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Systematic Considerations for a Ballast Water Treatment System (BWTS) Retrofits: A Review

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Abstract

As a country that has more than half of the country's total territorial waters, Indonesia is highly dependent on shipping activities. Therefore, knowledge of policy updates for each ship from IMO must also be taken into account, one of which is the policy regarding the Ballast Water Management System, which requires every ship to be installed with a Ballast Water Treatment System in order to achieve the goal of a green environment in voyage areas by inhibiting the spread of microorganisms that endanger the area that is caused by ballast water. This regulatory update then creates problems, especially for ships that have been operating for a long time, because the ship has to comply with the standards for D-1 and then also have to comply with the D-2 standards according to the time specified in the convention. So, this review article will discuss the solution to the issues with retrofitting ballast water treatment systems as the addition of a new system to the existing system on a ship that has sailed and pay attention to conceptual aspects consisting of considerations and operations to find the type of ballast water treatment that suits each ship's needs by analyzing the advantages and disadvantages of each technology type method. There is also consideration for several stages that are commonly used to determine the type of treatment, starting with assessment and planning requirements, selection of space, compliance with BWMS regulations, selection of the ballast water treatment system method, engineering drawing, installation planning, and commissioning. Apart from that, several related innovation considerations were also discussed, including the development of alternative treatment technology, which has the potential for efficiency both in operational aspects and safety standards. Based on research developments, retrofitting the Ballast Water Treatment System with the ultra-violet (UV) treatment is well known as the common treatment beside the electrolysis treatment. The results obtained show that the ultra-violet (UV) method is one of the most efficient treatments when viewed from the way it works and the time duration for the treatment process. This proves that ultra-violet treatment can produce maximum efficiency if the selection of needs and consideration of maximized aspects also exceed the safety aspect as well.

1. Introduction

The sea is an area where various activities occur, including activities that are mostly carried out by humans, most of which include on-board activities using ships, military activities, aquatic research, and education [1]–[3]. Various activities carried out in marine areas can trigger an imbalance between living creatures, especially between humans and marine biota that live in certain marine areas. One of the phenomena that causes this imbalance is on-board activity. The reason that causes this activity to be one of the contributors to the imbalance factor in the life of marine biota is the residual activity of on-board activities. The residual activities refer to the results of the on-board activity process, where in general, the ship has a system to maintain its balance when facing sea currents while sailing. This system is a ballast system, and the policy regarding this system has undergone several changes with the aim of maintaining the continuity of life and diversity of marine biota. This is caused by several risks arising from the ballast water exchange process, such as accidental marine translocations, in the results of the risk assessment carried out by Barry et al. [4] using species specification and environmental similarity methods to produce low-risk to high-risk scenarios.

Several risks arising from ballast exchange activities were also explained by Darling et al. [5], where the exchange of water ballast can be the cause of unintentional marine translocation and the introduction of environmentally significant species that may be invasive in the water area where the ballast exchange is located. Ballast water exchange itself is a concept launched by IMO [6] through the Marine Environmental Protection Committee (MEPC) as a concept update at the 2004 International Convention for the Control and Management of Ship's Ballast Water named as D-1 standard, with the provision that ships can carry out ballast water exchange as far as possible from the coastal area with a minimum distance of 50 nautical miles in waters with a minimum depth of 200 m and an efficiency of at least 95 percent volumetric. Kurniawan et al. [7] explained other risks through his research on the application of ballast water treatment on-dock, which then produces environmental impacts, including the result of the exchange of ballast water, which carries foreign macroorganisms and microorganisms as well as chemicals that are harmful to the port receiving the ballast water when it is discharged. Werschkun et al. [8] also stated that exposure to chemicals resulting from ballast exchange can be a factor that has a significant impact on ecosystems and genetic damage to natural biota, thus affecting the reproductive success of biota, which has the impact of reducing biodiversity.

