ZIBELINE INTERNATIONAL™ PUBLISHING

Water Conservation & Management (WCM)

DOI: http://doi.org/10.26480/wcm.02.2021.121.130

ISSN: 2523-5664 (Print)
ISSN: 2523-5672 (Online)
CODEN: WCMABD

CrossMark

REVIEW ARTICLE

A STUDY OF SHIP BALLAST WATER TREATMENT TECHNOLOGIES AND TECHNIQUES

Viet Duc Bui[a], Phuoc Quy Phong Nguyen[b], Dinh Tuyen Nguyen[c,*],

[a]Institute of Engineering, HUTECH University, Ho Chi Minh City, Vietnam.
[b] Institute of Maritime, Ho Chi Minh City University of Transport, Ho Chi Minh City, Vietnam
[c] PATET Research Group, Ho Chi Minh City University of Transport, Ho Chi Minh City, Vietnam
**Corresponding author email: dinhtuyen.nguyen@ut.edu.vn*

ARTICLE DETAILS

Article History:

Received 21 November 2021
Accepted 24 December 2021
Available online 28 December 2021

ABSTRACT

Ballast is a commonly used solution to ensure the stability and balance of ships during voyages. The volume of ballast water that is circulated by ships between different seas is extremely large, with which a lot of creatures move along. Organisms that follow the ballast water to a new environment mostly have a negative impact on the ecosystem there. Good ballast water management is an important measure to ensure that organisms do not migrate with the ballast water to other areas. Ballast water management requires specific regulations and regulatory policies that are relevant and applicable globally. The International Convention on the Control and Management of Ballast Water and Ship Sediments, adopted in 2004, has specified issues for ballast water management. Ballast water treatment technologies and techniques need to be studied so that the ballast water after treatment meets the requirements of the convention. This paper presents an overview of the technological and technical solutions currently being applied to treat ballast water to meet the requirements of the convention and points out the advantages and limitations of each solution. In the discussion, the authors also present a solution that combines many different ballast water treatment methods. This is a very effective solution, both technically and cost-effectively. The combined solution can be applied in the future to effectively treat ship ballast water.

KEYWORDS

ballast, technologies, techniques, treatment, combined solution

1. INTRODUCTION

Ships transport a huge amount of goods between countries and territories. The benefits that this medium brings are huge (Vakili et al., 2022). However, there are problems associated with that benefit, such as low travel speed, environmental pollution from fuel used for ships' engines or cargo on board, and ballast water. In order for ships to become a highly efficient means of transport, extensive studies on this vehicle are needed. Compared with the means of land and air, ships move much slower. Research and numerical simulation to find effective solutions to improve the speed as well as related factors have been shown by many studies (Surendran and Reddy, 2003; Chau et al., 2020; Li et al., 2020; Khalaf, 2021; Nam, 2020). Good solutions to improve ship speed can be mentioned in related studies such as research on suitable propulsion systems, studies showing the influence of currents on objects, and studies on the effects of hull shape on aerodynamic performance (Theotokatos and Tzelepis, 2015; Pham, 2020; Chau et al., 2020; Cuong and Phuong, 2020; Nguyen, 2020; Van and Trong, 2020). Ships use a lot of fuel for engines during trips, the research to find suitable fuels for engines used on ships is also promoted (Zhou et al., 2019; Pham, 2018).

Studies on efficient catalysts for engine fuels and investigations of fuel injection problems suitable for marine engines also help in the efficient use of fuel for ship engines (Zhu et al., 2012; Nguyen et al., 2020; Andreadis et al., 2010; Hoang, 2020). Studies have also shown potential fuels to replace fossil fuels that ships are using, such as biodiesel, alternative fuel (Noor et al., 2018; Hwai, 2021; Debnanth et al., 2015; Nguyen et al., 2021). Renewable energy is now also being researched to make the most of and efficiently use energy sources (Nguyen, 2020; Amrouche et al., 2016; Hoang, 2018; Baldi et al., 2019; Nguyen et al., 2021). Efficient energy management is a sustainable strategy (Cetin and Sogut, 2021; Nguyen et al., 2021). At the same time, before the impact of the COVID-19 pandemic, the transition to renewable energy in the global energy system and the high demand for clean fuel are inevitable (Dell and Jrand, 2001; Nizetic, 2021; Grandell et al., 2016; Nguyen et al., 2021). The large use of fuel by ship engines also leads to the problem of emissions from the engines that are harmful to the environment.

There have been studies on emission reduction techniques, such as using electric propulsion systems (Ni et al., 2020; Nguyen, 2021). Technology and techniques to reduce emissions have also been studied (Pham, 2019; Natale and Carotenuto, 2015; Vinayagam, 2021). During the COVID-19 pandemic, there were studies showing a decrease in CO_2 and NO_2 emissions (Nguyen et al., 2021; Liu, 2020; Huynh et al., 2021). In addition, environmental pollution caused by ships is another big challenge. Pollutants to the environment, such as oil leaks from ship engines, oil spills in ship accidents, heavy metals in fuel or cargo on board, leak into the environment (Chen, 2022). To solve this problem, there have been many studies to remove environmental pollutants, such as heavy metal removal research, research on oil spill removal equipment, and extensive research on spill absorbers (Nizetic, 2022; Ventikos, 2004; Nguyen et al., 2021; Le, 2018; Shadizadeh et al., 2014; Hoang et al., 2018; Nguyen et al., 2022).

As mentioned above, ballast water is also a matter of concern. Thanks to

Quick Response Code	Access this article online	
	Website: www.watconman.org	**DOI:** 10.26480/wcm.02.2021.121.130

Cite The Article: Viet Duc Bui, Phuoc Quy Phong Nguyen, Dinh Tuyen Nguyen (2021). A Study of Ship Ballast Water Treatment Technologies and Techniques. *Water Conservation & Management, 5(2): 121-130.*

the suitable applications, ballast water plays an important role in the operation of ocean transportation such as cargo handling, ship maneuvering, or displacing cargo operations (Council, 1996). The quality of ballast water, which mostly be taken directly from seawater, is usually decreased because of its friction with different kinds of surfaces. As the consequence, the activities of displacing and replacing wasted ballast water to the ocean directly harm the marine surroundings (Saltzman, 1997; Scriven et al., 2015). Moreover, ballast water in some cases can be the main reason responsible for the destruction of ecology while causing negative effects on economic and human health (Cao et al., 2014). In ballast water, there may be oil from an oil leak between the oil tank space and the ballast water tank. Ballast water containing oil is discharged into the environment, causing serious impacts on the ecosystem.

Absorbent materials or equipment for treatment of oil-containing water are the solution to this problem (Nizetic et al., 2021; Chau, 2018; Pham, 2021; Chau et al., 2021). Ballast water is considered the main reason for the unexpected invasion of exotic organisms into new habitats (Williams et al., 1988; Cariton and Geller, 1993; Ruiz, 2000). In efforts to reduce and prevent negative effects of ballast water in mentioned problems, the international community agreed to the "International Convention for the Control and Management of Ships' Ballast Water and Sediments" in 2004 (IMO, 2004). Requirements such as the specific quality and composition of ballast water will be strictly controlled. Many physical and chemical processing processes are studied to best meet the above requirements.

Annually, about 10000 Mt of ballast water is rotated through the activities of marine transportation. During the procedures of ballast water, it is inevitable that thousands of alien organisms enter new marine environments every day thereby causing negative effects on the economy and environment (Council, 1996; Bax et al., 2003; Le et al., 2021). A group researcher claimed that over 140 exotic organisms have been revealed to the Great Lakes of North America (Mills et al., 1993). Not only Great Lakes, but ballast water is also the main driver of the release of foreign organisms into new habitats in other US and Canadian waters (Parsons, 2003). According to the calculation of Ribera and Boudouresque [66] in research, Zebra mussel damaged 5000$ throughout the period of 1986 to 1995 by fouling the fishing nets, boat hulls, and buoys as well as clogging up the water intakes system of constructions adjacent to the sea (Ribera and Boudouresque, 1995).

In other events, coast comb jellyfish, Asian clam, and European crab invade the American Atlantic coast and destroy fisheries in several regions (Council, 1996; Bax et al., 2003). While displacing and replacing cargo, the tanks of the ship are filled with ballast water. Untreated ballast water brings along many living microorganisms, phytoplankton, zooplankton, etc and without any powerful treatment, these foreign species from ballast water are becoming one of four greatest threats to the world's oceans besides other land-based pollutants, overexploitation of marine resources, and direct destruction of coastal and ocean surroundings. Maximum viable organism concentrations in released ballast water, with viable organisms defined as those capable of effectively generating new living entities, were constituted by the D-2 regulation accordingly Ballast Water Performance Standard (IMO, 2018). The ballast water management system is considered the prerequisite to getting the standards according to the D-2 regulation. The BWMS must be authorized by the Government in accordance with the D-3 rule (Approval procedures for Ballast Water Management Systems).

The licensing procedure for ballast water management systems included land-based and onboard tests to determine the organism's removal effectiveness of the BMWS and its environmental acceptance; land-based testing referred to a test of the BWMS conducted in a laboratory, equipment company, or pilot plant (IMO, 2018). Until September 2020, among the eighty-four BWMSs accepted, most of them have been approved, including filtration or mechanical separation progress followed by physical or chemical treatments, or a mix of the two (IMO, 2020; Tsolaki and Diamadopoulos, 2010; Davidson et al., 2017). Although there are many different processing methods such as ozone or deoxygenation, the two most common treatment methods included UV treatment and electrochlorination treatment that were 40 systems and 22 systems respectively (Gerhard et al., 2019; Hess-Erga et al., 2019; Le et al., 2020). The treatments might well be administered throughout the ballasting and/or deballasting process, as well as during the cruise.

