convention is the ship owner's, even if the system itself has type approval. Therefore, it is very important to verify the operability of the BWTS before acquisition. Computational Fluid Dynamics (CFD) is a method that can be used to verify the desired operability (pressure drop, fluid distribution) of the ballast water system after BWTS installation.

There are many solutions and different kinds of circumstances. Therefore, the best alternative for a particular vessel may not be applicable to another.

The ship may have a BWTS that works well while sailing in salty ocean water, but might face problems while moving to fresh waters. A similar situation could occur if a ship that is used in legs that take several days, is moved to shorter legs that take only hours.

The main concern for the ship owner is to find a BWTS that fulfils the rules of the IMO and flag authorities as well as ship-specific requirements including the water characteristics where it is operated. The selected system should also be cost efficient and the operating the system should not cause problems for the ship's existing systems or require extra efforts from the ship's crew.

4.3 Factors to be considered

Each vessel is unique. There is a variety of factors such as her type, her age, her normal voyages per year etc. that has to be taken into consideration before the final decision regarding the BWTS technology that will be used. The installation of such a system is not an easy job and at the majority of the cases the vessel has to be off hire in order to install it. In case the vessel choose to install the system at dry dock without any preparation or prefabrication, the vessel may be off hire for 2 months.

The normal operation is the ship-owner to authorize an engineering company to study the case, all the components may be prefabricated by the shipyard before the vessel's arrival and the installation of the system will last approx. 2-3 weeks. By this method, Owner Company will save a lot of money since the vessel will be off hire for a very short time period.

4.4 Ship type and purposes

The most important issue when in order to choose a BWTS, is the type of the vessel, if it is a bulk carrier, a tanker, a RO/RO or a general cargo vessel. For example, on a tanker vessel the system that will be installed has to be explosion proof, if it has to be installed in a hazardous area. After this, ship-owner has to take into consideration the size of the vessel in collaboration with the operation of the vessel. For example for a bulk carrier vessel, Panamax size with two ballast pumps, if the operation of the vessel demands a quick loading and unloading of cargo then the system that will be installed has to be of ‘’full capacity’’, which means that all ballast pumps will be able to ballast and DE ballast with treated water simultaneously. In case that the vessel need to perform a quick loading of cargo (fast de-ballasting) but the unloading of the cargo do not be necessary to be fast (slow ballasting) then the owner may choose a side stream system in order to save money.

Furthermore, each surrounding of the ports is different, having different characteristics such water salinity, temperature or turbidity. For example, the ultra violet systems may have difficulties to work or a very high power consumption when the water turbidity is very high. From the other side, the electrolysis systems, cannot work without salty water which means that when the vessel is ballasting in low salinity areas such as rivers, should have a storage of salty water in a tank in order to ballast sea water and low salinity water into the tanks in order to be able the electrolysis to be performed.

In the table below, we may see representative ballast capacity and representative pumping rates depending on the type of vessel.

Vessel catergory	Vessel Type	Representative Ballast Capacity (m^3)	Respresentative Pump Rate (m^3/h)
High Ballast Dependent Vessels	Bulk Carriers		
	Handy	18,000	1,300
	Panamax	35,000	1,800
	Capesize	65,000	3,000
	Tankers		
	Handy	6,500	1,100
	Handymax-Aframax	31,000	2,500
	Suezmax	54,000	3,125
	VLCC	90,000	5,000
	ULCC	95,000	5,800
Low Ballast Dependent Vessels	Containerships		
	Feeder	3,000	250
	Feedermax	3,500	400
	Handy	8,000	400
	Subpanamax	14,000	500
	Panamax	17,000	500
	Postpanamax	20,000	750
	Other vessels		
	Chemical Carriers	11,000	600
	Passenger Ships	3,000	250
	General Cargo	4,500	400
	Ro/ro	8,000	400
	Combination Vessels	7,000	400

Table 2: Representative BW capacity and pumping rate depending on type of vessel. – Source: https://ww2.eagle.org/content/dam/eagle/advisories-and-debriefs/ABS_BWT_Advisory14312.pdf

4.5 Installation area and space needed

Each BWTS, has a different footprint regarding the space that occupies. The footprint varies also depending on the total m^3 of water that the system will treat per hour. This is a very important issue on a retrofit project since a BWTS may cannot be fitted in a vessel without much free space or too many modifications of existing systems may be required in order to be fitted properly.

Unfortunately, depending on the total ballast m^3/hr that the ballast pump can serve, the piping also varies which means that a ballast pipe may be from DN100 to DN650. Taking this into consideration with the pressure drop of the new installed system/piping, most systems have to be installed as close as possible to the ballast pumps.

4.6 Costs

The installation of a BWT system may be necessary but it is such a costume that some ship-owners are thinking about to install it or to scrap their vessel depending on her age. For that reason, the owner decide to prepare the installation before the vessel goes to shipyard and to prefabricate the new piping in order for his vessel to stay off hire for as minimum as possible. The most important costs of such an installation are the following:

1. Ballast Water Treatment System: The CAPEX (capital expenses) for the bought of a ballast water treatment system varies a lot depending of the vendor and the total capacity of the water that the system may treat per hour.

2. Design and Engineering: this cost depends of the size of the system that will be installed and from the complexity of installation regarding the free available space.

3. Installation: this costs is totally related with the engineering study and the geographic location that the installation will take place. If the engineering study has been performed without modifications, the vessel has enough space and the installation will take place in a shipyard with low cost in first material, then the installation cost will be affordable.

4. Operation: OPEX (or operational expenses) depending on the system and the salinity or humidity of the sea water, the operational costs of a ballast water treatment system may be vary. In order to calculate the opex of a system, we have to take into consideration a variety of factors such as the power consumption which is being calculated to fuel cost annually depending on the number of the voyages that a vessel may perform (for this calculation normally have to calculate with the worst case scenario of the maximum kwh), the maintenance costs of the system

4.7 Control systems and power consumption

When study a BWTS retrofit, you have always to check if the installation is possible from an electrical point of view. The power consumption of the new installed system, may affect the electrical power which produced by the electrical generators of the vessel. The total KW of a new system may also vary depending of the treated technology and the capacity of the system. The new added KW may be from 60kw to 400kw. This is also affecting the fuel consumption and has to be included in the feasibility study when calculating the operation expenses of a newly installed system. If the own generators of the ship are not enough for providing sufficient electrical power, it will require to implement an upgrade on the power generation of the vessel, a process that is very expensive and increases clearly the levels of exhaust emissions.

The installed BWTS, has to be connected to the main switchboard of the vessel in order to be powered on. The braking required capacity in Amperage has also to be checked and to comply with the vessel's systems in order not to be affected or not to affect other systems of the vessel. For this aim, it is installed an automated system connected to auxiliary services so as to, give an audible and visual alarm in any manned space that the BWTS can be handled in case of malfunction and to let the crew react properly. Below we may find an example of how a BWTS may affect the electric load analysis of the vessel.

DUTY OR SERVICE	NO. OFF	CAP. M3/H	TOTAL HEAD M WC	EFF PUMP %	ABSBD. KW	RATED KW	EFF. MOTOR %	MAX ABSBD KW	NORMAL AT SEA IN USE	L.F.	O.F.	KW DEMAND CONT.	INT.	EQ CONT	MANOEUVRING IN USE	L.F.	O.F.	KW DEMAND CONT.	INT.	EQ CONT	HARBOUR IN USE	L.F.	O.F.	KW DEMAND CONT.	INT.	EQ CONT	EMERGENCY LOAD IN USE	L.F.	O.F.	KW DEMAND CONT.	INT.	EQ CONT
Starting air compressor	2	270,0			53,70	55,0	93,0	57,7	0	0,80	0,05	0,0	0,0	0,0	2	0,80	0,20	0,0	92,4	18,5	1	0,80	0,10	0,0	46,2	4,6	0	0,80	0,20	0,0	0,0	0,0
Control air dryer filter	1				1,30		100,0	1,3	1	0,80	0,50	0,0	1,0	0,5	1	0,80	0,50	0,0	1,0	0,5	1	0,80	0,50	0,0	1,0	0,5	0	0,80	0,50	0,0	0,0	0,0
28. BOILER PLANT																																
Boiler F.D. fan	1				5,00	5,5	90,0	5,6	0	0,90	1,00	0,0	0,0	0,0	1	0,90	1,00	5,0	0,0	0,0	1	0,90	1,00	5,0	0,0	0,0	0	0,90	1,00	0,0	0,0	0,0
Pilot burner pump	1				0,50	0,4	90,0	0,6	0	0,90	1,00	0,0	0,0	0,0	1	0,90	1,00	0,5	0,0	0,0	1	0,90	1,00	0,5	0,0	0,0	0	0,90	1,00	0,0	0,0	0,0
29. FEED SYSTEM																																
Feed pumps combi boiler	2				3,50	4,0	85,0	4,1	1	0,80	1,00	3,3	0,0	0,0	1	0,80	1,00	3,3	0,0	0,0	1	0,80	1,00	3,3	0,0	0,0	0	0,00	0,00	0,0	0,0	0,0
33. LADDERS																																
Accommodation ladder	2				3,00	4,8	85,0	3,5	0	0,00	0,00	0,0	0,0	0,0	0	0,00	0,00	0,0	0,0	0,0	0	0,00	0,00	0,0	0,0	0,0	0	0,00	0,00	0,0	0,0	0,0
35. GENERATOR PLANT																																
Heating element Em. Diesel	1							1,0	1	1,00	0,50	0,0	1,0	0,5	1	1,00	0,50	0,0	1,0	0,5	1	1,00	0,50	0,0	1,0	0,5	0	1,00	0,50	0,0	0,0	0,0
38. LIGHTING																																
General lighting ect.	1							80,0	1	0,75	1,00	60,0	0,0	0,0	1	0,75	1,00	60,0	0,0	0,0	1	0,90	1,00	72,0	0,0	0,0	0,3	1,00	1,00	20,0	0,0	0,0
43. COMM. EQUIPMENT																																
Communication equipment	1							10,0	1	0,50	0,50	0,0	5,0	2,5	1	0,80	0,50	0,0	8,0	4,0	1	0,50	0,50	0,0	5,0	2,5	1	0,80	0,50	0,0	8,0	4,0
44. SPARES AND TOOLS																																
E.R. Crane Main hoist. motor	1							4,2	0	0,50	0,05	0,0	0,0	0,0	0	0,50	0,05	0,0	0,0	0,0	0	0,50	0,05	0,0	0,0	0,0	0	0,50	0,05	0,0	0,0	0,0
E.R.crane Mic.speed hoist mot.	1							0,9	0	0,00	0,00	0,0	0,0	0,0	0	0,00	0,00	0,0	0,0	0,0	0	0,50	0,05	0,0	0,0	0,0	0	0,00	0,00	0,0	0,0	0,0
E.R.crane Trolley driv.mot.	1							1,1	0	0,00	0,00	0,0	0,0	0,0	0	0,00	0,00	0,0	0,0	0,0	0	0,50	0,05	0,0	0,0	0,0	0	0,00	0,00	0,0	0,0	0,0
E.R.crane Traverse driv.mot.	1							1,1	0	0,00	0,00	0,0	0,0	0,0	0	0,00	0,00	0,0	0,0	0,0	0	0,50	0,05	0,0	0,0	0,0	0	0,00	0,00	0,0	0,0	0,0
TOTAL LOAD **												571	274	114				759	313	120				753	1187	363				271	48	16
								PEAK					845						1073						1940						319	
								AVERAGE					685						879						1116						287	