To overcome these risks, the International Maritime Organization (IMO) recently developed the regulations regarding the Ballast Water Treatment System which is included in Annex 5, requiring that all ships sailing internationally must be equipped with a Ballast Water Treatment System with a deadline of September 8, 2024 [9]. This aims to maintain marine ecosystems so that they are not contaminated by ship waste or microorganisms that are harmful to aquatic ecosystems. This regulation has been initiated since 2017 by IMO [10], and ships built in 2017 after the policy was launched must be equipped with a standard D2 Ballast Water Treatment System that must be approved to reduce the number of organisms discharged into the sea. Where ballast water management must release less than 10 living organisms/m^3 $\geq$ 50 micrometers in minimum dimensions and less than 10 living organisms/ml, and the removal of indicator microbes must not exceed the specified concentration [11]–[14]. This provision replaces D-1 for new ships and requires ships operating internationally to remove or neutralize aquatic organisms and pathogens before discharging ballast water. All ships that active in international traffic must have a valid ballast water management plan, logbook, and ballast water management certificate. Commissioning tests must be carried out to verify that ballast water discharge meets the D-2 standard, with test results following the regulations stated in the guidance for the commissioning testing of ballast water management systems. If damage occurs to the treatment system, the ship must repair or replace it to remain compliant, and the ballast water management certificate will be limited to D-1 if the BWTS is damaged.

However, it requires quite a long process considering the very large population and number of ships sailing regionally and internationally before this regulation is launched. This is certainly one of the spearheads and benchmarks, especially in the shipping industry, to spread its wings in developing and utilizing business innovation in this field. So that it can produce an adequate work plan and execution as well as minimum risk for the industry. One solution to deal with problems related to the emergence of new regulations for the Ballast Water Treatment System on old ships is retrofits [15]–[17], where the design and components of the Ballast Treatment are inserted into the existing system but must not interfere with the performance and space of other systems. In this retrofit process, there are various processes that must be designed in such a way as to produce output that is in accordance with policy and meets international class criteria for ship classification, such as BKI class institutions, Lloyds register, DNV and so on depends on the which class of the ships registered. This issue is what determines where the industry finds a solution to overcome this problem and minimize failures in arranging processes, activities, and work execution to make them more orderly, systematic, and comprehensive. However, based on Hermann et al. [18] research for implementation some solution of retroftting process, it is certainly faced with various problems, especially from the perspective of ship owners in various aspects, especially the financial aspect, where costs increase in line with the latest regulatory updates from existing policies.

Under these conditions, a special approach is needed to understand the needs of ship owners to minimize the risk of increasing costs incurred to comply with new policies so that ships can sail. With this, systematic considerations can be carried out by carrying out a comprehensive review of the Ballast Water Treatment System, which consists of grouping the types, considerations for operation, and analysis of the selection of BWTS installation methods that some of which were also carried out by Maglić et al. and Nanayakkara et al. [19], [20] that aims to produce good effectiveness. Thus, this review article generally has the main objective of meeting Sustainable Development Goals (SDGs) target number 14 concerning undewater life, which includes increasing compliance with international regulations through the IMO Convention on the Control and Management of Ballast Water Ships by installing a ballast water treatment system that is suitable to meet D-2 standards. In addition, the BWTS retrofit also aims to reduce negative environmental impacts by reducing the spread of invasive species through ballast water, increasing ship operational efficiency, and ensuring compliance with maritime and environmental safety standards. The benefits of systematic analysis of BWTS retrofit considerations are introducing more effective ballast water management technology and systems, also understanding the influence of international regulations on the BWTS industry. With the hope that this will help in building a more effective business strategy and understanding more deeply about the BWTS industry as a whole.

2. Ballast Water Treatment System

The ballast system is an important system in ships that is used to control ship stability and has several processes that can be shown in Figure 1. In the initial stages of cargo unloading and ballast water loading at the source port, the ship's cargo hold is emptied to accommodate the incoming cargo, while the ballast tanks are filled to stabilize the ship for safe transit. Furthermore, when a ship begins its voyage with empty cargo holds and full ballast tanks, this configuration helps maintain stability by compensating for weight differences caused by variations in load and fuel level. After reaching the destination port, the process reverses due to cargo loading. The cargo hold is filled with incoming cargo, while ballast water is removed to restore the ship's buoyancy and stability. This system operates by pumping ballast water into the ship's tanks to maintain safe operating conditions during shipping [14]. So this system can reduce pressure on the ship's hull, provide transverse stability, and compensate for changes in ship weight due to cargo and fuel variations [21]. In its function to maintain ship stability, ballast water stored in tanks is one of the places that has a risk of the emergence of new microorganisms that are also transported by the ballast water [22]–[25], so a system is needed to process the ballast water [26]. Ballast water treatment system is a treatment system for ballast water to reduce biological organisms, such as zooplankton, algae, and bacteria that settle in ballast water to prevent the entry and spread of invasive species and protect the surrounding marine environment [27]. This treatment system is indispensable in ensuring the preservation of marine biodiversity and ecosystem integrity while facilitating safe and sustainable shipping practices.