The BWM Convention requirements began to be implemented in September 2017 to gradually phase out the D-1 standard in favor of the D-2 standard by September 2024 (MEPC.287 (71)). Mandatory compliance with regulations D-1 and D-2 by shipowners of the BWM Convention will result in increased operating and additional costs (ABS, 2014; Nguyen et al., 2004; Sekimizu, 2021). Especially for the D-2 standard on the installation of ballast water treatment systems. This system will cost additional money in connection with the installation, operation, and maintenance of the ballast water treatment system. In 2015, shipowners' trade associations highlighted concerns about equipment and approval procedures after the IMO published its final report on the implementation of the standard D-2 of the BWM Convention (MEPC 69/4/4). Shipowners also expressed concern about the stability of the ballast water treatment system as well as fear about the time-consuming treatment system approval process.

These concerns are believed to stem from the very limited number of ballast water systems approved by IMO at the time of publication. In order to ease this anxiety, the MEPC.290 (71) (2017) resolution was announced by the Maritime Environment Protection Committee, with this resolution, this agency gave "the experience-building stage attached to the BWM Convention". The purpose of the resolution was to gather information about the various D-2 regulation related to devices and their function under real-world conditions. These research are very important for improving, evaluating, and ranking the different technologies on the market and giving ship owners more options for BWTS.

The ballast water exchange (BWE) criterion was considered according to the D-1 regulation while ballast water productivity standards after discharge from ships are specified by the D-2 regulation. It could be seen that the ballast water exchange was not a good solution to eliminate the spread of aquatic aquicolous and in order to improve this problem, BWS is considered as an effective method to fill in the shortcoming of BWE. As a part of Ballast Water Management Standards (BWMS), BWS determined the quantity and concentrations of indicator microorganisms in ballast water that must be met before disposal. More specifically, to manage the discharge ballast water, the Ballast Water and Sediments Management Plan were requested for all ships around the world. According to the plan, all ships had to bring and take detailed notes on the Ballast Water Record Book. IMO performed the regulations via 15 guidelines (G1 – G15) according to BWM Convention.

This was supposed to help achieve coherence in the approval process. Specifically, in these 15 guidelines, 2 guidelines G9 and G10 have provided information related to the use of active substances for the safe treatment of ballast water, ensure safety related to human health and marine environment, and new technologies for treating ballast water effectively, respectively (IMO, 2014). With such guidelines, ship owners must install ballast water treatment systems for international ships. Currently, according to IMO guidelines, there are many approved ballast water management systems (BWMS), ship owners can completely choose the right one for each area and different circumstances.

As of November 2019, the IMO has granted final clearance to 45 ballast water management systém, according to Jang et al. These include electrolysis systems (22 BWMS), chemical eruptions systems (13) and UV systems (6 BWMS), as well as ozone systems (4 BWMS) in the permitted BWMSs (IMO, 2019). According to the IMO classification, these systems are divided into two categories: active systems and non-active systems. The ballast water treatment methods onboard a ship vary according to the geographical region of the journey, the physical-chemical qualities of seawater, and the kind of organisms present. To eliminate, make harmless, or reduce the absorption or release of dangerous aquatic animals and diseases contained in ballast water, ballast water management used a variety of mechanical, physical, chemical, and biological methods, either alone or in combination.

In this article, we will highlight some ballast water management systems based on the D-2 standard issued by IMO. The article will be divided into 5 parts, in the next section, the paper will consider the literature review about ballast water treatment systems. In part 3, some models of ballast water treatment will be presented based on 2 types of active ingredients and non-active substances. And part 4 of the paper will discuss the benefits of these treatment models. The last part will be the conclusion of the paper.

2. Literature Review

Flow-through and empty/refill are considered as two main ways of the ballast water exchange. When the ballast water of the ship is released, these are two cost-effective methods of exchanging it in order to comply with Ballast Water Management Convention (BWMC) rule D-1. Ballast discharge activities, both at sea and in port, were subject to this requirement. In order to have a more detailed understanding of these 2 methods of ballast water discharge, as well as compare the quality of ballast water according to D-2 standard compared with the 2 discharge methods in accordance with D-1 standard. We have introduced strict requirements on ballast water quality are allowed to be discharged by IMO in Table 1.

Table 1: IMO standards for ballast water discharge (Rivas-Zaballos et al., 2021)

Organisms size/ Indicator microbes	Concentration
Organisms size	
Greater or equal to 50 µm in minimum dimension	Less than 10 viable organisms per m^3
Between 10 and 50 µm in minimum dimension	Less than 10 viable organisms per mL
Indicator microbes	
Vibrio cholerae (O1 and O139)	Less than 1 colony forming unit per 100 mL or less than 1 cfu per 1 g (wet weight) zooplankton samples
Escherichia coli	Less than 250 colony forming units per 100 mL
Intestinal enterococci	Less than 100 colony forming units per 100 mL

A ship's ballast tanks must be emptied and replenished sequentially as part of the empty/refill procedure, often known as the sequential technique or empty/refill method. This method requires the ballast tanks to be drained, emptied and then refilled. Bow-flare slamming may occur if specific tanks are emptied, leading to a loss of stability, a rise in ship structural stresses, and/or a decrease in forwarding drafts. The level of ballast water amplitude in ballast water spaces should also be considered and required to provide stability to the ship during navigation, this is similar to ballast water during cargo handling**.** Through a pump system and onboard piping systems, the empty/refill method is implemented. This pumping system will be responsible for sucking all the ballast water in the storage compartment to the sea, then thanks to this pumping system, the ballast compartments will be filled with water to stabilize the ship. Ballast water should be drained until there is no longer any suction in the ballast tanks, according to IMO norms.

The stability, endurance, draft, and trim of a ship may be affected by major changes in loading and unloading circumstances during full tank ballasting processes. It has been shown that exchange efficiency levels between 70% and 90% are more feasible according to studies mentioned by Dames and colleagues (Moore, 1999). This strategy would also be less effective in eradicating non-indigenous species, according to a study, since ballasting procedures would not remove much dirt and creatures at the bottom of tanks (Hay et al., 1997). With this ballast water change, there is always the risk of sediment being deposited and the possibility of organisms surviving and growing inside the ballast before being discharged. More specifically, 95% is the number required to be achieved during the emptying of the ballast water chamber before the ballast water is re-injected into the hold in accordance with BWMC Regulation D-1 of 2004 (Qi and Eames, 2015). For the same level of seawater disinfection, the slit kind of geometry uses 40 percent less energy than the cylindrical form (Badve et al., 2015).

The flow-through is considered the second method. In this way, the ballast water instead of being discharged/pumped one way will be stored in another area. When necessary, this reserve water will be arranged to overflow through the ballast water space according to the research of (Kalnina and Romule, 2020). The advantage of the method is that the ship's stability is always guaranteed, but the limitation of this method is there must be a ballast water storage tank, or it is always in excessive condition for permission. According to calculations, with this method, the amount of water injected into the ballast water tank will have to be increased 3 times to achieve the 95% required by the D-1 standard. For this method, the pump and discharge system are two separate systems. Using the sea chest's common water intakes, water is transported to the tanks and used throughout the facility. Ventilators and manholes on the ship's weather deck are used to remove water from the ship.

In addition to the theoretical calculations, Rigby and Parsons et al., undertook some field experiments (Rigby, 1995; Parsons et al., 1998). The results suggest that the 95% figure recommended by the standard D-1 of IMO needed to be revised if the volume of water 3 times the volume of the compartment is pumped through the ballast water chamber. In addition, the discharge of ballast water has several other strict regulations on the location of ballast discharge to avoid affecting the marine environment of a country. This number is usually required to be 200 nautical miles from the port that the vessel will dock in, some places require this number to be 50 miles along inland routes (Murphy, 2013). Ballast water exchange efficiency by two methods is given in Table 2.

Table 2: Water exchange efficiency for empty/refill and flowthrough ballast water exchange

Mode of exchange	Tank	Water Exchanged (%)	Reference
Flow-through	1	63.2	(Gregg et al., 2009; Rigby and Hallegraeff, 1993)
Flow-through	2	86.5	
Flow-through	3	95.0	
Flow-through	3	90.0, 99.0	(Taylor and Bruce, 2000)
Flow-through	1	86.0 – 96.0	(Villac, 2000)
Flow-through	3	>99	(Taylor et al., 2007)
Flow-through	2	>99	
Empty/refill	1	95.0	(Miller, 1998)
Empty/refill	1	95.0-99.0	(Zhang and Dickman, 1999)
Empty/refill	1	86.0	(Locke et al., 1993)

Given the two basic methods of ballast water exchange, it is clear that both of these methods discharge untreated ballast water. As a result, IMO has announced BWMC as an international treaty (IMO, 2004). By September 2017, 75% of the world's fleet by tonnage had signed on (IMO, 2004). The treaty mandates that all ships have a ballast water management plan, a ballast water record book, and an international certificate for managing ballast water in international waters. Instead of performing ballast water changes according to D-1 standards, ships will now have to be equipped with a ballast water treatment system according to D-2 standards to treat ballast water before being discharged into the environment. Furthermore, the IMO's Guideline 8 should be followed when developing and approving ballast water treatment systems (BWTSs). Additional protocols (IMO Guideline 9) must be created for the management of active substances in case these chemicals have detrimental impacts on the vessel or receiving environment (Hess-Erga et al., 2019). Based on the requirements for the quality of the discharged ballast water as well as the requirements for the ballast water treatment system standards onboard ships, in the next chapter, the article will highlight some of the ballast water treatment systems that have been Research based on previously published studies. These systems will be outlined and classified according to IMO Guidelines 8 and 9. Includes treatment systems that use active ingredients and systems that do not use active ingredients.