**

DUTY OR SERVICE	NO. OFF	CAP. M3/H	TOTAL HEAD M WC	EFF PUMP %	ABSBD. KW	RATED KW	EFF. MOTOR %	MAX ABSBD KW	NORMAL AT SEA IN USE	L.F.	O.F.	KW DEMAND CONT.	INT.	EQ. CONT	MANOEUVERING IN USE	L.F.	O.F.	KW DEMAND CONT.	INT.	EQ. CONT	HARBOUR IN USE	L.F.	O.F.	KW DEMAND CONT.	INT.	EQ. CONT	EMERGENCY LOAD IN USE	L.F.	O.F.	KW DEMAND CONT.	INT.	EQ. CONT
45. MISCELLANIOUS																																
BWTS	**1**				**343.27**																**1**			**343.27**								

Figure 11 Updated electric load analysis of the vessel due to BWTS installation. Source: Author

4.8 Stability of the vessel

Due to the BWTS retrofit, the vessel is being equipped with a new tonnage which may vary regarding the location of installation and the chosen system. Anew mass of approximately 5-25 tones is being installed. This may occur a difference in the stability of the vessel and has to be calculated the new center of gravity of the vessel. In case the added weight goes beyond the 2% of the vessel's, a revised stability booklet has to be performed and submit to the classification society of the vessel.

Moreover, it will be required to make again all calculations regarding the stability and a new watertight integrity plan to avoid any risk once sailing, berthed or at anchorage. Finally, if the change can represent a variation on the forces of the vessel, new structural drawings will be needed.

Below we may see added weight calculations for a Tanker where the installation of BWTS took place in a new deckhouse on the deck of the vessel.

CALCULATION OF NEW LIGHTWEIGHT PARTICULARS							
	WEIGHT (TONS)	LCG (m) FROM AMIDSHIPS	LONGI. MOMENT (T-m)	VCG (m) ABOVE B.L.	VERT. MOMENT (T-m)	TCG OFF C.L.(m)	TRANSV. MOMENT (T-M)
INITIAL LIGHTWEIGHT	14244.5	-10.372	-147744.0	11.679	166361.5	0.0	0.0
ADDED WEIGHT WITH BWTS	73.9	29.500	2181.2	19.000	1404.9	-10.200	-754.2
NEW LIGHTWEIGHT	14318.4	-10.166	-145562.7	11.7	167766.4	-0.05	-754.2

Difference on Light Weight(%)=	0.52%
d(LCGls)(%)=(LCGor-LCGnew)*100/LBP=	0.09%

Lbp=219.00m

CALCULATION OF NEW ADDED WEIGHT PARTICULARS	
DESCRIPTION	WEIGHT (TONS)
ELBOWS	10.4
FLANGES	5.1
PIPING	29.0
REDUCERS	1.2
VALVES	1.3
DECKHOUSE	16.2
DECKHOUSE FOUNDATION	5.8
BWTS EQUIPMENT ETC	5.0
NEW ADDED WEIGHT	73.9

Figure 12 New added weight calculations for a tanker vessel due to BWTS installation. Source: Author

4.9 Safety of the equipment

In order to ensure the safety of the crew, an update of the fire plan is always requested in order to ensure that the crew and the vessel will not face any safety issues on board especially in cases that the BWTS is being installed in a new compartment.

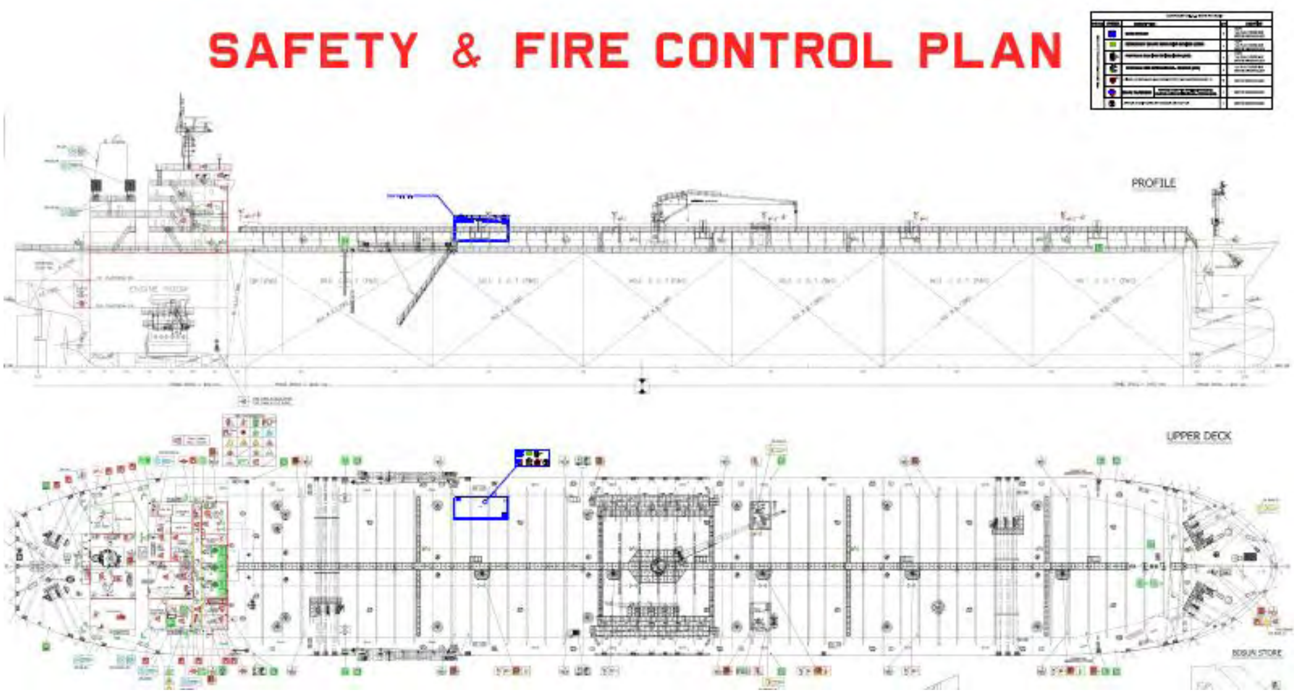


Figure 13 Updated fire plan of a vessel due to BWTS installation. Source: Author

5. ***Chapter - Process of study***

The process of installation of a Ballast Water treatment system can vary a lot from one existing vessel to a newbuilding vessel. In the first case, the difficulty is much higher as retrofitting a BWM System on an existing ship implies that as it was not considered once constructing the ship, there needs to be an adaptation of the system to current circumstances and systems of the ship. For an existing ship, it usually takes two weeks for the retrofit in the dockyard, being indispensable not to have any delay as it can signify a lost income for ship owner. For its installation, it usually takes part following partners: ship-owners, the supplier of the BWM System, an engineering firm in charge of the study and shipyard in charge of installing the system.

In the second case, the range of options are higher. In the circumstances of a newbuilding ship, the design of the ship is thought taking into account the BWM System that the specific vessel will require from the beginning. For a newbuilding vessel, the installation usually takes some months and any change can be carried out without affecting the operations of the vessel.

In existing vessels, when we have a retrofit project, the installation of a BWTS difficulty is really higher and every stage must be implemented with high accuracy. The retrofit installation project consists of the below phases:

- 3D Laser Scanning/Vessel survey
- Feasibility study report
- Detail Engineering design
- Pre-fabrication
- Installation Period
- System's verification and commissioning

5.1 Stage 1: 3D Laser Scanning/Vessel survey

Technicians attend the vessel in the first convenient port in order to perform a vessel's survey. During this survey, they will make a 3d scan of the most important compartments of the vessel that will be used for the design. Using this technology, the engineering company will be able to design 3d and to arrange the components in the 3d point cloud. They have also to analyze the area and check the most suitable choice for the installation of the system.