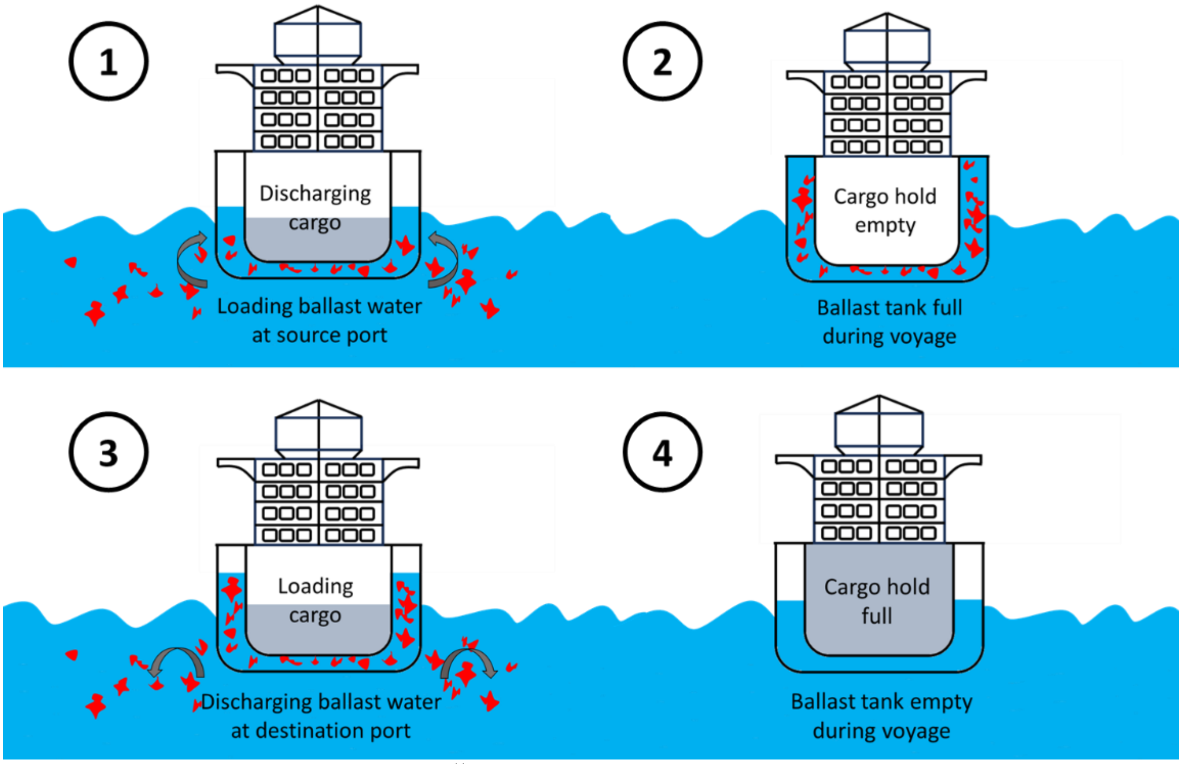

Figure 1. Ballast water treatment system process

2.1. Type of Ballast Water Treatment System

With the important function of the ballast water treatment system in preventing the entry and spread of invasive species and protecting the marine environment, especially in countries whose economies depend on the maritime sector [28], [29]. The types of BWTS that have been implemented in tropical countries can be classified into several types, as shown in Figure 2.