3. Ballast Water Treatment Technologies

There are many techniques to effectively treat ballast water. Therefore, it is essential to have a standard to choose the right technologies. Mechanical and chemical method was 2 ballast water treatment method was classified (Apetroaei et al., 2018). For mechanical ways included filtration, sophistication, sedimentation and flotation methods, coagulation-flocculation that were utilized in the ocean to solve the water ballast before it released. On the other hand, the chemical methods included chlorinated water, electrolysis, ozone, advanced oxidation, or pH management. Another divide treatment way is considered wider than based on the vessel location that is notified (Tsolaki and Diamadopoulos, 2010). In this research, the authors broached 3 treatment methods to solve the ballast water consisting of after unloading cargos at the port, before unloading cargos, and using chemical active substances. In most cases, the methods utilized for treating ballast water are adapted from those employed in urban and other industrial applications. However, their utilization is hampered by fundamental variables like space, cost, and effectiveness (concerning the IMO released ballast water regulations). Solid-liquid split and sterilization were 2 technologies that were utilized in the ballast water treatment procedure. According to the authors, trade ballast water treatment systems involved two or more treatment phases, the first of which was a solid-liquid split stage followed by disinfection. Figure 1 below demonstrated the information about this system.

In this article, we divided ballast water treatment methods in two directions: non-active substances systems, active substances systems accordingly IMO. According to the IMO update, by November 2021, a total of 47 Ballast water management systems using Active Substances have received Final Approval from IMO. The (IMO) has certified 22 systems that utilized active substances in compliance with the 2016 Guidelines (G8) or the BWMS Code, and 29 systems that were using active substances in accordance with the requirements (G8). Electrolysis, Advanced oxidation, and Ozone were some of the most notable measurements of systems that were utilized active substances. UV (ultra-violet), filtration, deoxygenation, and heat are some of the most prominent measures of the systems that did not use the active substance (Gerhard et al., 2019). There were significant differences in the procedures for approving Conventional Ballast Water Treatment systems for these two systems.

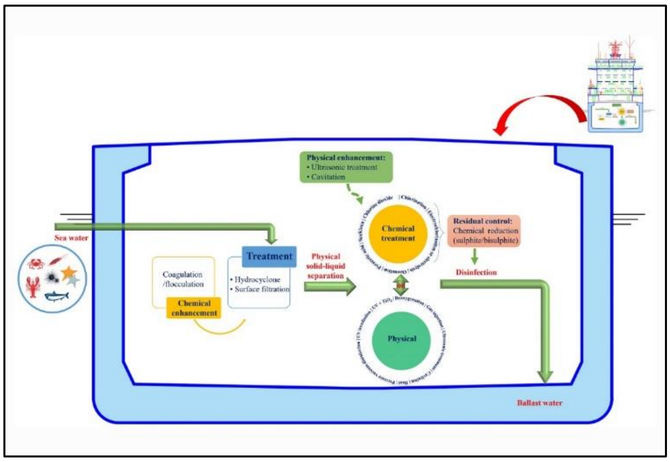

Figure 1: Overview of the general BWT technology process (LR, 2015)

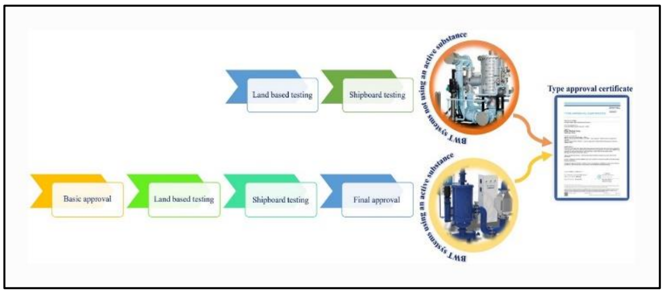

Figure 2: Steps for approval of BWT in accordance with the Convention (Vorkapic et al., 2016)

3.1 Non-active substances systems

Ultraviolet (UV) was the method in which ultraviolet light was used to subtract the aquatic organism in ballast water. This method is considered that had high costs because the costs associated with installation and operation are very large. Additionally, vehicles fitted with this system also required a large enough power supply to keep the system running. The light of organic molecules known as DNA would be absorbed by UV technology, and as a result, its applicability as a sterilization therapy is well-known (Su et al., 2014; Hijnen et al., 2006). A variety of catalysts or oxidants could be photo-activated under ultraviolet light, it leading to the Advanced Oxidation Process (AOP), which employs strong oxidizing radicals (mostly OH) that react instantly with microorganisms in water such as plankton, microalgae, and other microorganisms (Moreno-Andres et al., 2017). The 3 plankton species include Phaeodactylum tricornutum (8 × 3 µm, oval), Synechococcus sp. (from 2 to 3 µm in diameter, spherical) and Anabaena sp. (3.3–9.5 × 2–6.3 µm, fibrous) has been studied and evaluated (Lewin et al., 1958; Olenina et al., 2006; Prasanna et al., 2006; Rivas-Zaballos et al., 2021). These were 3 species of organisms that are less than 10 µm in size. The authors focused on the inactivation effect of the UV treatment in a potential standard test organism (STO).

The results show that Synechococcus sp is the least affected species of UV rays. Despite its slow growth rate, the high UV objection of Synechococcus sp., combined with the productivity and widespread distribution of this species throughout the world, as well as the ecological significance of this species, all serve as compelling arguments in favor of considering this species as a valuable STO for ballast water treatment advancement in the UV treatment process (Romero-Martínez et al., 2021). The authors proposed a solution to increase the bacteria treatment capacity of the UV method. The results of this study suggested that the addition of hydrogen peroxide or peroxymonosulfate salt increased the microbial inactivation effect of the UV method for ballast water treatment. The experimental target here is the microalgae Tetraselmis suecica. The results showed that each of these chemicals when given at a concentration of 10 ppm, lowered the initial cell concentration by more than 96 percent, enhanced the UV inactivation rate, and allowed the treatment to achieve a higher degree of inactivation.

As a result of these enhancements, the UV necessary to maintain continuous compliance with BWMC guidelines would be reduced. With this reduction, the ability to reduce the load on the ship's power source would partly reduce the costs associated with the ballast water treatment system. According to another study conducted by Shi et al., a new ballast water treatment device (UVOM) was developed for the treatment of ballast water (Shi, 2020). UVOM's primary equipment included a membrane filtration, connection pipes, a UV catalytic TiO_2 unit, and an ozone producer as part of its overall design. The effects of salinity, stream velocity, and UV intensity on progress efficiency was studied to see how they affected the process. The results showed that salinity had less of an influence on the removal effectiveness of UVOM, and that flow velocity and UV strength were more essential factors in the removal process. In order to satisfy the D-2 standard, for a flow rate not exceeding 200 L/h the UV intensity was 50W while the UV strength will increase to 75 W if the flow rate exceeds 400 L/H. Furthermore, the findings revealed that the relative value of flow rate (65.96 percent) was much greater than the relative significance of UV intensity (34.04 percent).

However, there is a lot of controversy surrounding this solution like the use of UV light only inactivates microorganisms, but does not kill, plankton that can recover after impacting with UV light is a dangerous problem with the environment or the cost to invest in this treatment system is relatively high (Martinez et al., 2013; Moreno-Andreas et al., 2016). Filtration was a screening procedure that is very successful in the remediation of ballast water. The majority of treatment systems utilized filtration as a physical split treatment to remove bigger organisms (i.e., those with a size greater than 50 m). Filters with a mesh size of fewer than 50 µm were often used (Mitsui, 2013). Organisms and sediments could be removed from the water of ballast, by filtration steps mixed with gravity split (Matheickal et al., 2003). Filters were usually located near the ballast water pumps on ships. Salinity, turbidity, temperature, organics, vibration, and other factors had an impact on filter devices, which in turn had an impact on the subsequent stages in the system of ballast water treatment (Waite, 2003).

Screen filtration, disc filtration, and cartridge type filtering were among the newer kind of filters that are being utilized in ballast water treatment systems**.** Environmentally friendly filtration works by trapping microorganisms and sediments as the water flows through porous screens, filter medium, or layers of grooved disks. In any single treatment system or multi-method system, filtration was always suggested as an essential treatment option (Muntisov et al., 1993; Parsons and Harkins, 2000; Parsons and Harkins, 2002; Tang et al., 2006; Cangelosi, 2007). However, if filtration alone was used, the quality of the ballast water would not be able to achieve the IMO D-2 standard. Therefore, it was necessary to combine the filtering method with another method to meet the requirements of IMO. A mesoscale experimental system and increased plankton in ballast water have been investigated and designed (Wu et al., 2021). The mix between filter system and electro-catalysis system was considered as a ballast-water management system kind. It was determined how effective the treated ballast water was biological during holding durations of 10, 20, 30, 40, and 50 minutes. Biological effectiveness was considerably modified by holding time. After holding time in 50 minutes, the quality of ballast water released that was processed qualified according to the D-2 regulation. In addition, there are several ballast water treatment systems available on the market that combine the filtration method and some other methods such as PureBallast, BIO-SEA, RayClean BWTS, or OxyClean BWTS (Vorkapic et al., 2016).