During this first phase, it is important to obtain information of the vessel such arrangement drawings, piping diagrams, power available on board, ballasting/de ballasting operations modes.

5.2 Stage 2: Feasibility study report

The feasibility study is one of the most important stages of an engineering study. During this stage, the owner has to choose from 1-as many as he wants vendors in order to compare the systems and find which one is the most suitable for his vessel.

Main considerations / criteria for conducting the feasibility study were as follows:

- If the available space is sufficient for the installation of the components
- Different installation scenarios per maker
- If the total dynamic head of the pump is enough to carry out the system
- Electric load analysis for each system and comparison table
- CAPEX analysis and comparison performance
- OPEX analysis and comparison performance

In addition to the above, the final selection of the most suitable BWTS for the ship in question, shall be done with the assist of a decision-making tools that are intended to provide the ship-owner with an overview of different categories of criteria related to ballast water treatment and information regarding what system will provide the best match in relation to the needs.

The feasibility study is being performed after the 3d scanning survey completion and the point cloud registration. Lastly, a final comparison table has to be made related with the total cost for each maker in order to help the owner to decide the most suitable system.

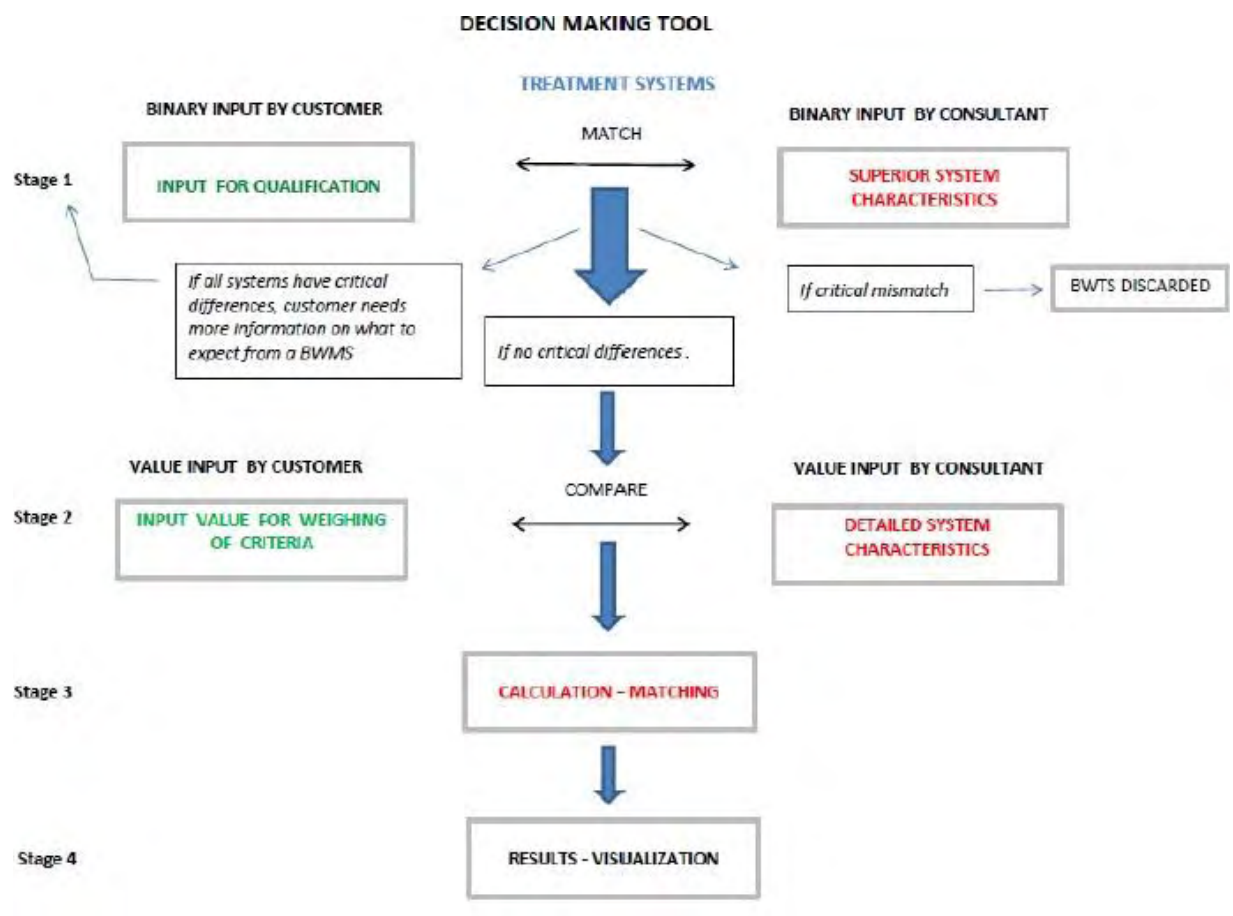


Figure 24 Flow diagram, describing the decision-making tool

Figure 14 Flow diagram showing the decision making tool

5.3 Stage 3: Detail Engineering design

After the final decision of the owner company regarding the treatment technology and the final system that will install on his vessel, the engineering company has to finalize the study.

In order to do this, there is a variety of drawings that have to be designed and submitted to the classification society of the vessel for approval. Each vessel has to comply with one or two classification society's rules for example Lloyd's register, American Bureau of shipping... Each part that has to do with the safety of the crew and the vessel cannot be constructed without the class permission/approval. Therefore, all the drawings related also to ballast treatment retrofit installation have to be check by the classification society.

When the class approval received, the owner together with the engineering company, may send the drawings to various shipyards in order to receive the most competitive offers.

The most important issue in an engineering study, is the isometric drawings of the pipelines together with the Bill of Material that the shipyard will need for the installation.

Part of the engineering study is also the electrical design issues of the installation such as the power consumption, required cables and breakers for the installation, short circuit calculations.

Finally, a technical specification report has to be created which need to describe all the jobs that have to be made on board for a smooth installation.

Figure 15 Design of a BWTS retrofit project on a bulk carrier. Source: Author

5.4 Stage 4: Pre-fabrication

After the engineering design finalization and since all the piping materials has been determined, the shipyard has to pre-fabricate all the related with the system components, before the vessel goes to dry dock in order to save time. All the structure components, piping work and electrical parts have to be constructed and located into vessel together with the BWTS components in order to start the installation. At this stage of the project, it is very important for the drawings to have a great accuracy and the pre-fabricated part to be constructed according to the drawing. The accuracy has to be at 1-3 millimeters.