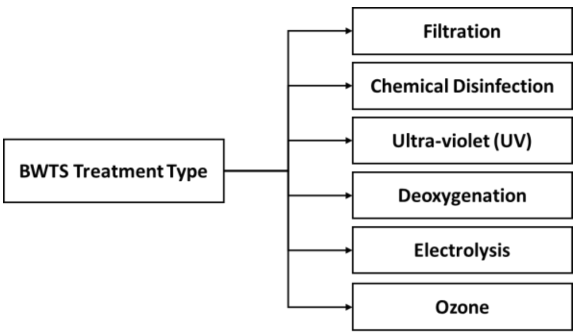

Figure 2. Ballast water treatment type

1. Filtration systems: uses physical media in the form of a filter to filter solid particles in ballast water.
2. Chemical disinfection: ballast water treatment system that involves the use of chemicals to remove microorganisms from ballast water with chemicals that can be oxidative or non-oxidative.
3. Ultra-violet treatment: uses ultraviolet (UV) light to kill microorganisms in ballast water by damaging the DNA of the microorganisms until they cannot reproduce.
4. Deoxygenation treatment: ballast water treatment system that reduces the oxygen content in the water to kill microorganisms.
5. Electrolysis: uses electrolysis technology to overcome the risk of spreading foreign organisms through ship ballast water by involving the use of electric current to produce compounds that can kill or inactivate pathogenic microorganisms and other foreign organisms.
6. Ozone: using ozone as a disinfecting agent to address the risk of spreading foreign organisms through ship ballast water through ozonation involves the use of ozone (O_3) to kill or inactivate pathogenic microorganisms.

The selection of an appropriate ballast water treatment system (BWTS) amidst the myriad available options is contingent upon a plethora of considerations encompassing efficacy against ballast water organisms, environmental friendliness, crew safety, cost effectiveness, ease of installation and operation, and availability of space on the ship [30]–[33]. With the complexity of these factors, a thorough analysis of the different types of BWTS is essential to facilitate decision-making. Therefore, an in-depth study of the advantages and disadvantages associated with different BWTS variants serves as a fundamental step to clarify the suitability for specific maritime applications. So, several types of BTWS mentioned above are then first analyzed for their advantages and disadvantages to make it easier to consider choosing a BWTS system, which can be seen in Table 1.

Table 1. Ballast water treatment system advantages and disadvantages of each type

BWTS types	Advantages	Disadvantages
Filtration Systems	- Non-chemical - Effective against macroorganism - Not depends to other energy - No additional ingredients - Not affect water quality - No potentially damage ship structures - Simple and stable	- High operating cost - Depends on water quality and availability - Requires regular maintenance - Not effective on dissolved substances and microorganism - Requires regular maintenance - Potentially risk of corrosion or filter damage
Chemical Disinfection	- Effectively against microorganisms - Effective in large volumes or quantities - Not affect water quality - Not depends to other energy - Easy to operate - Low operating cost	- Produces chemical residue - Negative effects on the environment - Limited to some organism - Requires close monitoring - Use potentially dangerous chemicals
Ultra-violet Treatment	- Non-chemical - Effective against microorganisms - No additional ingredients - No potentially damage ship structures - Fast process - Good monitoring and control - Not affect water quality	- High operating cost - High energy consumption - Does not remove solutes - Requires regular maintenance - Requires additional space - Unable handle macroorganism
Deoxygenation Treatment	- Non-chemical and physical - Reduces excess oxygen levels - Easy to operate	- Does not remove solutes - Potentially detrimental to the ecosystem - Requires close monitoring
Electrolysis	- Non-chemical	

	- Effective against microorganisms - Non-harmful residue - Controllable system - Easy to operate - Good monitoring and control	- High energy consumption - High operating cost - Requires close monitoring - Sensitivity to water condition - Requires regular maintenance - Potentially damage ship structures - Requires additional space
Ozone	- Non-chemical - Non-harmful residue - Effective against macroorganism - Good monitoring and control - Non-sensitive to water condition - Not affect water quality	- High operating cost - Requires close monitoring - Can be dangerous ozone to humans - Requires regular maintenance - Depends on air availability

3. Ballast Water Treatment System Considerations and Operation

Retrofitting a new system into an existing system is complex and should require a fairly in-depth study, especially conceptually in terms of the considerations and operation of the BWTS. Several steps that can be taken before determining the BWTS retrofit method are shown in Figure 3.