The ballast water was heated to a temperature between 35 and 45 degrees Celsius in order to destroy any organisms present (Saglam and Duzgunes, 2018). Ballast water treatment using heat and deoxygenation was thought to be successful. However, this combination between heat-deoxygenation and filtration was believed to be very rare, as evidenced by the rare occurrence of ballast water treatment systems. This system only appeared 4 times in Australia and never appeared in the US as observed by the author (Gerhad et al., 2019). Because of the difficulties in adapting vessel tanks and the resting phases of some microorganisms that could withstand anoxia, these systems were uncommon (Holmstrup, 2006). Ballast water might be used as a resource for distillation onboard the ship to satisfy the anticipated freshwater supply need, according to theoretical studies and practical factors are also important. Gude introduced that ballast water might be used as a resource for distillation onboard the ship to satisfy the anticipated freshwater supply need, according to theoretical studies and practical factors are also important (Gude, 2019). With the main engine capacity of 7500 kW, this could be considered as a useful waste heat source for desalination in ballast water. Ballast water management and treatment, as well as the non-renewable footprint of onboard water resources in the maritime sector, might benefit from this scenario.

3.2 Active substances systems

Currently, the use of active ingredients for disinfection in ballast water is still a controversial issue. There are many opinions that these substances are not harmful to the environment, but some others believe that the use of these active substances before discharging ballast water will lead to those active substances being released into the environment. Some commonly used active ingredients include Biocides, Chlorine, NaOCl, Electrolytic, and Ozone (Tsolaki and Diamadopoulus, 2010). Kim and Park conducted research to compare the sterilizing effects of electrolysis, UV therapy, and electrolysis coupled with UV for the better treatment of zooplankton (size 50 μm) (Kim and Park, 2021). Based on sterilization time, the methods are arranged in the following order electrolysis followed by electrolysis combined UV, and finally, UV radiation. 1,300 W, 8,400 W, and 4,500 W are the amounts of electricity required to power the electrolysis, UV radiation, and UV combined electrolysis, respectively. It can be seen that, based on the sterilization time, the combination of UV and electrolysis is still behind electrolysis alone while the electricity consumption is many times higher.

E. coli inactivity by the mixed UV/Ag–TiO2/O3 treatment was boosted, and the inactivation effectiveness was increased with increasing UV intensity and ozone dosage in 2011, who compared it with separate unit processes using ozone or UV/Ag–TiO2 (Wu et al., 2011). Regarding E. coli inactivity in simulated ballast water, this research found that the UV/Ag–TiO2/O3 method was effective. The combination UV/Ag–TiO2/O3 treatment was more effective than the separate treatments in terms of inactivation. Increased UV strength and ozone exposure led to a rapid increase in E. coli inactivity especially during the early stages of the reaction. The amount of ozone and the concentration of total residual oxidants were proportional to each other. Water with a high TRO concentration at low temperatures remains toxic for a long time.

As an indicator bacterium, the walrus algae, Scripsiella trochoidea, was used in the research to evaluate the performance of various standard and advanced oxidation techniques for prospective ballast water treatment (Yang et al., 2015). Treatment with UV radiation, ozone, hydrogen peroxide, and their different combinations resulted in a stable and uniform culture. After 10 seconds of irradiation of UV radiation, micro-organisms were almost inactivated. But then, re-photosynthesis of plankton occurred for all methods that used UV radiation as a phytoplankton treatment in ballast water. For O3, the deactivation efficiency was 100% after 5 minutes of treatment, however for H2O2, the inactivation efficiency was just 80% after the same period. The combination of methods was done such as the combination of Ozone and UV light or the combination of UV and H2O2. These combined methods showed an almost immediate effect when both inhibiting the photosynthesis of plankton cells and increasing the processing capacity of the method. Furthermore, this combination produced negligible residual oxidants. Therefore, in this study, the combination of UV and Ozone rays was recommended as an effective and minimally harmful ballast water treatment method.

Ozone is known as an unstable oxidizing agent and has a powerful ability to destroy harmful cells. Research demonstrated that using ozone to treat ballast water for about 5 to 10 hours reduces the amount of plankton by 71% to 99% (Tsolaki et al., 2010). Artificial seawater has been utilized in the research (Jones et al., 2006). In this study, the ozone concentration has been optimized by using artificial seawater to create a ballast water environment. This environment utilized 5 marine species in short-term batch experiments (less than 5 hours). The disaggregation and formation of TRO after resolving by ozone treatment have been calculated (Perrins et al., 2006). The result showed that ozone could effectively treat marine organisms at initial residual oxidizing concentrations of 2–5 mg/l. With ozone-based oxidants at the level of 1 to 3 mg/l, it would make the treatment of plankton in the ballast water environment remarkably effective. This reduction level was equivalent to chlorine but leaves less environmental impact (Maddox, 2004).

4. Discussion

In this study, we looked at several applications for the treatment of ship ballast water before it is released into the marine environment. It can be said that these are highly practical and useful applications for the environment. However, it can be concluded from the analysis of the above applications that the combined application of several methods will yield better results than a single ballast water treatment method (Nguyen et al., 2021). So as to meet the most positive results, presented a system that controlled the ballast water and sediments (Cohen and Dobbs, 2015). This system consisted of 4 steps derived from 4 methods:

1. Filtration by mechanical sieve
2. Coagulation and flocculation make the bigger than 50 μm plankton lie down in the low layers
3. For the plankton larger than 50 μm, using the membrane filter
4. UV irradiation

Concerns have been raised concerning the BWTS's efficacy. It was worrying that these systems were not yet oriented towards human health and safety, as evidenced by the fact that 95% of ballast water treatment systems have criteria related to discharge. These criteria are almost met even though they have not been processed yet (Cohen and Dobbs, 2015). In another instance, an archetype ClO2-generating system's treatment was largely efficient against planktonic assemblages, although microorganism communities recovered after a few days of the therapy (Maranda et al., 2013). Some other arguments suggested that the active substances affected the phytoplankton based on various factors such as the alkalinity of the water and the compounds in the water (Cha, 2015). According to the findings, temperatures, and concentrations of sea ice, rather than salinity, influence habitat appropriateness for 61% of species, in contrast to the present techniques of risk assessment (11 percent) (Leidenberger, 2015). Finally, the structure of a ship was also a matter of concern. The cause was believed to be the treatment systems using UV rays and chlorine which cause corrosion in ballast water tanks due to their strong oxidizing properties (Feng et al., 2015; Feng et al., 2015). The findings of also show that the corrosive potential of UV light increases slightly while the continuous use of disinfectants can cause damage to the biofilm of the ballast tank (Wang et al., 2013).

Treatment system needs will further raise the cost of constructing a new ship. Owners of ships sometimes have difficulty deciding on the optimum ballast water treatment system for their vessels. Making the appropriate choice requires careful consideration of several things. The final decision on the best ballast water treatment system is left to the shipowner or operator, who must take into account a variety of factors, including the ship's price, type (new construction or existing vessel), ballast system capacity, and the seas and ports through which the vessel travels (Vorkapic et al., 2016). Currently, the marine environment is facing many problems and one of them is ballast water management. This has important implications for maintaining marine biodiversity and economic environments. Many ships use the method of changing ballast water at sea, especially ships on short voyages (Shapoori and Gholami, 2014). This affects the marine environment a lot, especially the coastal environment or the continental shelf. However, studies have shown that shorter cruises have a higher possibility of discovering living planktons and microbes than longer ones. To avoid the growth of invasive and other microbial pathogens, ships that exchange ballast water should also use ballast water treatment. One study in a 25-year cycle calculated the cost per cubic meter of ballast water treated before being released into the environment. The treatment options mentioned include UV combined filtration, active compound filtration, cavitation combined deoxygenation, and chlorine electrolysis combined electrolysis. Figure 3 below shows the cost for each ballast water treatment method in m3 (Gude, 2019).

As shown in Figure 3, the lowest cost of ballast water treatment belongs to tankers VLCC ship while the highest cost belongs to General Cargo Breakbulk ship. This implies that the ballast water may be reused or disposed of in the maritime environment after treatment by the procedures outlined above. Higher value-added benefits may be obtained at similar treatment costs by repurposing ballast water as a source of freshwater for desalination processes.