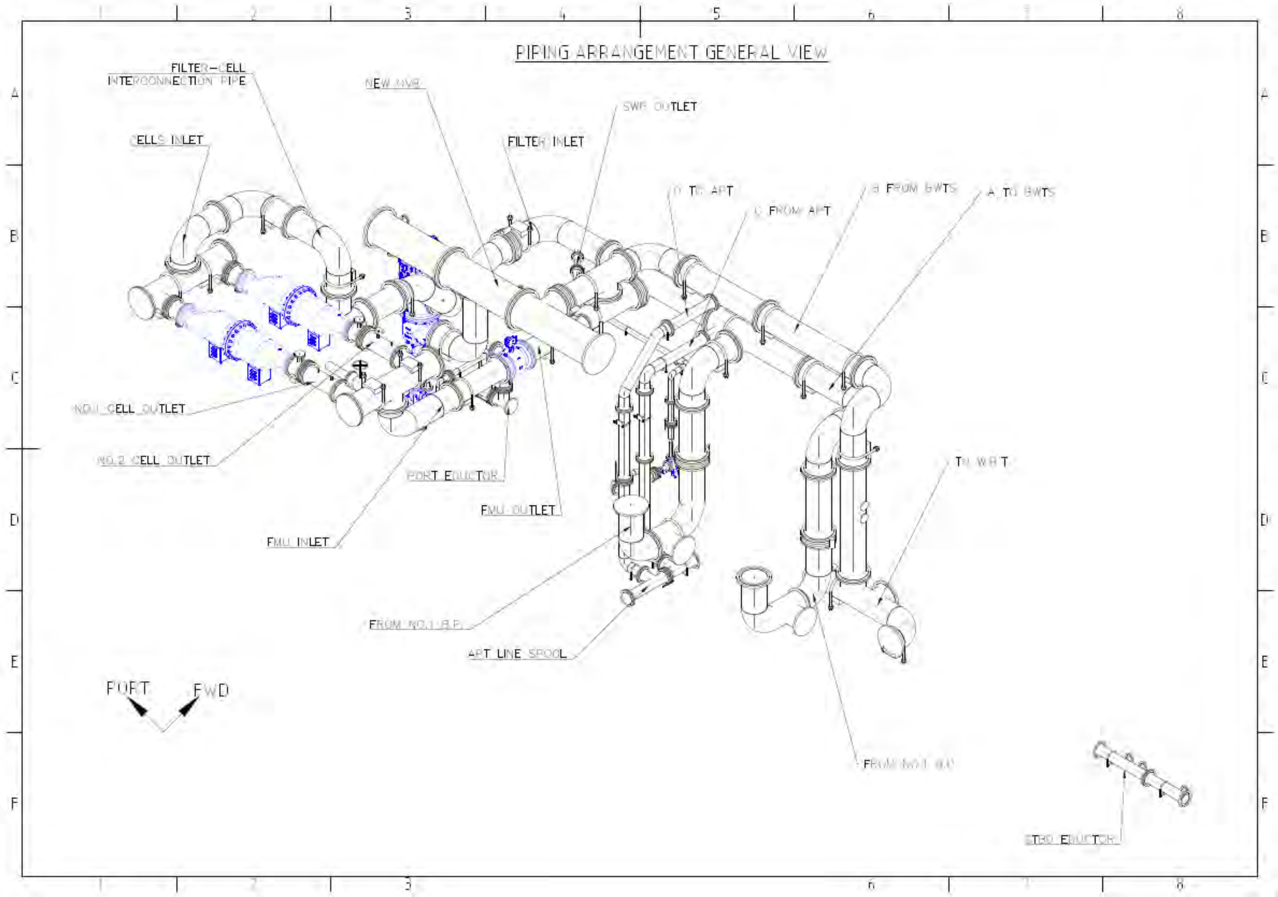
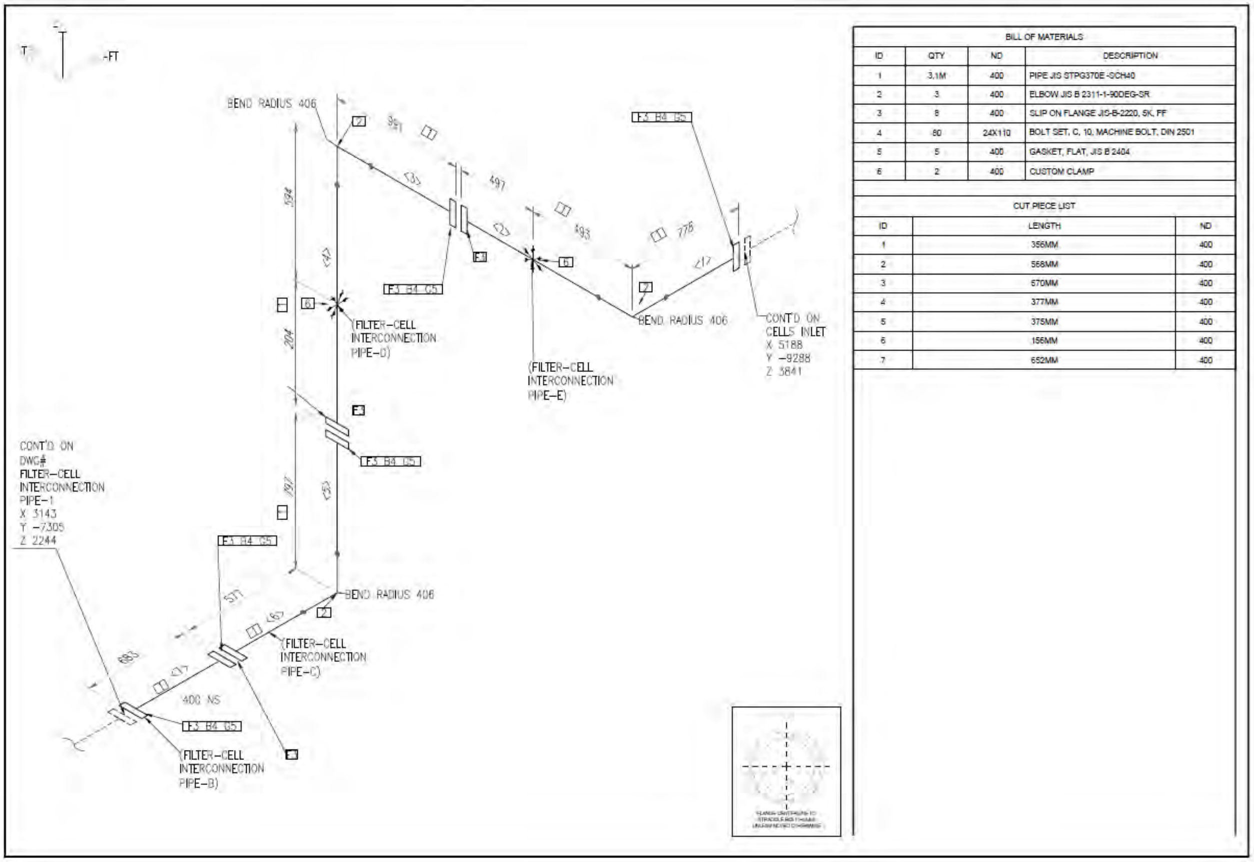


Figure 16 General design of a BWTS installation project. Source: Author



BILL OF MATERIALS			
ID	QTY	ND	DESCRIPTION
1	3.1M	400	PIPE JIS STPG370E -SCH40
2	3	400	ELBOW JIS B 2311-1-90DEG-SR
3	8	400	SLIP ON FLANGE JIS-B-2220, 5K, FF
4	80	24X110	BOLT SET, C, 10, MACHINE BOLT, DIN 2501
5	5	400	GASKET, FLAT, JIS B 2404
6	2	400	CUSTOM CLAMP

CUT PIECE LIST		
ID	LENGTH	ND
1	356MM	400
2	568MM	400
3	570MM	400
4	377MM	400
5	375MM	400
6	156MM	400
7	652MM	400

Figure 17 Piping isometric drawing for prefabrication, for a BWTS installation. Source: Author

5.5 Stage 5: Installation period

There are two options and places where a BWTS may be installed. The first one is when the installation takes place in a shipyard (dry dock) the second one is during sailing. During sailing installation is not recommended due to issues that may occurred related with the safety of the workers who are not related with sailing. Moreover during sailing installation, presuppose a perfect organization of the materials, last but not least during sailing installation may demand up to 6 weeks working time. On the other side, installation on shipyard may demand 1 up to three weeks depending on the quality of the engineering study and the familiarization of the shipyard.

For this reason, it most common for an installation to take place at a shipyard and not during sailing. In any case it has to be made an accurate management plan since there is a high demand for accuracy in such a projects.

5.6 Stage 6: System's verification and commissioning

During the installation period and especially when it finish, the attending surveyor who is acting as a representative of the classification society, has to check that everything is in order and that everything has been constructed according to the classification society's rules and comments.

From the vendor's side, there has to be a representative of the maker who will check that everything has been installed according to maker's instructions and when this will also finish, shipyard will make the necessary pressure test to the piping. The pressure test must be performed with the permission of the ship-owner of the vessel (or a representative of him) and the class surveyor. After the pressure test carried out and all working properly, and the technician of the system's maker complete the commissioning of the system, the class surveyor can deliver all documentation that prove that the system is complying all international regulations. A recognized classification society (in general in representation of the Flag State) then can receive all the documentation regarding the treatment technology that have been installed and can give final approval for the system.

6 Chapter - Ballast Water Treatment Systems Comparison

In this chapter we will proceed with a comparison of some systems in order to find out which system could fit better on a Panamax tanker, equipped with two ballast pumps of 1500 m^3 each and one independent system for the treatment of the Aft Peak Tank. For this study we have make an investigation for 2x1500 systems for the main ballast pumps and 1x120 system for the APT. The systems that we have chosen for the comparison, are using different systems technologies and according to researches they are the systems that sales most in Greek market.

6.1.1 ECOCHLOR BWTS

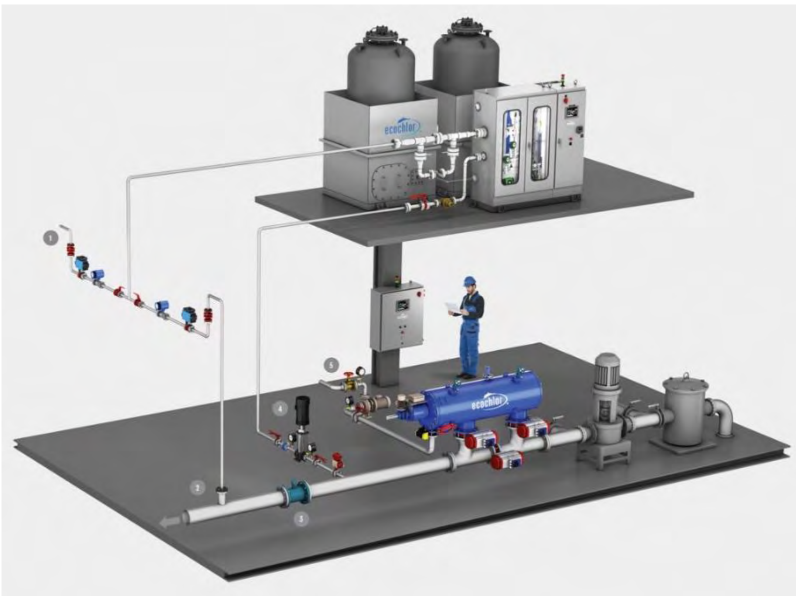


Figure 18 https://euploialtd.eu/ecochlor-bwts

6.1.2 Technology Used For Treatment

The treatment technology that Ecochlor uses, is a filter unit combined with ClO_2 treatment.

Filter: The filter that Ecochlor uses, is being constructed by filter safe and has a 40μm weave-wire (stainless steel) screen with an automatic back flushing operation process.

ClO2 Treatment: Supply water is sent to a chlorine dioxide generator and passes through a Venturi. In the meantime, the procurement chemicals sulfuric acid and purate which are stored in different tanks are mixed inside a mixing chamber producing ClO2 with maximum concentration 5mg/l. The capacity of supplied water and ClO2 passing through the Venturi is controlled by various sensors. Finally, ClO2 solution is sent to the ballast line at the outlet side of the filter.

6.1.3 Issues to Be Considered

During ballasting operation, the water has to be filtered by the filter unit and to be treated by the ClO2 injection.

On the other side when de ballasting, there is no need for the water to be passed through the treatment unit and no neutralization is taking place. In order to be sure that the treatment operation has been completed, there is a minimum of 48 hours holding time where the water has to be in ballast tanks prior to discharge. The holding time may be reduced to 24 hours, subject to manual monitoring of ClO2 residuals. Moreover a great advantage of the system is that De-ballasting by gravity is possible.

In any case, it is required that the vessel's crew manually monitors ClO2 residuals. If ClO2 Measured value exceeds 0.2 mg/l, then discharge of ballast is prohibited.