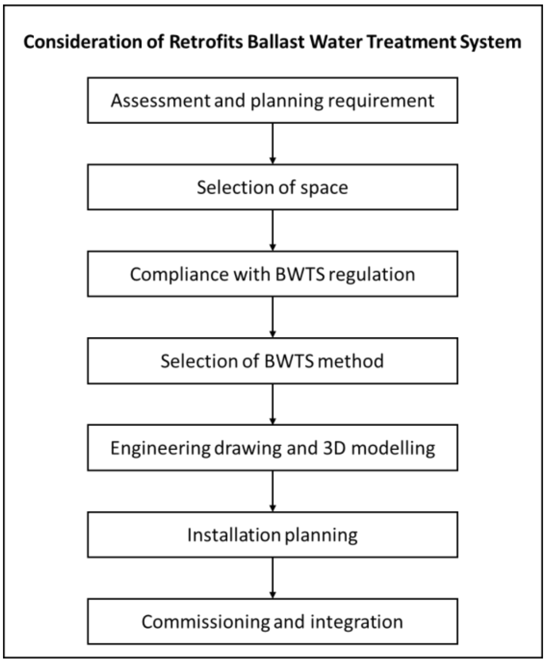

Figure 3. Step of consideration for retrofits ballast water treatment system

1. Assesment and planning requirement
   The consideration process in Figure 3 begins with a thorough assessment by identifying specific requirements for the retrofit case. This assessment encompasses a comprehensive evaluation of various factors, including the dimensions or size of the ballast tank, consideration of the position of other piping systems, and the specific needs of the ship like the reasearch that conducted by Chatterjee [34]. By conducting a thorough assessment, stakeholders can garner crucial insights into the intricacies of the retrofit project, laying the groundwork for informed decision-making and effective planning strategies. Risk assessment can also be carried out by fulfilling the key principles in the guidance released by IMO [35] to exceed te effectiveness in achieving an appropriate level of protection, transparency with clearly documented and availability to decision-makers, consistency to achieve a uniform high level of performance with suitable methodology, comprehensiveness to economic,

environmental, social and cultural, risk management to determine the acceptable level of risk in each instance, precautionary to consider an indicator of potential risk, science based, and continuous improvement.

2. Selection of space
   Based on the insights gained from the assessment phase, the next steps require careful planning to accommodate the retrofit within the vessel's spatial limits. This involves selecting appropriate space within the ship's infrastructure to integrate the Ballast Water Treatment System (BWTS), ensuring optimal use of available space so that it does not overlap with other systems while complying with regulatory and operational requirements. Buana et al. [36] also took the space selection process based on holistic consideration of the ship layout, operational dynamics, and BWTS technical specifications with design evaluation methodology, thereby facilitating the integration of the retrofit system into the existing ship infrastructure.
3. Compliance with BWTS regulation
   The space selected for retrofit must be strictly aligned with the applicable BWTS regulations specified by the International Maritime Organization (IMO) and other relevant environmental standards. In general, according to guidance from IMO [37], the stakeholder must be prepare administration approval that includes important aspects to be fulfilled include system testing and maintenance, crew training, environmental safety, BWTS testing, and control safety. Another compliance with regulatory mandates, as described by DNV [38] requires adherence to strict guidelines and specifications tailored to the retrofit scenario. By ensuring alignment with the regulatory framework, stakeholders can mitigate regulatory risks and uphold the integrity of maritime environmental conservation efforts.
4. Selection of BWTS method
   After space selection, the focus shifts to determining the most appropriate BWTS method based on predetermined criteria and considerations that has been decided on the previous process. Factors such as system size, type, and compliance with ship regulatory requirements are carefully evaluated to ensure compliance with the retrofit project objectives and operational aspects. The BWTS method has various different criteria according to the type and size of the ship, so the method chosen must meet the specified requirements for processing the volume of ballast water required in accordance with IMO regulations, thereby ensuring effective and appropriate ballast water treatment.
5. Engineering drawing and 3D modelling
   The engineering and 3D modeling process is carried out to form a visualization of the retrofit that has been planned and integrate it into existing equipment and systems on the ship [39], [40]. This can be realized by re-drawing the ship's drawing, diagram which can be done with basic engineering, on-board surveys, and 3D scanning to simplify the modeling process, which has the final output in the form of an updated layout of the ship where the BWTS installation layout has been installed and its components have been integrated correctly. This iterative process produces detailed engineering drawings and digital models that serve as valuable references for subsequent installation and integration phases, simplifying project execution and minimizing potential discrepancies.
6. Installation planning
   The layout update from the previous process will be used as a reference for the installation planning process, which starts with prefabrication that involve fabricating piping and other critical components of the BWTS system according to specified dimensions and requirements. Then the installation phase requires careful placement and integration of prefabricated components onto the ship, ensuring alignment with engineering drawings and operational specifications. Satir [41] stated that installation space is very important for ship, which have limited free space for additional systems especially for active fleets, so installation planning must be planned carefully to produce durability that is able to determine operating time and the possibility of system failure.
7. Commissioning and integration
   After all the components are installed, there is a very important process, namely commissioning and integration, where this process is the determining process for the success of the BWTS retrofit by ensuring that the ship on which the BWTS has been installed operates well, in accordance with the manufacturer's standards and applicable regulations [42], [43]. By carefully implementing commissioning and integration protocols, stakeholders can ensure the functionality and performance of BWTS retrofits, thereby ensuring safe and efficient ship operations while complying with applicable regulatory requirements.