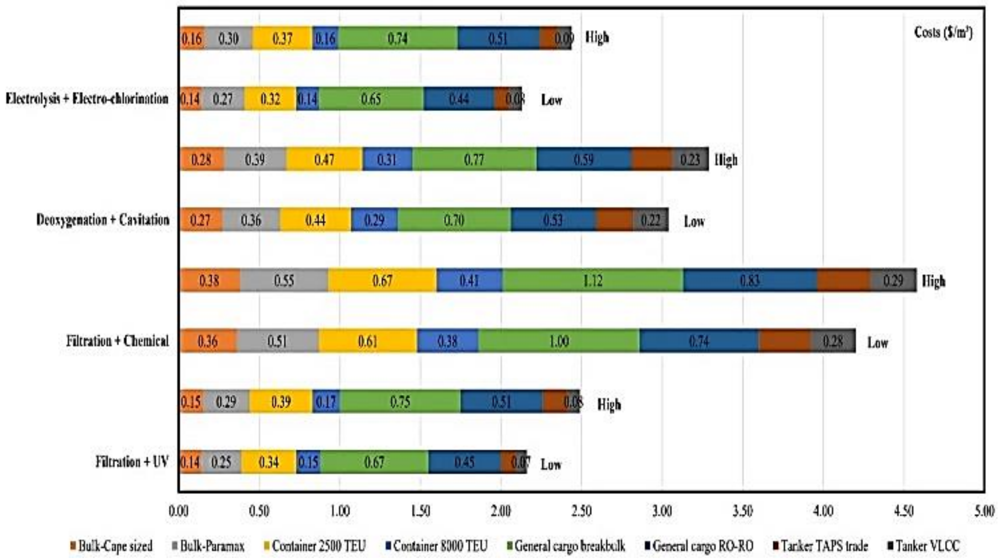

Figure 3: Cost statistics for different ballast water treatment methods - low and high treatment costs are presented separately for comparison (Gude, 2019)

5. Conclusions

Effective management of ship ballast water is imperative in ensuring that organisms do not migrate with the ballast water to different seas. More research is needed to improve ballast water treatment technology and techniques, diversify solutions, and aim to minimize the cost per ballast water treatment system. After mechanical solutions such as filtration are used to treat ballast water, the quality of the ballast water is difficult to meet the prescribed requirements. Chemical treatment of ballast water has the advantage of killing most of the organisms in the ballast water, but when discharging the ballast, these chemicals will follow the ballast water to seawater and seriously affect the marine environment. UV treatment is very effective and does not affect the environment, but the cost is very high and it is not easy for ship owners to invest in installation. The solution using active ingredients such as biocides, electrolysis, ozone, etc. is still controversial about the impact of this method on the marine environment. Ballast water treatment engineering and technology solutions increase the cost of building a ship, so shipowners tend to choose low-cost solutions. However, with low-cost solutions, the stability of the system is not high. After a short period of operation, the system degrades in its ability to meet the requirements of the convention. Combining different methods of ballast water treatment on ships will achieve high efficiency and ensure stable operation of the system, thereby reducing costs for ship owners.

References

ABS (American Bureau of Shipping), 2014. Ballast Water Treatment Advisory 2014. https://ww2.eagle.org/content/dam/eagle/advisories-and-debriefs/ABS_BWT_Advisory14312.pdf (accessed Dec. 21, 2021).

Amrouche, S.O., Rekioua, D., Rekioua, T., and Bacha, S., 2016. Overview of energy storage in renewable energy systems. Int. J. Hydrogen Energy, 41 (45), Pp. 20914–20927. doi: 10.1016/j.ijhydene.2016.06.243.

Andreadis, P., Zobanakis, A., Chryssakis, C., and Kaiktsis, L., 2010. Effects of fuel injection parameters on performance and emissions formation in a large-bore marine diesel engine. Int. J. Engine Res., 12 (1), Pp. 14–29. doi: 10.1243/14680874JER511.

Apetroaei, M.R., Atodiresei, D.V., Rău, I., Apetroaei, G.M., Lilios, G., and Schroder, V., 2018. Overview on the practical methods of ballast water treatment. J. Phys. Conf. Ser., 1122, Pp. 012035. doi: 10.1088/1742-6596/1122/1/012035.

Badve, M.P., Bhagat, M.N., and Pandit, A.B., 2015. Microbial disinfection of seawater using hydrodynamic cavitation. Sep. Purif. Technol., 151, Pp. 31–38. doi: 10.1016/j.seppur.2015.07.020.

Baldi, F., Azzi, A., and Maréchal, F., 2019. From renewable energy to ship fuel: ammonia as an energy vector and mean for energy storage. Pp. 1747–1752.

Bax, N., Williamson, A., Aguero, M., Gonzalez, E., and Geeves, W., 2003. Marine invasive alien species: a threat to global biodiversity. Mar. Policy, 27 (4), Pp. 313–323. doi: 10.1016/S0308-597X(03)00041-1.

Cangelosi, A.A., 2007. The response of zooplankton and phytoplankton from the North American Great Lakes to filtration. Harmful Algae, 6 (4), Pp. 547–566. doi: 10.1016/j.hal.2006.11.005.

Cao, Y., Æsøy, V., and Stene, A., 2014. Ballast Water Analysis and Heat Treatment Using Waste Heat Recovery Systems On Board Ships. in ECMS, Pp. 115–121.

Cariton, J.T., and Geller, J.B., 1993. Ecological Roulette: The Global Transport of Nonindigenous Marine Organisms. Science, 261 (5117), Pp. 78–82. doi: 10.1126/science.261.5117.78.

Çetin, O., and Sogut, M.Z., 2021. A new strategic approach of energy management onboard ships supported by exergy and economic criteria: A case study of a cargo ship. Ocean Eng., 219, Pp. 108137. doi: 10.1016/j.oceaneng.2020.108137.

Cha, H.G., 2015. Enhancing the efficacy of electrolytic chlorination for ballast water treatment by adding carbon dioxide. Mar. Pollut. Bull., 95 (1), Pp. 315–323. doi: 10.1016/j.marpolbul.2015.03.025.

Chau, M.Q., 2018. A Mini Review of Using Oleophilic Skimmers For Oil Spill Recovery. J. Mech. Eng. Res. Dev., 41 (2), Pp. 92–96. doi: DOI: 10.26480/jmerd.02.2018.92.96.

Chau, M.Q., Do, H.C., Le, T.T., Nguyen, X.P., and Nguyen, D.T., 2020. A numerical study on the flow considering the influence of moving objects under the free surface in marine engineering. Pp. 040002, doi: 10.1063/5.0030625.

Chau, M.Q., Nguyen, X.P., Do, H.C., and Le, T.T., 2020. Numerical simulation for transverse migration of finite-size clean bubbles in homogeneous shear turbulence. AIP Conference Proceedings 2292, Pp. 040004, doi: 10.1063/5.0030627.

Chau, M.Q., Truong, T.T., and Le, T.H., 2021. Oil spill cleanup by raw cellulose-based absorbents: a green and sustainable approach. Energy Sources, Part A Recover. Util. Environ. Eff., Pp. 1–14.

Chen, W.H., 2022. Biomass-derived biochar: From production to application in removing heavy metal-contaminated water. Process Saf. Environ. Prot.,

Cohen, A.N., and Dobbs, F.C., 2015. Failure of the public health testing program for ballast water treatment systems. Mar. Pollut. Bull., 91 (1), Pp. 29–34. doi: 10.1016/j.marpolbul.2014.12.031.

Council, N.R., 1996. Stemming the tide: controlling introductions of nonindigenous species by ships' ballast water. National Academies Press.

Cuong, T.D., and Phuong, N.T., 2020. Adaptive Sliding Mode Control of Mobile Manipulator Welding System for Flat Hull Block. J. Technol. Innov., 1 (2), Pp. 61–65. doi: 10.26480/jtin.02.2021.61.65.

Davidson, I.C., Minton, M.S., Carney, K.J., Miller, A.W., and Ruiz, G.M., 2017.

Pioneering patterns of ballast treatment in the emerging era of marine vector management. Mar. Policy, 78, Pp. 158–162. doi: 10.1016/j.marpol.2017.01.021.

Debnath, B.K., Saha, U.K., and Sahoo, N., 2015. A comprehensive review on the application of emulsions as an alternative fuel for diesel engines. Renew. Sustain. Energy Rev., 42, Pp. 196–211. doi: 10.1016/j.rser.2014.10.023.

Dell, R., and JRand, D.A., 2001. Energy storage - a key technology for global energy sustainability. J. Power Sources, 100 (1–2), Pp. 2–17. doi: 10.1016/S0378-7753(01)00894-1.

Feng, D., Shi, J., and Sun, D., 2015. Inactivation of microalgae in ballast water with pulse intense light treatment. Mar. Pollut. Bull., 90 (1–2), Pp. 299–303. doi: 10.1016/j.marpolbul.2014.09.006.

Feng, D., Xu, S., and Liu, G., 2015. Application of immobilized TiO2 photocatalysis to improve the inactivation of Heterosigma akashiwo in ballast water by intense pulsed light. Chemosphere, 125, Pp. 102–107. doi: 10.1016/j.chemosphere.2014.11.060.

Gerhard, W.A., Lundgreen, K., Drillet, G., Baumler, R., Holbech, H., and Gunsch, C.H., 2019. Installation and use of ballast water treatment systems – Implications for compliance and enforcement. Ocean Coast. Manag., 181, Pp. 104907. doi: 10.1016/j.ocecoaman.2019.104907.

Grandell, L., Lehtilä, A., Kivinen, A., Koljonen, T., Kihlman, S., and Lauri, L.S., 2016. Role of critical metals in the future markets of clean energy technologies. Renew. Energy, 95, Pp. 53–62. doi: 10.1016/j.renene.2016.03.102.

Gregg, M., Rigby, R., and Hallegraeff, G., 2009. Review of two decades of progress in the development of management options for reducing or eradicating phytoplankton, zooplankton and bacteria in ship's ballast water. Aquat. Invasions, 4 (3), Pp. 521–565. doi: 10.3391/ai.2009.4.3.14.