- *Filter's cleaning:*

When the (ΔP) pressure difference in inlet and outlet of the filter is 0.5 bar, automatic cleaning is taking place with the use of a suction scanner and proximity nozzles and a suction back flushing pump. Cleaning operation takes about 60 sec.

- *How is being affected the treatment method with respect to salinity, turbidity and temperature:*

The efficacy is not affected by salinity, turbidity, or temperature of the incoming ballast water. However, until USCG type approval, salinity of ballast water treated in the United States must be greater than 1

PSU (in accordance with USCG AMS Policy).

6.1.4 Complexity of installation:

The ClO_2 generator and the two filters can be installed as modular units in different compartments of the vessel. The filters have to be installed next to the ballast pumps in order not to increase the total pressure drop of the system, but the ClO_2 generator module can be installed in Engine Room, Steering Gear Room or outside the Engine Room inside a deck house, subject to Class approval.

However, the ambient temperature must be controlled to be above 5°C and below 40°C. The installation during retrofit projects is of limited complexity. Piping installation to / from filter, water supply to ClO_2 generator, air supply to ClO_2 generator, filling and vent lines of chemical tanks and power supply to control system are required.

6.1.5 Advantages and Disadvantages

ADVANTAGES	
a)	Low power consumption.
b)	Can be operated in fresh water, brackish and low temperature waters.
c)	Treatment only during ballasting
d)	ClO_2 generator is not required to be installed in the vicinity of the pumps, which gives flexibility to installation.
e)	Relatively simple installation, due to small number of equipment elements and limited electrical installations.
f)	Low pressure drop in the system.
g)	USCG type approval certification process in progress – ECOCHLOR is expected to be among the first 5-10 systems to be TA.
DISADVANTAGES	
a)	24-48 hours of holding time are required prior de-ballasting.
b)	De-ballasting is not permitted if sampling shows remaining quantity of ClO_2 is above a certain maximum level.
c)	Hazardous environment due to chemicals.
d)	Increased logistics requirement for chemicals supply.
e)	High operational cost.
f)	Long term effect of TROs to coatings, corrosion increase and piping systems is not yet evaluated.

6.2 <u>HEADWAY SYSTEM</u>

Figure 19 Source: https://mastms.gr/services-grid/headway-ballast-water-treatment/

6.2.1 <u>Technology Used For Treatment</u>

Treatment process description: Filtration & Electro-catalysis Unit (EUT).

<u>Filtration:</u> Mechanical filtration of particles, sediments and organisms larger than 50 μm.

<u>EUT Unit:</u> Advanced Oxidation Process (AOP) is applied to destruct organisms in water through an oxidative breakdown initiated by a powerful oxidizing species such as hydroxyl radicals. The Electro-Catalysis Unit produces a large number of Hydroxyl and other highly active oxidizing substances (concentration 2 mg/L).

<u>Neutralization:</u> TRO sensors check ballast water TRO levels before discharge. Once when the

TRO level of the treated ballast water is under 0.2 ppm it can be discharged directly.

6.2.2 Issues to Be Considered

Ballasting: During ballasting the ballast water passes through the filter and then the whole quantity of water flows into the EUT unit where the remaining viable organisms are eliminated. De-ballasting: During de-ballasting no treatment is taking place apart from neutralization. The pre-set TRO concentration can be by using the neutralization step that neutralizes any TRO in excess of the D-2 standards by treating the discharge with sodium thiosulfate.

Stripping: No treatment is required during stripping, apart from neutralization, when required.

- *Filter's cleaning:*

The pressure drop over the filter (between inlet and outlet) is used to initiate a self-cleaning cycle. When pressure reaches 0.5 bar the back-flushing starts automatically. The filter contains a number of filter elements (candles), where only two of the filter elements are cleaned by back- flushing at the same time during a self-cleaning cycle and the remaining pre-filter elements continue the filtration of the ballast water. However, lately a new filter has been launched, using filter basket instead of candles.

- *Effect of the efficacy with respect to salinity, turbidity and temperature:*

Efficacy of the system is not affected by sea water temperature and turbidity. According to IMO final approval, the system operates effectively in water with a salinity of minimum 1.8 PSU. According to latest tests, system can operate effectively in water with very low salinity, of about 0.8~0.9 PSU.9.3

6.2.3 Complexity of installation:

The system has a modular design that enables individual installation and is considered to have a rather small footprint. Also, extra space for the storage of neutralization agent should be taken into account regarding system's installation. Since all treated water is passing through the EUT unit, practically all the equipment must be installed near ballast pumps, subject to Class approval.

6.2.4 Advantages and Disadvantages

ADVANTAGES	
a)	Treatment only during ballasting, while neutralization takes place in de-ballasting (if required).
b)	Relatively low power consumption.
c)	Relatively low operational cost.
d)	Relatively small footprint.
e)	Chinese system which has received Type Approval by DNV.
f)	System can operate in low salinity water (0.9PSU).
DISADVANTAGES	
a)	System cannot operate in fresh water.
b)	Long term effect of TROs to coatings, corrosion increase and piping system is not yet fully evaluated.
c)	Hydrogen by-product.

6.3 ALFA LAVAL – PUREBALLAST 3

Figure 20 Source: https://www.alfalaval.com/products/process-solutions/ballast-water-treatment-system/pureballast-3-1/

6.3.1 Technology Used for Treatment

PUREBALLAST 3 is the 3rd generation of PUREBALLAST BWTS which entered the market in 2014. It is based on the same operating principle, however PUREBALLAST 3 uses new filters while AOT units are significantly smaller. For this project, PUREBALLAST 3.1 is proposed.

Treatment process description: Filtration & WALLENIUS AOT Treatment units.

Filtration: An automatic, self-cleaning filter of 20 μm, with a fine mesh basket ballasting operation (manufactured by FILTREX, made in Italy).

WALLENIUS AOT units: The PUREBALLAST AOT process occurs within a closed chamber known as a WALLENIUS AOT unit. The micro-organisms extermination is done with a high intensity ultraviolet system using medium pressure lamps.

CIP: For keeping standard performance, an automatic Cleaning-in-Place (CIP) system is used, which circulates a non-toxic and 100% biodegradable cleaning solution that prevents seawater scaling within the AOT units. This solution is reusable and is replaced only once per year or when its pH reaches 3.0. The cleaning cycle, which takes 15 minutes per AOT unit, occurs automatically after each ballasting and de-ballasting operation

6.3.2 Issues to Be Considered

Ballasting: In preparation for ballasting, the lamps of the WALLENIUS AOT units undergo a brief startup sequence, during which they are cooled by a flow of seawater. During initialization, the lamps are warmed. Cooling water is pumped to the AOTs to secure that the lamps are not overheated. When the lamps are warm, the actual ballast process starts. When ballasting begins, the incoming ballast water first passes through the filter, which removes organisms and particles larger than 20 μm. The water then continues through the WALLENIUS AOT units, which treats the water before it enters the ballast water tanks. The process flow is monitored by the flow meter to secure that the flow does not exceed the certified rate. Once ballasting is completed, the AOT units are cleaned via an automated Cleaning-in-Place (CIP) cycle, which takes approximately 15 minutes per unit. This cycle can be automatically initiated directly after ballasting, or manually initiated from the control system within 30 hours. The AOT units are automatically rinsed with fresh water before the CIP cycle begins and fills with fresh water upon its completion. The filter is also rinsed with fresh water once ballasting is completed.

De-ballasting: During de-ballasting the filter is by-passed. After leaving the ballast water tanks, the outgoing ballast water passes through the WALLENIUS AOT units to eliminate any regrowth of microorganisms that may have occurred in transit. The process flow is monitored by the flow meter to secure that the flow does not exceed the certified rate.

Stripping: Stripping can be performed to empty the ballast tanks. It can be used either with the

Installation of an additional stripping pump or a stripping educator after installing a sieve for filtering 5mm particles.

- ***Filter's cleaning:***

The pressure drop over the filter (between inlet and outlet) is used to initiate a self-cleaning cycle. When pressure reaches 0.5 bars the back-flushing starts automatically. ΔP 2 bars is needed between the outlet of the filter and the back-flushing discharge line for a reliable efficient back-flushing. This pressure difference is provided by means of a counter pressure valve after the filter.

- ***Effect of the efficacy with respect to salinity, turbidity and temperature:***

The subject system can operate in fresh water and in low temperatures as well. Efficacy in fresh water is tested during recent USCG land base tests and it is reported successful. The minimum UV transmittance is allowed to be 42% (where 0% is no transmittance at all) at full flow.

6.3.3 Complexity of installation:

PUREBALLAST equipment has to be fitted in the vicinity of ballast pumps. The increased number of parts makes installation rather challenging. A single system can handle capacities from 300 m^3/h~3000 m^3/h, with individual AOT units handling a flow of 300 m^3/h and 1000 m^3/h and filters handling flows up to 1000 m^3/h. One CIP unit is needed for each pump.

6.3.4 Advantages and Disadvantages

ADVANTAGES	
a)	One of the biggest manufacturers in marine industry worldwide.
b)	No use of chemicals.
c)	There is no effect on ballast tanks coatings.
d)	Can operate in low UV transmittance conditions (42%) at full flow (100%)
e)	System can operate in fresh water
f)	USCG type approval obtained.
DISADVANTAGES	
a)	Treatment during ballasting and de-ballasting. Consequently, the stripping operation is an additional consideration.
b)	Clogging of filter (20 μm) when operating in very dirty water is an issue of serious concern.
c)	Operation is highly dependent on ballast water's turbidity.

6.4 NK CO. –BLUEBALLAST SYSTEM

Figure 21 Source: https://www.oceanking.gr/sauer-manometer-2/

6.4.1 Technology Used for Treatment

Oxygen Generator: Includes an air compressor, an oxygen generator itself and an oxygen receiver.

