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DESIGN AND FABRICATION OF A BALLAST WATER TREATMENT SYSTEM

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CERTIFICATION

This is to certify that this project, the Design, and Fabrication of a ballast water treatment system, was carried out by OKWUOSE CHUKWUKA HILLARY (ENG1805270),

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DEDICATION

This project is dedicated to God Almighty, the source of all wisdom, strength, and inspiration. In moments of doubt and challenge, His divine guidance has been the driving force and His grace has illuminated a path. To the families of each member of this group, for their endless support in love.

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ABSTRACT

In this study, we focused on the design and fabrication of an efficient combined [8] ballast water treatment system using chlorine, filtration, and heating. We aimed to compare the effectiveness and cost efficiency of this system with other individual treatment like chemical treatment, and filtration with active substances. Our research highlights [1] the importance of ballast water treatment systems in maintaining marine ecosystems, protecting human health, and supporting economic activities in the shipping industry. By evaluating the performance of our combined system, we contribute to the development of sustainable solutions [9] for ballast water treatment.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

Ships are constructed to move safely through water while carrying cargo. However, when a ship travels without cargo or only partially loaded, it needs additional weight on board to operate safely and effectively. This is where ballast comes in. Ballast is the extra material that keeps the ship deep enough in the water for efficient propeller and rudder operation. In the past, ships used solid ballast such as rocks, sand, or metal but since 1880, they have primarily used water as ballast because it's readily available and more economical than solid options. When a ship is empty of cargo, it fills with ballast water which is then discharged when new cargo is loaded onto the vessel.

The rise of global trade, initially with wooden sailboats and later steel ships powered by engines, has brought unintended consequences. Like many human activities, the increasing movement of ships across the world at higher speeds affects both the environment and human health. This includes spreading species beyond their native habitats.

The Millennium Ecosystem Assessment (2005) highlighted the significant impact that invasive alien species have had on islands in recent times. Furthermore, it predicted that this impact will only intensify over the next few decades, particularly with regard to inland waters and coastal areas. Invasive alien species (IAS) are now widely acknowledged as being one of the principal catalysts behind biodiversity loss, ecosystem functioning alteration, and changes in both supporting and provisioning services.

Although essential for the safe operation of ships, ballast water has been found to harbor various organisms that are inadvertently transported into the ballast tanks. Upon reaching their destination port and being discharged back into open waters, many of these organisms can survive long enough to establish themselves as invasive species in a new environment. This makes ballast water an important vector for introducing alien/non-native/non-indigenous species from one part of the world to another.

1.2 PROBLEM STATEMENT

The Ballast Water Management Convention, adopted by the International Maritime Organization in 2004, was set up to prevent the spread of harmful aquatic organisms from one region to another. Most of the invasive species were identified, and various treatment methods were established. Addressing invasive species is listed as a target under the United Nations Sustainable Development Goal, which calls on states, by 2020, to introduce measures to prevent the introduction and significantly reduce the impact of invasive species on land and water as statistic shows that there are about 7,000 species transferred every hour of every day.

Here are some problems associated with the treatment systems highlighted by IMO:

1. Cost concerns in relation to installation, operations, and maintenance of the system may be too high for the ship owner

2. Regulations about ballast water treatment are unclear or constantly changing, which presents issues for the maritime sector. Standards shifts or regionally specific requirements might cause misunderstandings, make it harder to comply with the law, and possibly postpone the adoption of the right technology to fulfill international regulatory needs.

3. Problems concerning the environmental efficacy 6 of ballast water treatment systems persist despite attempts to reduce dangers. There are still concerns about these systems' capacity to completely remove dangerous infections and invasive species, which casts doubt on their overall environmental impact and ability to protect maritime ecosystems.

4. Systems for treating ballast water must be rigorously maintained and monitored in order to function well. Ship crews and operators face operational problems in ensuring these systems function properly across a wide variety of vessels and environmental circumstances. Appropriate training and maintenance plans are necessary to prevent malfunctions or insufficient care.

5. It's possible that current technologies can't address every aspect of treating ballast water completely. To improve treatment efficacy and environmental protection, continual research and development are required since limitations in current treatment procedures can leave gaps in the eradication of hazardous species or pollutants.

6. Effective monitoring and enforcement [6] of ballast water treatment regulations present difficulties for the authorities tasked with overseeing adherence to them. Enforcement practices that are inconsistent and the requirement for strong compliance mechanisms can make it challenging to maintain regulatory standards in the maritime industry.

7. [2] Ballast water treatment system testing and approval are difficult and time-consuming procedures. The industry's readiness for compliance may be impacted by the need to ensure that treatment systems satisfy strict regulatory standards and complete extensive testing procedures before being deployed onboard vessels. This might delay the general availability of approved technology.

1.3 RELEVANCE OF THE PROJECT

This project is relevant in the maritime sector in helping ship owners decide which treatment system to include in their vessels to reduce the transfer of invasive species from one place to another while keeping both installation and maintenance costs minimal.

1.4 AIMS AND OBJECTIVES

This project work aims to compare the effectiveness and cost-effectiveness of Filtration, chlorination, heating, and the mixture of the three methods together as ballast water treatment methods. By conducting a thorough analysis, we aim to determine which method is most effective in reducing the presence of harmful aquatic organisms while considering the associated costs.

The objectives of this project involve:

● The comparison of the cost associated with implementing each treatment method.

● Compliance with international regulations

● The creation of a reliable and safe means of treating ballast water.