Gude, V.G., 2019. Thermal desalination of ballast water using onboard waste heat in marine industry. Int. J. Energy Res., 43 (11), Pp. 6026–6037. doi: 10.1002/er.4647.

Hay, C., Handley, S., Dodgshun, T., Taylor, M., and Gibbs, W., 1997. Cawthron's Ballast Water Research Programme. Final Report 1996-97. Cawthron Report No.417.

Hess-Erga, O.K., Moreno-Andrés, J., Enger, O., and Vadstein, O., 2019. Microorganisms in ballast water: Disinfection, community dynamics, and implications for management. Sci. Total Environ., 657, Pp. 704–716. doi: 10.1016/j.scitotenv.2018.12.004.

Hijnen, W.A.M., Beerendonk, E.F., and Medema, G.J., 2006. Inactivation credit of UV radiation for viruses, bacteria and protozoan (oo)cysts in water: A review. Water Res., 40 (1), Pp. 3–22. doi: 10.1016/j.watres.2005.10.030.

Hoang, A.T., 2018. Waste heat recovery from diesel engines based on Organic Rankine Cycle. Appl. Energy, 231, Pp. 138–166.

Hoang, A.T., 2020. Applicability of fuel injection techniques for modern diesel engines, Pp. 020018, doi: 10.1063/5.0000133.

Hoang, P.H., Chung, N.H., Dien, L.Q., Nguyen, X.P., and Pham, X.D., 2018. The efficient lignocellulose-based sorbent for oil spill treatment from polyurethane and agricultural residue of Vietnam. Energy Sources, Part A Recover. Util. Environ. Eff., 40 (3), Pp. 312–319. doi: 10.1080/15567036.2017.1415397.

Holmstrup, M., 2006. Influence of storage conditions on viability of quiescent copepod eggs (Acartia tonsa Dana): effects of temperature, salinity and anoxia. Aquac. Res., 37 (6), Pp. 625–631. doi: 10.1111/j.1365-2109.2006.01472.x.

Huynh, T.T., Nguyen, X.P., Nguyen, T.K.T., and Le, T.H., 2021. An analysis and review on the global NO2 emission during lockdowns in COVID-19 period. Energy Sources, Part A Recover. Util. Environ. Eff., Pp. 1–21. doi: 10.1080/15567036.2021.1902431.

Hwai, C.O., 2021. A review on application of artificial neural network (ANN) for performance and emission characteristics of diesel engine fueled with biodiesel-based fuels. Sustain. Energy Technol. Assessments, 47, Pp. 101416. doi: https://doi.org/10.1016/j.seta.2021.101416.

IMO (International Maritime Organization), 2014. International Convention for the Control and Management of Ships' Ballast Water and Sediments 2015, MEPC, 2014. MEPC 66/INF.2 Harmful aquatic organisms in ballast water, List of ballast water management Guidelines, guidance documents and approved ballast," 2014. https://www.imo.org/en/OurWork/Environment/Pages/BWMConventionandGuidelines.aspx (accessed Dec. 22, 2021).

IMO (International Maritime Organization), 2018. Code for Approval of Ballast Water Management Systems (BMWS Code). Resolution MEPC. 300(72). https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.300(72).pdf (accessed Dec. 20, 2021).

IMO (International Maritime Organization), 2019. List of Ballast Water Management Systems that Make Use of Active Substance Which Received Basic and Final Approval. (BWM.2/Circ.34/Rev.8)," 2019. https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/BWM.2-Circ.34-Rev.8.pdf (accessed Dec. 22, 2021).

IMO (International Maritime Organization), 2020. Latest Information of Approval of Ballast Water Management System G8 MEPC174(58) & G8 MEPC279(70)/BWMS Code MEPC300(72).

IMO (International Maritime Organization), 2021. International convention for the control and management of ships' ballast water and sediments. BWM/CONF./36, 2004. https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Control-and-Management-of-Ships%27-Ballast-Water-and-Sediments-(BWM).aspx (accessed Dec. 20, 2021).

Jones, A.C., Gensemer, R.W., Stubblefield, W.A., Van Genderen, E., Dethloff, G.M., and Cooper, W.J., 2006. Toxicity of ozonated seawater to marine organisms. Environ. Toxicol. Chem., 25 (10), Pp. 2683–2691. doi: 10.1897/05-535R.1.

Kalniņa, R., and Romule, A., 2020. Analysis of Ballast Water Treatment Technologies on Ships Operating in the Baltic Sea Region. Transp. Aerosp. Eng., 8 (1), Pp. 15–20. doi: 10.2478/tae-2020-0002.

Khalaf, O.I., 2021. Thermodynamic Simulation on the Change in Phase for Carburizing Process. C. Mater. Contin., 68 (1), Pp. 1129–1145.

Kim, D.S., and Park, Y.S., Zooplankton Removal in Seawater using UV, Electrolysis and UV+electrolysis Process. J. Environ. Sci. Int., 30 (7), Pp. 597–604. doi: 10.5322/JESI.2021.30.7.597.

Le, N.V.L., Le, T.H., Dong, T.M.H., Le, V.V., and Tung, D., 2020. Augmentation of Solar Water Distiller Performance with PV/T. WATER Conserv. Manag., 5 (1), Pp. 46–52. doi: 10.26480/wcm.01.2021.46.52.

Le, N.V.L., Nguyen, D.T., Al-Tawaha, A.R.M., and Vo, D. T., 2021. A Study on Legal Policies and Solutions for Ship Ballast Water Treatment. Water Conserv. Manag., 5 (2), Pp. 114–120. doi: http://doi.org/10.26480/wcm.02.2021.114.120.

Le, V.V., 2018. An absorption capacity investigation of new absorbent based on polyurethane foams and rice straw for oil spill cleanup. Pet. Sci. Technol., 36 (5), Pp. 361–370. doi: 10.1080/10916466.2018.1425722.

Leidenberger, S., 2015. Evaluating the potential of ecological niche modelling as a component in marine non-indigenous species risk assessments. Mar. Pollut. Bull., 97 (1–2), Pp. 470–487. doi: 10.1016/j.marpolbul.2015.04.033.

Lewin, J.C., Lewin, R.A., and Philpott, D.E., 1985. Observations on Phaeodactylum tricornutum. J. Gen. Microbiol., 18 (2), Pp. 418–426. doi: 10.1099/00221287-18-2-418.

Li, F., Goerlandt, F., and Kujala, P., Numerical simulation of ship performance in level ice: A framework and a model. Appl. Ocean Res., 102, Pp. 102288. doi: 10.1016/j.apor.2020.102288.

Liu, Z., 2020. Near-real-time monitoring of global CO2 emissions reveals the effects of the COVID-19 pandemic. Nat. Commun., 11 (1), Pp. 5172. doi: 10.1038/s41467-020-18922-7.

Locke, A., Reid, D.M., van Leeuwen, H.C., Sprules, W.G., and Carlton, J.T., 1993. Ballast Wafer Exchange as a Means of Controlling Dispersal of Freshwater Organisms by Ships. Can. J. Fish. Aquat. Sci., 50 (10), Pp. 2086–2093. doi: 10.1139/f93-232.

LR (Lloyd's Register), 2015. Understanding ballast water management:

Guidance for shipowners and operators. https://www.fws.gov/anstaskforce/Meetings/2016_November/7a_Ballast Water Guidance 2015.pdf (accessed Dec. 25, 2021).

Maddox, T.L., 2004. Onboard Ballast Water Treatment/Management with Ozone & Sonics–Phase II. United States Dep. Commer.

Maranda, L., Cox, A.M., Campbell, R.G., and Smith, D.C., 2013. Chlorine dioxide as a treatment for ballast water to control invasive species: Shipboard testing. Mar. Pollut. Bull., 75 (1–2), Pp. 76–89. doi: 10.1016/j.marpolbul.2013.08.002.

Martínez, L.F., Mahamud, M.M., Lavín, A.G., and Bueno, J.L., 2013. The regrowth of phytoplankton cultures after UV disinfection. Mar. Pollut. Bull., 67 (1–2), Pp. 152–157. doi: 10.1016/j.marpolbul.2012.11.019.

Matheickal, J., Hwa, T.J., Tun, C.M., Mylvaganam, S., Holmes, M., and Loke, L., 2003. Development of Dinoflgellate 'Cyst on Demand' Protocol and Comparison of Particle Monitoring Techniques for Ballast Wate r Treatment Evaluation. in 2nd International Ballast Water Treatment R&D Symposium, Pp. 326.

Miller, W., 1998. Ballast research at the Smithsonian Environmental Research Centre.

Mills, E.L., Leach, J.H., Carlton, J.T., and Secor, C.L., 1993. Exotic Species in the Great Lakes: A History of Biotic Crises and Anthropogenic Introductions. J. Great Lakes Res., 19 (1), Pp. 1–54. doi: 10.1016/S0380-1330(93)71197-1.

Mitsui, O.S.K.L., 2013. MOL to Install Ballast Water Treatment System on VLCC. https://www.mol.co.jp/en/pr/2013/13002.html (accessed Dec. 22, 2021).

Mohd Noor, C.W., Noor, M.M., and Mamat, R., 2018. Biodiesel as alternative fuel for marine diesel engine applications: A review. Renew. Sustain. Energy Rev., 94, Pp. 127–142. doi: 10.1016/j.rser.2018.05.031.

Moore, D., 1999. Ballast Water Exchange and Treatment: Executive Summary.