Ozone Generator: Includes the ozone generator itself, an ozone destructor to remove any excess ozone and a chiller to keep the system cool.

Ozone Injector: Includes circulation pump, injector itself and a jet nozzle.

Monitoring & Control: Includes an ozone concentration analyzer and a Total Residual Oxidants (TRO) monitor.

Neutralizer system: Two sets of TRO sensors are included and if required thio-sulfate is fed to the ballast water prior discharge.

6.4.2 Issues to Be Considered

Ballasting: The Oxygen Generator takes ambient air and strips off the nitrogen and concentrates the oxygen to supply the ozone generator, which produces ozone from oxygen passing through a high frequency electric field. A portion of incoming ballast water is diverted to the injector, where ozone from the ozone generator is mixed with, before ballast re-enters the main ballast stream. Ozone kills some of the organisms during ballasting, however immediately reacts with bromine that occurs naturally in sea water to form hypobromous acid and other bromine byproducts. Ozone has a half-life of 5.8 sec in sea water, while the created residual oxidants continue killing the remaining organisms. The maximum concentration of TRO is 0.2 mg/L.

De-ballasting: No treatment is required during discharge. Two sets of TRO sensors detect the TRO level on the ballast water prior to discharge and if required thio-sulfate is fed to the ballast water. 12 hours of holding time is required.

De-ballasting by gravity is possible.

In practice, when de-ballasting is carried out after 48 hours of ballasting, neutralizer shall not be operated. If the level of TRO exceeds 0.2 ppm, it should be used.

Stripping: Since no treatment is taking place during de-ballasting, there is no effect to stripping process.

- *Filter's cleaning:* No filter is used.

- *Effect of the efficacy with respect to salinity, turbidity and temperature:*

In situations where ship carries fresh water as ballast, Ozone has a half-life of around 30 minutes, enough to kill all microorganisms. No residuals are being created. Efficacy is not affected by water's turbidity and temperature. Efficacy in fresh water not yet proved. The system is not limited by the water salinity.

6.4.3 Complexity of installation:

Installation is considered to be very simple especially for retrofitting, since only the ozone injector must be connected to the existing ballast line. The ozone injector is the only item that can be installed at the vicinity of pumps, the rest of the equipment can be installed on any place inside the engine room or in a deck house at a non-hazardous area, and must be well ventilated and with improved safety measures. However, Class approval may require various risk assessments due to use of the hazardous and harmful ozone and special arrangements may be requested.

6.4.4 Advantages and Disadvantages

ADVANTAGES	
a)	Easy installation, which can take place without the need of dry docking. A minor modification is required on the existing ballast water pipe line.
b)	Treatment only during ballasting.
c)	There is no pressure drop on the system.
d)	Compact design with small shipboard footprint.
e)	No separate system for treatment of APT.
f)	No filters being used.
DISADVANTAGES	
a)	Use of ozone, which is one of the strongest known oxidants, presenting high risk for vessel and crew and questionable behavior with tanks' coatings.
b)	12 hours holding time.
c)	Relatively high-power consumption.
d)	Increased level of automation and apparatus complexity has caused various failures in already installed system.

6.5 ESK - ERMA FIRST FIT

Figure 22 Figure: https://www.epe.gr/ERMA_FIRST_Brochure.pdf

6.5.1 Technology Used For Treatment

ERMA FIRST FIT is a 2nd generation BWTS. The first generation, ERMA FIRST, is based on pre-filtering, cyclonic separation and full flow electrolysis. In the 2nd generation system, ERMA FIRST FIT, pre-filter and cyclonic separator are replaced by an automatically back-flushed filter.

Single stage filtration & full flow electrolysis.

Filter: The filtration is conducted through a 40μm weave-wire (stainless steel) screen. The Filter manufacturer is FILTERSAFE – or FILTREX (in this case a system with FILTERSAFE has been offered). Back flushing of the filter is automatic.

Electrolysis: An electrolytic cell is used for the production of free chlorine for the elimination of the remaining viable organisms. In the process of electrolysis, the water is exposed to a direct current of low-voltage which is applied to special coated electrodes. Between the electrodes the naturally present chlorides in the water will be converted into oxidizing and disinfecting agents. Electrolysis will, among other disinfectants, also create sodium hypochlorite.

A free chlorine sensor located downstream of the cell, monitors the free chlorine concentration. The production rate of the Active Substances is continuously tuned to the ballast flow rate and the measurement of the free chlorine. Depending on the flow rate and the free chlorine measurement, the current and the voltage of the cell change in order to maintain the pre-set free chorine concentration. The maximum chlorine concentration produced is 6mg/l.

Neutralization unit: An independent neutralization unit is utilized for the neutralization of the remaining free chlorine during the de-ballasting. This compact unit consists of a dosing pump, a free chlorine sensor and an amplifier/controller. The dosing rate of the pump is automatically adjusted according to the chlorine sensor reading.

6.5.2 Issues to Be Considered

Treatment process during ballasting / de-ballasting:

Ballasting: During ballasting, the water enters the filter where organisms and sediment with diameter of 40 microns and above are removed. The water free of material and organisms larger than 40 microns enters the electrolyzer(s). From the chlorides of the water, free chlorine is produced through the electrolysis process. The maximum chlorine concentration produced is 6 mg/L. The water from then enters the ballast tanks. When the differential pressure between inlet and outlet of the filter reaches 0.5

bars, result of filter screen clogging, the flushing mode starts. During this the screen is backwashed through a drain valve and a suction pump. The duration of suck flushing is set to 30 seconds. The drain water is discharged overboard.

De-ballasting: During de-ballasting the system is by-passed. Only a chlorine sensor samples the residual chlorine at the discharge line. If this is greater than 0.2 mg/l then it drives a dosing pump for the dosage of a neutralizing agent (Sodium Bisulfite). A second chlorine sensor installed at the far end point confirms the successful neutralization of the free chlorine. Stripping: No treatment is required during stripping, apart from neutralization, when required. The minimum holding time of ballast water required is about 4 hours.

- *Filter's cleaning:*

When ΔP of filter is 0.5 bar, automatic cleaning is taking place with the use of a suction scanner and proximity nozzles. A suction pump is used to deliver the back-flushed water overboard. Cleaning operation takes about 30 sec.

- *Effect of the efficacy with respect to salinity, turbidity and temperature:*

Efficacy of the system is not affected by sea water turbidity. The electrolytic cell of the system is designed to produce the identified Active Substances at temperatures as low as 5^oC (as per IMO Type Approval Certificate) and with water salinity more than 0.9PSU. In fresh water the level of produced active substances measured by chlorine sensors is very low and the system automatically shuts down.

6.5.3 Complexity of installation:

ERMA FIRST FIT can be installed either as skid or each equipment separately in the vicinity of pumps, subject to Class approval. The filters can be installed vertically or horizontally. Extra space for the storage of neutralization agent should be taken into account regarding system's installation.

6.5.4 Advantages and Disadvantages

ADVANTAGES	
a)	Main treatment only at ballasting, while neutralization is applied during de-ballasting, if necessary.
b)	Relatively small footprint.
c)	Electrolysis system that can operate at relatively low salinity (0.9PSU).
d)	Relatively low purchase cost.
e)	Reasonable maintenance cost was provided.
DISADVANTAGES	
a)	System cannot operate in fresh water.
b)	Operational cost is highly dependent on fuel prices.
c)	The system is not effective in fresh water.
d)	Long term effect of TROs to coatings, corrosion increase and piping systems is not yet evaluated.
e)	Hydrogen by-product.

6.6 TECHCROSS – ELECTRO-CLEEN SYSTEM

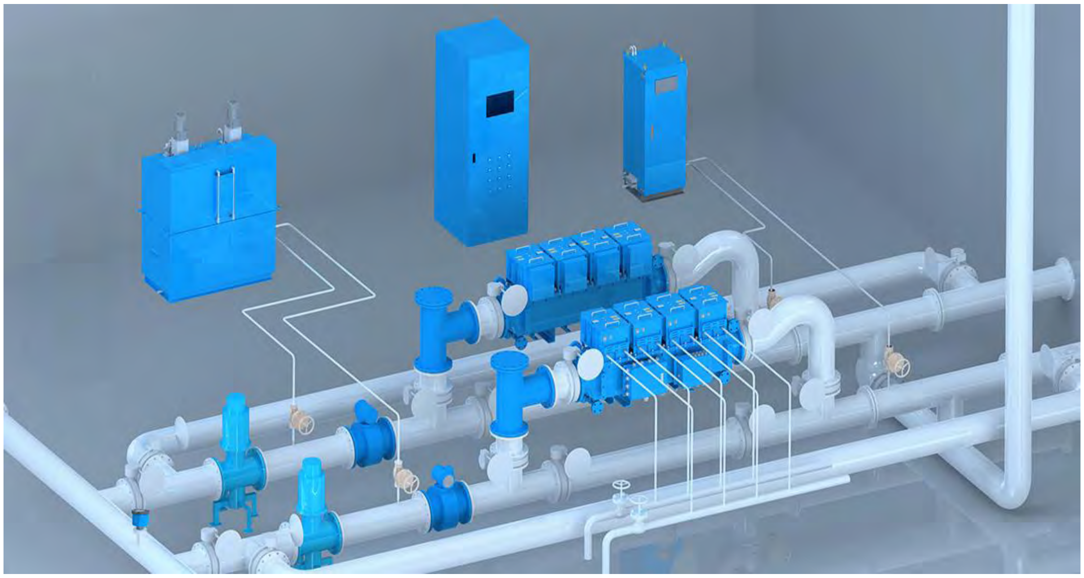


Figure 23 Source: http://techcross.com/eng/product/overview.asp

6.6.1 Technology Used For Treatment

Treatment process description: Electrolysis Disinfection.