Retrofitting a Ballast Water Treatment System (BWTS) involves comprehensive consideration of various factors obtained from systematic observations covering various aspects based on aspects of the BWTS regulations. A thorough understanding of the international regulatory requirements outlined in the Ballast Water Management Convention by the International Maritime Organization (IMO) requires the establishment of a basic framework for retrofit decisions. This is done by compiling some of the latest developments in the D-2 standard governing the exchange of water ballast and the requirements for ship certification during navigation. This is also followed by an in-depth understanding of available water ballast treatment technologies that serve as an important decision-making tool, facilitating the selection of methods tailored to ship specifications and retrofit processes, from electrochlorination to ultraviolet (UV) irradiation and other advanced technologies. Then the retrofit process requires careful planning and systematic execution, incorporating elements such as 3D scanning for modeling, updating ship diagrams, prefabricating components, pipe installation, and integration of chemical storage tanks where possible. So a detailed analysis of technical, structural, hydraulic, and electrical aspects is also very important to ensure the retrofit design is in line with the operational objectives of the ship. Additionally, ensuring BWTS retrofits provide results that comply with certification requirements and regulatory standards is critical, requiring the development of a comprehensive natural resource management plan that includes ballast water exchange or treatment procedures and shutdown plans for maintenance and upkeep. By carefully considering these factors, stakeholders can navigate the complex terrain of BWTS retrofitting, ensuring compliance with regulatory mandates, operational efficiency, and environmental sustainability.

3.1. Several Analysis to Select Ballast Water Retrofit Method

In the process itself, BWTS retrofit has various challenges and problems. There are several studies that have carried out analyzes related to BWTS retrofit as in the Table 2.

Table 2. Previous research in selection of retrofit ballast water treatment system

Year	Author	Type of Method Analysis	Aspect selection	Type of BWTS
2017	Jee & Lee. [44]	Comparative feasibility study	- Technologies - Installation - Cost analysis	- Electrolysis - Ultra-violet (UV) - Ozone
2024	Domínguez et al. [45]	Experimental treatment evaluation	- Microbiological strains - Water matrices - Concentration - Experimental and data treatment	- Ozone
2023	Xiao et al. [46]	Experimental treatment evaluation	- Experimental design - Sample collection - Bacterial analysis - Statistical analysis	- Filtration + Ultra-violet (UV)
2022	Bailey et al. [47]	Opportunistic selection	- Sample collection - Field counts - Statistical analysis - Taxonomic identification	- Chemical - Electrolysis - Ultra-violet (UV) - Ozone
2022	Kim et al. [48]	Fuzzy AHP	- Economic - General - Operational - Equipment - External	- Electrolysis - Ultra-violet (UV) - Ozone - Filtration + Ultra-violet (UV)
2022	Chen et al. [49]	FAHP and TOPSIS	- Space - Functionality - Confidence	- Ultra-violet (UV) - Electrolysis - Deoxygenation - Ozone
2017	Karahalios. [50]	TOPSIS and AHP	- Costs and benefits - Maintenance - Power requirements - Treatment time - Footprint - Maximum height	- Ultra-violet (UV) - Electrolysis

Based on research over the past few years, many developments have been made to find the best solution for retrofitting ballast water treatment systems by combining existing treatment types. Each study brings out various aspects of BWTS methods, such as electrolysis, ultraviolet (UV) treatment, ozone treatment, and filtration, noting their existence based on various criteria such as installation, cost, treatment of microbiological strains, economic, and operational considerations. This analysis provides valuable insight into the selection and application of BWTS methods, assisting in the development of effective and sustainable ballast water treatment strategies. The common types that are used for retrofit BWTS research are ultra-violet and electrolysis. However, to do this, it is very important to consider aspect selection to maximize the efficiency of the BWTS due to differences in system requirements depending on the type of ship, voyage route, and the duration of the voyage like on the research that conducted by Pereira et al. [51].