Moreno-Andrés, J., Romero-Martínez, L., Acevedo-Merino, A., and Nebot, E., 2017. UV-based technologies for marine water disinfection and the application to ballast water: Does salinity interfere with disinfection processes?. Sci. Total Environ., 581–582, Pp. 144–152. doi: 10.1016/j.scitotenv.2016.12.077.

Moreno-Andrés, J., Romero-Martínez, L., Acevedo-Merino, A., and Nebot, E., 2016. Determining disinfection efficiency on E. faecalis in saltwater by photolysis of H2O2: Implications for ballast water treatment. Chem. Eng. J., 283, Pp. 1339–1348. doi: 10.1016/j.cej.2015.08.079.

Muntisov, M., van Oorschot, R., Docherty, C., Beggs, C., and Lord, D., 1993. Ballast water treatment for the removal of marine organisms. AQIS Ballast Water Research Series Report No. 1." Australian Government Publishing Service, Canberra.

Murphy, K.R., 2013. Exploring the limits of dissolved organic matter fluorescence for determining seawater sources and ballast water exchange on the US Pacific coast. J. Mar. Syst., 111–112, Pp. 157–166. doi: 10.1016/j.jmarsys.2012.10.010.

Nam, T.T., 2020. Analysis of a Cantilever Column Subjected to Cyclic Loading. J. Technol. Innov., 1 (2), Pp. 38–39. doi: 10.26480/jtin.02.2021.38.39.

Natale, F.D., and Carotenuto, C., 2015. Particulate matter in marine diesel engines exhausts: Emissions and control strategies. Transp. Res. Part D Transp. Environ., 40, Pp. 166–191. doi: 10.1016/j.trd.2015.08.011.

Nguyen, H.P., 2021. The electric propulsion system as a green solution for management strategy of <scp> CO 2 </scp> emission in ocean shipping: A comprehensive review. Int. Trans. Electr. Energy Syst., 31 (11). doi: 10.1002/2050-7038.12580.

Nguyen, H.P., Le, P.Q.H., Pham, V.V., Nguyen, X.P., and Balasubramaniam, D., 2021. Application of the Internet of Things in 3E (efficiency, economy, and environment) factor-based energy management as smart and sustainable strategy. Energy Sources, Part A Recover. Util. Environ. Eff., Pp. 1–23, 2021.

Nguyen, T.H., Le, T.H., Le, V.V., and Dong, T.M.H., 2021. A Study on Selection of Ballast Water Treatment Technologies to Meet BWM 2004 Convention. Water Conserv. Manag., 5 (1), Pp. 53–59. doi: http://doi.org/10.26480/wcm.01.2021.53.59.

Nguyen, X.G., Nguyen, D.T., Pham, V.V., and Vo, D.T., 2022. Highlights of Oil Treatment Technologies and Rise of Oil-Absorbing Materials in Ocean Cleaning Strategy. Water Conserv. Manag., 6 (1), Pp. 6–14. doi: 10.26480/wcm.01.2022.06.14.

Nguyen, X.P., 2020. A simulation study on the effects of hull form on aerodynamic performances of the ships. Pp. 020015, doi: 10.1063/5.0000140.

Nguyen, X.P., 2020. The Flywheel Energy Storage System: An Effective Solution to Accumulate Renewable Energy. in 2020 6th International Conference on Advanced Computing and Communication Systems (ICACCS), Pp. 1322–1328. doi: 10.1109/ICACCS48705.2020.9074469.

Nguyen, X.P., Duong, X.Q., and Huynh, T.T., 2021. Sorbent-based devices for the removal of spilled oil from water: a review," Environ. Sci. Pollut. Res., 28 (23), Pp. 28876–28910. doi: 10.1007/s11356-021-13775-z.

Nguyen, X.P., Le, A.T., Huynh, T.T., and Pham, V.V., 2021. COVID-19 and the Global Shift Progress to Clean Energy. J. Energy Resour. Technol., 143 (9). doi: 10.1115/1.4050779.

Nguyen, X.P., Le, N.D., Pham, V.V., Huynh, T.T., and Dong, V.H., 2021. Mission, challenges, and prospects of renewable energy development in Vietnam," Energy Sources, Part A Recover. Util. Environ. Eff., Pp. 1–13. doi: 10.1080/15567036.2021.1965264.

Nguyen, X.P., Nguyen, D.C., and Duong, L.H., 2020. A review of solutions to improve the efficiency of hydrogen-rich catalysts for engine application. Pp. 040009. doi: 10.1063/5.0030996.

Nguyen, X.P., Nguyen, D.T., Pham, V.V., and Bui, V.D., 2021. Evaluation of the Synergistic Effect in Wastewater Treatment from Ships by the Advanced Combination System. Water Conserv. Manag., 5 (1), Pp. 60–65. doi: http://doi.org/10.26480/wcm.01.2021.60.65.

Nguyen, X.P., Ölçer, A.I., and Huynh, T.T., 2021. Record decline in global CO 2 emissions prompted by COVID-19 pandemic and its implications on future climate change policies. Energy Sources, Part A Recover. Util. Environ. Eff., Pp. 1–4. doi: 10.1080/15567036.2021.1879969.

Nguyen, X.P., Ölçer, A.I., Engel, D., Pham, V.V., and Nayak, S.K., 2021. Biomass-derived 2,5-dimethylfuran as a promising alternative fuel: An application review on the compression and spark ignition engine. Fuel Process. Technol., 214, Pp. 106687. doi: 10.1016/j.fuproc.2020.106687.

Ni, P., Wang, X., and Li, H., 2020. A review on regulations, current status, effects and reduction strategies of emissions for marine diesel engines. Fuel, 279, Pp. 118477. doi: 10.1016/j.fuel.2020.118477.

Nižetić, S., 2021. Impacts of COVID-19 pandemic on the global energy system and the shift progress to renewable energy: Opportunities, challenges, and policy implications. Energy Policy, 154, Pp. 112322. doi: 10.1016/j.enpol.2021.112322.

Nižetić, S., 2022. Heavy metal removal by biomass-derived carbon nanotubes as a greener environmental remediation: A comprehensive review. Chemosphere, 287, Pp. 131959. doi: https://doi.org/10.1016/j.chemosphere.2021.131959.

Nižetić, S., Duong, Q.X., Rowinski, L., and Nguyen, X.P., 2021. Advanced super-hydrophobic polymer-based porous absorbents for the treatment of oil-polluted water. Chemosphere, 277, Pp. 130274. doi: 10.1016/j.chemosphere.2021.130274.

Olenina, I., Hajdu, S., Edler, L., Andersson, A., Wasmund, N., and Busch, S., 2006. Biovolumes and size-classes of phytoplankton in the Baltic Sea. https://epic.awi.de/id/eprint/30141/1/bsep106.pdf (accessed Dec. 22, 2021).

Parsons, M.G., 2003. Considerations in the Design of the Primary Treatment for Ballast Systems. Mar. Technol. SNAME News, 40 (01), Pp. 49–60. doi: 10.5957/mt1.2003.40.1.49.

Parsons, M.G., and Harkins, R.W., 2000. The Great Lakes Ballast Technology Demonstration Project Filtration Mechanical Test Program. Mar. Technol. SNAME News, 37 (03), Pp. 129–140. doi: 10.5957/mt1.2000.37.3.129.

Parsons, M.G., and Harkins, R.W., 2002. Full Scale Particle Removal

Performance of Three Types of Mechanical Separation Devices for the Primary Treatment of Ballast Water. Mar. Technol. SNAME News, 39 (04), Pp. 211–222. doi: 10.5957/mt1.2002.39.4.211.

Parsons, M.G., Harkins, R.W., Mackey, T.P., Munro, D.J., and Cangelosi, A., 1998. Design of the Great Lakes ballast technology demonstration project. Trans. Nav. Archit. Mar. Eng., 105, Pp. 323–348.

Perrins, J.C., Cooper, W.J., van Leeuwen, J.H., and Herwig, R.P., 2006. Ozonation of seawater from different locations: Formation and decay of total residual oxidant—implications for ballast water treatment. Mar. Pollut. Bull., 52 (9), Pp. 1023–1033. doi: 10.1016/j.marpolbul.2006.01.007.

Pham, V.V., 2018. A Review on Fuels Used for Marine Diesel Engines. J. Mech. Eng. Res. Dev., 41 (4), Pp. 22–32. doi: 10.26480/jmerd.04.2018.22.32.

Pham, V.V., 2019. Technological Perspective for Reducing Emissions from Marine Engines. Int. J. Adv. Sci. Eng. Inf. Technol., 9 (6), Pp. 1989. doi: 10.18517/ijaseit.9.6.10429.

Pham, V.V., 2020. Aalyzing and selecting the typical propulsion systems for ocean supply vessels. in 2020 6th International Conference on Advanced Computing and Communication Systems (ICACCS), Pp. 1349–1357. doi: 10.1109/ICACCS48705.2020.9074276.

Pham, X.D., 2021. An investigation of remediation and recovery of oil spill and toxic heavy metal from maritime pollution by a new absorbent material. J. Mar. Eng. Technol., 20 (3), Pp. 159–169. doi: 10.1080/20464177.2018.1544401.

Prasanna, R., Kumar, R., Sood, A., Prasanna, B.M., and Singh, P., 2006. Morphological, physiochemical and molecular characterization of Anabaena strains. Microbiol. Res., 161 (3), Pp. 187–202. doi: 10.1016/j.micres.2005.08.001.