ELECTRO-CLEEN System consists of:

(A.) ECS-B is a combination of ECU and PRE:

ECU (Electro-Chamber Unit): It is installed on ballast piping after ballast pump discharge and disinfects micro-organisms in the ballast water.

PRE (Power Rectifier Equipment): Converts the input voltage from 440V AC to 10V DC and supplies the electrolysis module while periodically changing the polarity of electrodes by the timer setting.

(B.) PDE24A is combined of PDE, LOP and PCU:

PDE (Power Distributor Equipment): Power distributor & multifunctional relay.

Local Operation Panel (LOP): Provides AC 220V DC 24V power to ECS unit and sensors after being supplied AC 22V power from PCU or PDE. It also includes GSU (gas sensor unit) and CSU (conductivity sensor unit).

PCU (Power Control Unit): PCU is installed in the ballast room or on the distributor panel and controls ECS to prevent problems in case of emergency that may occur to the system. It collects all data from sensor units.

(C.) ANU (Auto Neutralization System Unit): When TRO concentration is more than 0.2mg/L neutralization of ballast water takes place by injecting sodium thiosulphate in order to reduce TRO concentration.

Electrolysis:

Treatment process of system which uses electro-chlorination is electrochemical generation of the biocide solution onboard and high concentration of hypochlorite solution is injected directly into the ballast pipe line.

ECS-B uses electrolysis, however, with the application of electric currents, electric potential increases disinfection efficacy by destroying the cell membrane of micro-organisms generating oxidant particles. In addition, OH-radicals generated during the electrolysis procedure by titanium electrodes, also disinfect micro-organisms. Through electrolysis, an adequate amount of TRO is generated (maximum 10 mg/L).

Neutralization system: It is installed in order to decrease the TRO concentration by ECS-B before discharging the treated water in the ballast tanks and during de-ballasting.

6.6.2 Issues to Be Considered

Treatment process during ballasting / de-ballasting:

Ballasting: During ballasting, when the whole flow of sea water passes through the Electro- Chamber Unit after the ballast pump, disinfectants such as hypochlorite are generated by electrolysis, which disinfect harmful microorganisms in the seawater. The maximum allowable dosage of Active Substances is 10 mg/ L as TRO, and must be monitored and recorded during uptake by the TSU. The conductivity of ballast water is measured at uptake and the results aresent to Control PC. The Control PC uses this information to adjust the current needed to be supplied to electrolysis module in order to generate a TRO of 10 mg/L to disinfect the ballast water. In addition, a TRO sensor is located after the treatment prior to the ballast tank, which supplies a feedback control signal to the control PC to further adjust the current needed to maintain the TRO concentration at 10 mg/L. This disinfection process includes the part that supplies current to the electrodes in the ECS-B module and the cooler unit (rectifier, power distributor and heat-exchanger) that is controlled by the online TRO sensor and control PC. The residual chlorine in the water prohibits the re-growth of microorganisms in the ballast tank.

De-ballasting: During de-ballasting no ECS-B treatment is required. In order to minimize the toxic effects of TRO, the treated water is neutralized, at discharge, by sodium thiosulphate and the TRO concentration of neutralized water is checked again using the online TSU. Maximum allowable discharge concentration of Active Substances is less than 0.02 mg/ L as TRO which must be monitored and recorded during discharge by the TSU.

6 hours minimum holding time is required prior de-ballasting.

Stripping: No treatment is required during stripping, apart from neutralization, when required.

- *Filter's cleaning:* No filter is being used.
- *Effect of the efficacy with respect to salinity, turbidity and temperature:*

Efficacy of the system is not affected by sea turbidity. The maker claims that the system operates even at very low ambient temperatures of $0^{o}C$ up to $45^{o}C$. The system is effective in sea water, brackish water and also in fresh water with low salt content and cannot treat water with salinity lower than 1 PSU.

6.6.3 <u>Complexity of installation:</u>

The system has a modular design that enables individual installation. Moreover, the ECS-B system has a much simpler design in comparison with ECS-A, that makes its installation easier, subject to Class approval. ECU is to be installed on main ballast piping line, while other components can be located separately on any space available on board. Nevertheless, since many components compared to other systems are being used, the actual required space for the installation is practically much higher than the system's total footprint that is very small.

6.6.4 <u>Advantages and Disadvantages</u>

ADVANTAGES	
a)	No use of filters eliminates the clogging problem.
b)	Main treatment only at ballasting, while neutralization is applied during de-ballasting.
c)	Large number of installations, which helps system's improvement through operational feedback.
d)	Subject system can operate at very low salinity waters.
e)	High efficacy.
DISADVANTAGES	
a)	No use of filters makes questionable the efficacy due to the use of the same dosing with systems having filters.
b)	The system is not effective in fresh water.
c)	Long term effect of TRO's to coatings, corrosion increase and piping system is not yet evaluated.
d)	No maintenance cost is provided.
e)	Hydrogen by-product.

6.7 CONCLUSION

A very important factor for the selection of the equipment is the operator's particular operating practices and internal risk assessments, which will determine how important the disadvantages of each vendor are. Furthermore, the decisive tool for the pre-selection of specific system(s) to be retrofitted on board the specific vessel design is the feasibility of its retrofitting. There are various good and economical systems which retrofit installation may be proven to be complicated.

For the evaluation of the systems, the following parameters must be taken into account:

VENDOR'S NAME	Ballast System Capacity	Total Footprint	Total Power Consumption	Total Pressure Drop	Total Weight
	m^3	m^2	kW	Bar	Tons
ECOCHLOR	2 x 1500 1 x 120 (APT)	23	25	0.5	18
HYUNDAI	2 x 1500 1 x 120 (APT)	22	170	0.5	12
TCHCROSS	2 x 1500 1 x 120 (APT)	10	240	0.4	6
HEADWAY	2 x 1500 1 x 120 (APT)	18	130	0.6	7
ERMA FIRST	2 x 1500 1 x 120 (APT)	15	220	0.7	8
ALFA LAVAL	2 x 1500 1 x 120 (APT)	13	310	0.8	10
NK CO. BLUEBALLAST	2 x 1500 1 x 120 (APT)	22	250	0	15

Figure 24 Comparison table for different BWTS vendors, Source: Author

6.7.4 Efficiency of the system:

Unfortunately the UV systems cannot treat properly in areas that the ballast water with severe turbidity and the electrolysis systems cannot be operated when the salinity of the water is low. For the electrolysis systems, there is a solution for this problem. Majority of the vessels, when installing an electrolysis system, uses a tank as a storage of salty water. When the vessel needs to be ballasted in low salinity waters, then ballast low salinity water, mixed with high salinity water which is storage in the holding tank.

On the other hand, the use of chemicals can successfully treat ballast water under all conditions.

6.7.5 Filters:

Clogging of filter when operating in very dirty water is a serious problem. Very dense mesh will surely lead to clogging (or continuous backwashing in the base case) in dirty waters.

Upon the engineering study, minimum inlet pressure requirements must be carefully considered.

However, the presence of a filter has significantly positive effect on the efficacy of BWT Systems.

6.7.6 Vessel's impact:

Many of the UV systems and some of the Electrolysis systems have an increased footprint and their installation may be very difficult, even non-feasible.

Most of UV systems maximum power requirements, as well as electrolysis in low salinity water, are relatively high. Revision of Electric Load Analysis is in many cases necessary. That may affect even the commercial description of the vessel.

The decrease of the maximum capacity of the ballast pumps due to the BWT system's pressure drop must be calculated during the engineering study, in order the necessity of pumps' upgrading or booster pumps' installation is evaluated.

6.7.7 Budgetary and operational / maintenance cost

When selecting a BWTS, one of the most important factors to be considered by the owner is the capital expenses to by the system and the operational expenses to maintain the system

Comparative tables have to be performed during the feasibility study in order to find out which investment could be the best for the vessel and for the owner.

7 ***Chapter - Thinks to consider in order to reduce Ballast impact***

*7.1 **Importance of the control of Ballast Water of ships***

Assuming from all the above, the Ballast Water is a crucial parameter for a vessel but it has to be treated properly since it's transportation may affect the human health, the economy and the environment, as well. IMO together with the rest of organizations have realized this problem and they started with a dynamic position forced all the ship-owners worldwide to be also aware of this problem.

The control of the stability of a vessel is really important and cannot be avoided. Therefore the best solution is to treat their ballast water when performing the operation of ballast/ de- ballast. That means the installation of a Ballast Water Treatment systems on board vessels.

*7.2 **Partnership of GloBallast***

In order the impact of harmful species to be minimized, the United Nations Development Program (UNDP), the Global Environment Facility (GEF), and IMO have worked together under the GloBallast Partnerships Project to foster an unprecedented international and public-private cooperation in the area of ballast water management, since 2000. (IMO, 2019)

This program started at 2000 and it was in 2007 when the most important partners/ organizations got into force. These organizations, the United Nations Development Programme (UNDP, in charge of the implementation) the International Maritime Organization (IMO, in charge of the execution) and Global Environment Facility (GEF, contributing with the funding of the project).

The basic scenario was the establishment of a time period from the BWM Convention to assure that the problem of the ballast untreated water will be controlled worldwide. At the early stage, this time period was 5 years, from end of 2007 till 2012, but it was extended till the summer of 2017.

There were not the main organization that were leading the program, for it's implementation there were too many countries that helped on this part such as: Bahamas, Chile, Colombia, Croatia, Egypt, Jordan, Nigeria, Panama, and others. The initial investment on this project was about USD 13.7M from GEF and UNDP, and other USD 51.9M of co-financing contribution.