4. Discussion

The ballast water treatment methods discussed in the previous section exhibit a range of advantages and disadvantages, each with implications for vessel operations, regulatory compliance, and environmental impact. Bailey et al. [47] highlighted the potential of BWTS to reduce high-risk introduction events, yet identified concerns regarding regulatory compliance due to Total Residual Oxidant (TRO) levels exceeding specified limits to determine the safety and consistently meets regulatory standards in terms of potential safety issues from a maintenance perspective. Domínguez et al. [47] emphasized the effectiveness and cost-effectiveness of ozone treatment, tempered by its lack of residual effect and the production of harmful by-products. That similar with Xiao et al. [46] by highlighted the effectiveness of filtration and real-time UV irradiation in reducing bacterial abundance while cautioning against potential risks such as the survival of pathogenic bacteria and the emergence of new species which can run optimally if supported by safety aspects of operation, and proper maintenance is very important to prevent BWTS system failure through routine maintenance, calibration, and monitoring of system components such as filters, UV lights, sensors, and control systems. Jee & Lee. [44] detailed the benefits of direct flow electrolysis and UV type BWTS, including practicality and affordability, offset by challenges such as the need for alternative chlorine sources and higher CAPEX for certain systems. Apart from that, it also discusses the safety aspects of UV type BWTS requiring precautions during operation and maintenance due to the potential danger of exposure to UV rays, with an appeal to follow the manufacturer's guidelines for safe use and maintenance to ensure efficient performance and safety. Kim et al. [48] underscored the importance of safety and eco-friendliness in BWTS selection just like Chen et al. [49] outlined the environmental friendliness and efficiency of UV BWTS, contrasted with concerns regarding water turbidity affecting treatment efficacy and potential harm from UV exposure. Karahalios [50] noted the effectiveness of UV and chlorine-based treatment systems in preventing the spread of invasive species, tempered by concerns related to corrosion and damage to tank biofilm structures and also a spotlight on safety aspects that emphasizes the importance of factors such as crew safety, prevention of marine pollution, and costs associated with the initial investment and maintenance of a BWTS. These insights underscore the complex considerations involved in BWTS selection, necessitating a nuanced understanding of each method's strengths and limitations in the context of specific ship operations and environmental conditions.

Based on several studies regarding the analysis of the selection of retrofit BWTS, it discusses the importance of aligning aspect selection with safety aspects that support the optimal performance of BWTS. The safety aspects in question include several important areas, namely the installation and design section, where special attention is required to the space required for the system for the type of method chosen, such as the filter system, the amount of total residual oxidant (TRO) solution, and the programmability of the BWTS control system. Environmental control also needs to be carried out to understand extreme weather conditions such as rain, humidity, and heat in the installation space as factors that support optimal system operation. Apart from that, BWTS maintenance planning is also included in the safety aspect, which must include spare part equipment, after-sales service, and identification of BWTS operation tests with the results in the form of reports by interested stakeholders such as ABS [52]. Areas that also include coverage of the BWTS safety aspect are ballast water management planning to control water quality by testing and controlling the amount of sea water used for the exchange ballast water process as stated in the guidelines for ballast water management and the development of ballast water management plans by IMO [53]. This is then followed by BWTS testing, with several coverages that include testing water quality, control systems, and consumption, followed by crew education and training in BWTS operations, where the resource training process through the ship's crew is the final key to ensuring overall operational safety.