Qi, Z., and Eames, I., 2015. Implications of ballast tank geometry and treatment technology on NIS removal. Ocean Eng., 103, Pp. 211–222. doi: 10.1016/j.oceaneng.2015.04.046.

Ribera, M.A., and Boudouresque, C.F., 1995. Introduced marine plants, with special reference to macroalgae: mechanisms and impact. Prog. Phycol. Res., 11, Pp. 187–268.

Rigby, G., 1995. On-board treatments and ballasting options. in Symposium on Ballast Water-A Marine Cocktail on the Move., Pp. 106–113.

Rigby, G., and Hallegraeff, G., 1993. Shipping ballast water trials on the bulk carrier M.V. 'Iron Whyalla', in Japan and en-route to Canada. In: AQIS Ballast Water Research Series Report No.2. Australian Government Publishing Service, Canberra.

Rivas-Zaballos, I., Romero-Martínez, L., Moreno-Garrido, I., Acevedo-Merino, A., and Nebot, E., 2021. Evaluation of three photosynthetic species smaller than ten microns as possible standard test organisms of ultraviolet-based ballast water treatment. Mar. Pollut. Bull., 170, Pp. 112643. doi: 10.1016/j.marpolbul.2021.112643.

Romero-Martínez, L., Rivas-Zaballos, I., Moreno-Andrés, J., Moreno-Garrido, I., Acevedo-Merino, A., and Nebot, E., 2021. Improving the microalgae inactivating efficacy of ultraviolet ballast water treatment in combination with hydrogen peroxide or peroxymonosulfate salt. Mar. Pollut. Bull., 162, Pp. 111886. doi: 10.1016/j.marpolbul.2020.111886.

Ruiz, G.M., 2000. Global spread of microorganisms by ships. Nature, 408, Pp. 49–50. doi: 10.1038/35040695.

Saglam, H., and Duzgunes, E., 2018. Effect of Ballast Water on Marine Ecosystem, pp. 373–382.

Saltzman, J., 1997. Stemming the Tide: Controlling Introductions of Nonindigenous Species by Ships' Ballast Water. Mar. Technol. Soc. Mar. Technol. Soc. J., 31 (3), Pp. 82.

Scriven, D.R., DiBacco, C., Locke, A., and Therriault, T.W., 2015. Ballast water management in Canada: A historical perspective and implications for the future. Mar. Policy, 59, Pp. 121–133. doi: 10.1016/j.marpol.2015.05.014.

Sekimizu, K., 2012. International Chamber of Shipping Conference. https://www.imo.org/en/MediaCentre/SecretaryGeneral/Pages/ICS2012.aspx (accessed Dec. 21, 2021).

Shadizadeh, S.R., Khodashenas, A., Abtahi, S.M., and Roayaei, E., 2014. Experimental Investigation of Oil Spill Cleanup Using Cholan as a Natural Oil Absorber. Energy Sources, Part A Recover. Util. Environ. Eff., 36 (9), Pp. 982–992. doi: 10.1080/15567036.2010.549924.

Shapoori, M., and Gholami, M., 2014. Effect of a ballast water treatment system on survivorship of natural populations of marine plankton in Persian Gulf, Iran. Mar Sci, 4 (2), Pp. 44–48.

Shi, Y., 2020. The investigation and simulation of the UVOM ballast water treatment device. IOP Conf. Ser. Earth Environ. Sci., 450 (1), Pp. 012026. doi: 10.1088/1755-1315/450/1/012026.

Su, Y., Straathof, N.J.W., Hessel, V., and Noël, T., 2014. Photochemical Transformations Accelerated in Continuous-Flow Reactors: Basic Concepts and Applications. Chem. - A Eur. J., 20 (34), Pp. 10562–10589. doi: 10.1002/chem.201400283.

Surendran, S., and Reddy, J.V.R., 2003. Numerical simulation of ship stability for dynamic environment. Ocean Eng., 30 (10), Pp. 1305–1317. doi: 10.1016/S0029-8018(02)00109-9.

Tang, Z., Butkus, M.A., and Xie, 2006. Crumb rubber filtration: A potential technology for ballast water treatment. Mar. Environ. Res., 61 (4), Pp. 410–423. doi: 10.1016/j.marenvres.2005.06.003.

Taylor, A., and Bruce, E., 2000. Mid ocean ballast exchange: Shipboard trials of methods for verifying efficiency. Report prepared for Ministry of Fisheries. Cawthron Institute, Halifax, New Zealand, Report No. 524.

Taylor, M., MacKenzie, L., Dodgshun, T., Hopkins, G., de Zwart, E., and Hunt, C., 2007. Trans-Pacific shipboard trials on planktonic communities as indicators of open ocean ballast water exchange. Mar. Ecol. Prog. Ser., 350, Pp. 41–54. doi: 10.3354/meps07016.

Theotokatos, G., and Tzelepis, V., 2015. A computational study on the performance and emission parameters mapping of a ship propulsion system. Proc. Inst. Mech. Eng. Part M J. Eng. Marit. Environ., 229 (1), Pp. 58–76. doi: 10.1177/1475090213498715.

Tsolaki, E., and Diamadopoulos, E., 2010. Technologies for ballast water treatment: a review. J. Chem. Technol. Biotechnol., 85 (1), Pp. 19–32. doi: 10.1002/jctb.2276.

Vakili, S., Ölçer, A.I., Schönborn, A., and Ballini, F., 2022. Energy-related clean and green framework for shipbuilding community towards zero-emissions: A strategic analysis from concept to case study. Int. J. Energy Res., https://doi.org/10.1002/er.7649

Van, P.P., and Trong, T.K., 2020. Effect of Porosity on Behaviours of Plate Structures. J. Technol. Innov., 1 (1), Pp. 10–12. doi: 10.26480/jtin.01.2021.10.12.

Ventikos, N., 2004. A high-level synthesis of oil spill response equipment and countermeasures. J. Hazard. Mater., 107 (1–2), Pp. 51–58. doi: 10.1016/j.jhazmat.2003.11.009.

Villac, M.C., 2000. Ballast water exchange: testing the dilution method," in Proceedings of the 9th International Conference on Harmful Algal Blooms. Intergovernmental Oceanographic Commission of UNESCO, Paris, pp. 470–473.

Vinayagam, N.K., 2021. Smart control strategy for effective Hydrocarbon and Carbon monoxide emission reduction on a conventional diesel engine using the pooled impact of pre-and post-combustion techniques. J. Clean. Prod., Pp. 127310.

Vorkapić, A., Komar, I., and Jelić-Mrčelić, G., 2016. Shipboard Ballast Water Treatment Systems on Seagoing Ships. Trans. Marit. Sci., 5 (1), Pp. 19–28. doi: 10.7225/toms. v05.n01.003.

Waite, T., 2003. Removal of natural populations of marine plankton by a large-scale ballast water treatment system. Mar. Ecol. Prog. Ser., 258, Pp. 51–63. doi: 10.3354/meps258051.

Wang, Z., Zhao, J., Jia, X., Fang, J., Zhang, B., and Ding, G., 2013. Influence of Inactivation Treatment of Ship's Ballast Water on Corrosion Resistance of Ship Steel Plate. J. Iron Steel Res. Int., 20 (11), Pp. 85–89. doi: 10.1016/S1006-706X(13)60201-0.

Williams, R.J., Griffiths, F.B., Van der Wal, E.J., and Kelly, J., 1988. Cargo vessel ballast water as a vector for the transport of non-indigenous marine species. Estuar. Coast. Shelf Sci., 26 (4), Pp. 409–420. doi: 10.1016/0272-7714(88)90021-2.

Wu, D., You, H., Zhang, R., Chen, C., and Du, J., 2011. Inactivation of Escherichia coli using UV/Ag TiO2/O3-mediated advanced oxidation: application to ballast water disinfection. J. Chem. Technol. Biotechnol., 86 (12), Pp. 1521–1526. doi: 10.1002/jctb.2667.

Wu, H., Cheng, F., Wang, Q., Chen, Y., and Yuan, L., 2021. Evaluating the biological efficacy of a ballast water management system using filtration and electro-catalysis with an accurate definition of holding time. Water Sci. Technol., 84 (8), Pp. 1908–1918. doi: 10.2166/wst.2021.410.

Yang, Z., Jiang, W., Zhang, Y., and Lim, T.M., 2015. Inactivation of dinoflagellate Scripsiella trochoidea in synthetic ballast water by advanced oxidation processes. Environ. Technol., 36 (6), Pp. 750–759. doi: 10.1080/09593330.2014.960478.

Zhang, F., and Dickman, M., 1999. Mid-ocean exchange of container vessel ballast water. 1: Seasonal factors affecting the transport of harmful diatoms and dinoflagellates. Mar. Ecol. Prog. Ser., 176, Pp. 243–251. doi: 10.3354/meps176243.

Zhou, S., Zhou, J., and Zhu, Y., 2019. Chemical composition and size distribution of particulate matters from marine diesel engines with different fuel oils. Fuel, 235, Pp. 972–983. doi: 10.1016/j.fuel.2018.08.080.

Zhu, M., Ma, Y., and Zhang, D., 2012. Effect of a homogeneous combustion catalyst on the combustion characteristics and fuel efficiency in a diesel engine. Appl. Energy, 91 (1), Pp. 166–172. doi: 10.1016/j.apenergy.2011.09.007.