In these 10 years, the following achievements took place.

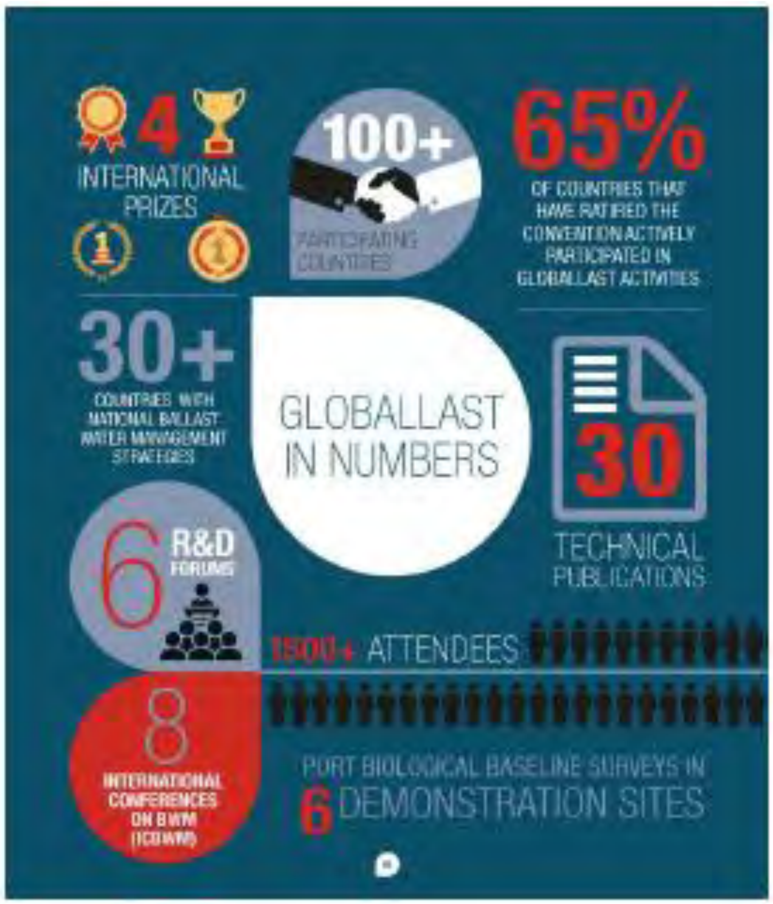


Figure 25 Source: http://www.imo.org/en/OurWork/Environment/MajorProjects/Pages/GloBallast-in-numbers.aspx

The most important achievements that the GloBallast Partnership managed to succeed are described as follows:

- Establishment of a Project Coordinator Unit at IMO.

- Development of a network where we may find a lot of databases all relevant information regarding ballast water.

- The law regarding the control of ballast water has been accepted by a variety of countries and they can help by their side, the project's implementation.

- It has been developed a specialized training center for the crew and the staff of ship own companies affected by the BWM Convention, related with the ballast water.

*7.3 **Proposals of BWM Infrastructure Investment Guidance***

There is a study, published by IMO published providing guidance about necessary investments for reduction of the impact of BW. This document, was financed by Royal Haskoning DHV and the European Bank.

In this document, are represented the following:

➢ Facilities such as ballast tanks sediments to be installed in different ports. This could reduce the impact of the alien species and it is considered to be a small investment for each port, on about 2 M EUROS.

➢ Monitoring biodiversity system: when control and monitor the biodiversity it may be detected the presentence of invasive species when they are being discharged overboard and have already started to spread.

➢ Proper cleaning of ballast water tanks: this could eliminate the spread of the alien species and costs almost nothing.

- Improvement of Port State Controls: the port state controls should be more strictly and have to perform more controls on board
- Investments of new companies for finding new treatment technics: there are already many different technologies that can be used for treatment and comply with IMO standards.
- Taxes reduce to owners who apply new technologies: it could be a worldwide decision to lower the taxes to the owners who apply new technologies on board their vessels and respect the environment.

*7.4 **Different technologies to be installed instead of ballast water***

During the latest years, there have been studied and invested a lot of alternative methods. Two of them we may find here below:

- Investigation of other buoyancy systems:

University of Michigan, has find out an alternative in order for the vessels to avoid using ballast water. In this study, they suggest to replace ballast tanks with some buoyancy systems using trunks that will start at the bow thruster and will ended to the stern below the waterline. According to this method, the water will pass below the cargo area thanks to this, the water cannot cause danger since it is not stored to the vessel’s tanks.

The disadvantage of this method, is that this type of vessels will have greatly increased operational costs.

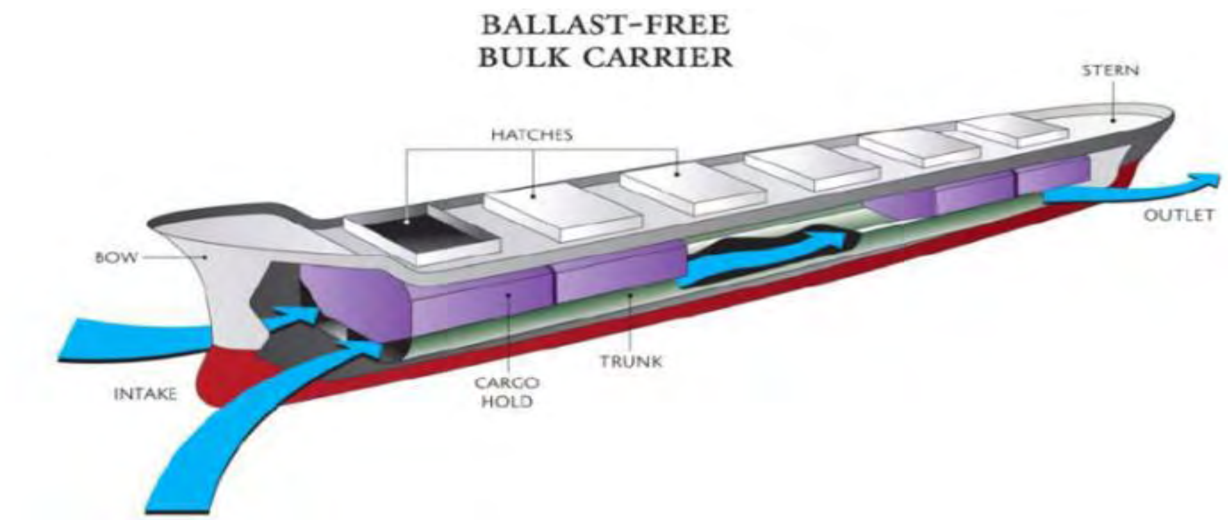


Figure 26 System of buoyancy as proposed by UoM

Source: https://safety4sea.com/wp-content/uploads/2018/09/ballast-free-concept-e1536847793974.png

- Vessel’s structure designed as a V-HULL:

In this method, the usage of ballast tanks cannot be completed avoided, as the other method did. The basic idea is to design a v-hull that can safely travel world around and have also the proper stability in different loading conditions without to be ballasted. Unfortunately this could not be ensured when the vessel travel in non-calm seas. In case of emergency there should be tanks that should be ballasted in order to increase

The idea of the V-HULL is now applied in new buildings LNG carriers and it may become the first ballast free design on a merchant vessel.

This LNG carrier is of 7,500 cubic meters and the manager company is the German Bernhard Schulte.

Another advantage of this method apart from the non installed BWTS, is that it may have longer life since the tanks will not be a part of corrosion due to ballast water. But not to forget that this is the first time that such a technology will be carried out and we have to remain in order to see the results.

8 Chapter - Conclusion

8.1 Ballast Water Management Convention

The International Convention for the Control and Management of Ships' Ballast Water and Sediments, which entered into force on 2017, has become an essential regulation for the control of the ballasting and de-ballasting operations by worldwide vessels. Before the IMO entered into action, many cases of invasive species have been recorded, being mainly produced from the ballast water used for ships stability.

On the one hand, the Convention, and its compulsory standards D-1 & D-2, has played an essential role for avoiding the spread of invasive species and for reducing the impact of vessels on local environments. But on the other hand it can still be checked more strictly by local authorities.

8.2 Treatment technologies

The treatment technology is one of the most important actors for reducing the impact of BW from ships. BWM Systems have the role of treating the ballast water correctly in order to eliminate the organisms from the seawater loaded on ballast tanks.

It is very important to remark that the use of systems which are not based on chemical products can represent the cleanest way of treating the BW, assuring not polluting the environment when de-ballasting.

Finally, we would like to remind that for a proper control of the levels of organisms it is needed the use of 2 or more systems that, combined, can perform correctly the task of reducing the impact of BW.

8.3 <u>Process of study, installation and control of BW Management System</u>

It can be concluded that BWM Convention represented a huge economic impact for the shipowners and the charterers as they needed to adapt their vessels to the new standards. Therefore, newbuild vessels had an advantage over existing vessels as the design is already made from the beginning, taking into consideration the system that the vessel will require.

8.4 <u>Comparative analysis of different BWM Systems</u>

Finally, it is important to remark that there is not one BWM System recommended above the others. Every method and every system has different features. Therefore, the suitability to a particular vessel will depend on its characteristics and needs (dimensions, BW needed, type of cargo, usual sailing route…).

8.5 <u>How to reduce Ballast Water impact</u>

Firstly, there are still many different ways to improve the control over the treatment and discharge of ballast waters from ships.

Secondly, in the near future it will be required to reduce the use of BWM Systems and to increase the use of alternative methods that can substitute the role of the BW. Alternative designs clearly need to ensure a good level of efficiency and security for substituting completely the role of BWM Systems. In addition, this type of design can achieve a long service life due to the reduction of corrosion caused by seawater.

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