To support the analysis of the choice of treatment methods that have been carried out, several innovative methods can be combined for consideration. This method is called hybrid technology, one of which is that used by Dong et al. [22] which combines three treatment methods consisting of filtration, membrane separation, and deoxygenation which uses pressure swing adsorption technology to produce pure nitrogen in water ballast tanks, thereby minimizing ship hull corrosion and providing corrosion protection for tank bulkheads. Then Dong et al. [54] also improvised another combined method, namely membrane separation and N2 deoxidation, which was equally effective in eliminating bacteria in fresh water and sea water at the same time and significantly reduced the number of bacteria and the density of indicator bacteria to meet the D-2 standard. However, some of these combination methods require several tests with a wider geographical scheme to determine the performance of the equipment, with increasing challenging water conditions as an additional consideration for international ships on long-distance voyages. Apart from that, some treatment combinations may also not be able to completely eliminate bacteria contained in water ballast, and variations in pathogenic bacteria differ from the pathogen parameters proposed by the IMO Ballast Water Management Convention. The system complexity may increase maintenance and repair costs, and complex integration between different technologies becomes a new challenge that arises. However, optimizing the hybrid system design to minimize maintenance requirements and increase ease of integration between its components using better compatibility standards can be considered to minimize risks.The next innovation is BWTS containerization, as carried out by Ishola & Kontovas. [55] by using mobile-port-based, which produces a high level of feasibility. However, this method may cause some problems because it requires additional space on the ship's deck, which can reduce space for other cargo and even affect the stability of the ship. In addition, the use of BWTS containers can increase the overall weight of the ship, thereby impacting fuel consumption and ship efficiency. These problems may be minimized by developing more compact and lightweight designs for BWTS containers and ensuring that their placement does not interfere with ship operations or limit space for other cargo. In addition, designing BWTS containers that are more modular, easily customizable, and offer more flexible alternative solutions, such as semi-container systems or direct integration with the ship structure, can also be considered.The modular approach itself can also be used as another alternative, where system components are installed in separate modules to facilitate installation and maintenance. Although potentially longer installation times and the risk of integration failure between different modules are drawbacks, improving module design can minimize these problems. Veldhuis et al. [56] stated that the modular concept of BWTS is an effective and fast tool to meet the requirements of IMO standards and measure existing organisms and their survival, but this must also be followed by factors detecting the presence and fate of pathogens in humans to produce testing protocols and effective and practical monitoring.

Another alternative that may help the operational considerations of the process is the use of 3D scanning technology for modeling and mapping the ship's engine room, which can also help ensure optimal placement of BWTS equipment during the retrofit process. This method uses 3D laser technology to capture topographic data from the ship's engine room to create precise 3D layout. The scanned image results are used to assist in the retrofit process and select a system that is suitable for the ship's engine room by reviewing aspects of the installation and maintenance process. 3D scanning technology also makes it possible to identify errors or difficulties that may occur during the BWTS installation process, making it possible to reduce costs and installation time. Mahmud et al. [57] state that the application of 3D scanning can lead to significant progress by promising to increase project results by a percentage of 25%, reduce project time, and save overall project costs by 15%. However, the use of 3D scanning technology has several disadvantages, including higher costs, potential errors in equipment calibration, and inaccurate data. To overcome this, steps such as choosing more affordable and effective equipment, as well as improving procedures for using equipment and data.

5. Conclusion

This article as a whole reviews the considerations for choosing the type of treatment for the case of retrofitting or adding a system to the Ballast Water Treatment System to fulfill the IMO policy regarding the Ballast Water Management System with emphasizes routine maintenance, calibration, and proper system monitoring to prevent system failure. The integration of innovative methods, such as hybrid technologies and containerization, offers promising solutions but presents challenges such as increased system complexity and space limitations. Selecting the optimal BWTS requires a deep understanding of the strengths and limitations of each method. Using 3D scanning technology for retrofits can simplify the process and increase the accuracy of system placement, although this has its own challenges, such as higher costs and the potential for errors. Integrating safety aspects into the BWTS selection and retrofit process is critical to ensuring optimal performance and regulatory compliance while minimizing environmental impacts and operational risks. It was found that the most efficient method is the ultra-violet (UV) treatment method because of its effectiveness in disinfection and deactivating organisms and pathogens. It also has other advantages, including being non-chemical, which does not require additional ingredients, does not affect water quality, has no potential damage to ships, and is the fastest treatment compared to the others, even though it is not combined with other treatments. However, it also has several disadvantages that can be overcome with more detailed planning and consideration. Beside that, ultra-violet is one of the two technologies most commonly used in BWTS, apart from electrolysis, which is suitable for various aspect selection and analysis methods used as considerations for selecting the type of BWTS.

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