1.5 SCOPE OF THE PROJECT

The scope of this project involves the evaluation of the cost-effectiveness of different ballast water treatment methods which include;

1. Filtration
2. Chlorination
3. Heating
4. Combination of all three systems.

A model is fabricated to carry out this analysis. The study will examine their impact in reducing harmful organisms and contrast each other's cost-to-efficiency ratios, all while keeping to IMO regulations.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Ballast water is a crucial component of maritime transportation, used to stabilize ships by adjusting their weight and balance. However, the transfer of ballast water has inadvertently led to the spread of invasive species and sediments, causing significant environmental damage in coastal waters worldwide. [7] To address this issue, various technologies have been developed for treating ballast water before discharge. This literature review aims to explore different [1] ballast water treatment system technologies and their effectiveness in mitigating the risks associated with ballast water discharge.

Ballast water, used to stabilize ships at sea, has been identified as a significant vector for the spread of invasive species and sediments across different marine environments. The introduction of nonindigenous species through ballast water poses serious ecological and economic threats, prompting the need for effective treatment systems to mitigate these risks. Various technologies have been developed and studied to address the challenges associated with ballast water management. This literature review aims to provide an overview of the different [1] ballast water treatment system technologies, their applications in the maritime industry, advantages, disadvantages, and the need for further research in this critical area.
Overview of [2] Ballast Water Treatment System Technologies The review of ballast water treatment systems reveals a range of techniques employed in the maritime sector to combat the spread of invasive species. These technologies include physical treatments, chemical methods, as well as systems utilizing heating and electric field technology. Physical treatment methods are highlighted as simple, sustainable, cost-effective, and environmentally friendly options for treating ballast water. On the other hand, chemical methods are noted for generating disinfection by-products that may have implications for

environmental and human health. Systems combining heating and electric field technologies are considered more expensive but offer consistent effectiveness regardless of variations in ballast water composition or environmental conditions.

Challenges and Considerations One of the key challenges identified in implementing [1] ballast water treatment systems is the need to balance efficiency with environmental impact. While each treatment technology has its strengths and weaknesses, no single method is deemed entirely efficient in managing microorganisms present in ballast water. Therefore, [17] there is a growing consensus on the importance of integrating multiple treatment techniques to enhance overall effectiveness and efficiency in controlling invasive species transfer through ballast water.

2.2 REGULATORY FRAMEWORK

The International Maritime Organization (IMO) adopted the Ballast Water Management Convention in 2004 to regulate ballast water practices on commercial vessels engaged in international voyages. The convention requires ships to develop specific ballast water management plans to meet prescribed standards for treating [4] ballast water and sediments. Compliance with these regulations is crucial for minimizing [20] the introduction of invasive species into foreign ecosystems and reducing ecological damage caused by untreated ballast water discharge.

Future Directions The literature underscores the necessity for continued research and practical implementation efforts aimed at improving existing technologies and ensuring a sustainable maritime ecosystem. Advancements in ballast water treatment systems are essential to address evolving [20] challenges posed by invasive species proliferation and environmental degradation resulting from untreated ballast water discharge.

[7] While various ballast water treatment system technologies exist with their respective advantages and limitations, a holistic approach that combines different treatment methods is recommended for enhanced efficacy in managing invasive species transfer through ballast water.

2.2.1 INTERNATIONAL MARITIME ORGANIZATION [2] CONVENTION FOR THE CONTROL AND MANAGEMENT OF SHIPS' BALLAST WATER AND SEDIMENT

The International Maritime Organization (IMO) released a set of proposed regulations for ballast water management methods in February 2004 following more than ten years of deliberation, negotiation, and stakeholder input. Without these kinds of guidelines, the lack of clarity regarding the discharge conditions of ballast water and the requirements for specific treatment practices has significantly hindered the development of ballast water technology. According to the proposed regulations, the primary method of managing ballast water will be empty-refill or flow-through ballast water exchange (BWE) until 2009. Following this, and between 2014 and 2016, ships will no longer be able to load or discharge untreated ballast water due to a performance standard [8] for ballast water treatment systems not being satisfied. The criterion calls for less than 10 live organisms per milliliter of organisms between 10 and 50 μm in size, [2] less than 10 viable organisms per cubic meter of minimum dimension larger than 50 μm, and particular requirements for indicator bacteria and Vibrio cholerae. The introduction of these proposed laws may have the biggest global impact on research into [23] ballast water treatment technologies, and as a result, the development and deployment of these systems will likely happen much more quickly.

2.3 CURRENT [4] BALLAST WATER TREATMENT SYSTEMS

2.3.1 PHYSICAL TREATMENT

Physical treatment methods involve processes such as:

● Filtration and physical separators: Filtration involves the removal of organisms and particles from ballast water by passing it through physical barriers such as screens, meshes, or membranes, while physical separators such as hydro-cyclones utilize the centrifugal force of vortices to separate the organisms from the water. Filtration systems may utilize different pore sizes and configurations to target specific organisms but must be within the maximum allowable size listed by IMO, which is between 10 and 50 µm (please refer to section 2.2.1) ensuring comprehensive treatment. Filtration may be the least harmful to the environment when it comes to eliminating non-native species from water because they don't include any harmful ingredients. Large-scale research frequently investigated physical separation and filtering methods in conjunction with UV light or the addition of chemical biocides to inactivate organisms. In an ideal situation, the treatment system would be implemented as soon as water is brought aboard a ship. The material gathered [10] by the physical separation systems or filtration media following backwashing would either be released in the area where the ballast water is being loaded, or, in a less ideal situation, retained and subjected to additional treatment (i.e., inactivation of the organisms) before disposal.

● Ultraviolet (UV) irradiation: Ballast water is disinfected using UV radiation by subjecting it to UV light, which breaks down microorganisms' DNA and prevents them from procreating. UV lamps are usually placed inside tanks or pipelines carrying ballast water in UV treatment systems. This technique is appropriate for ongoing treatment while traveling because it provides quick and effective disinfection without the use of chemicals. One benefit of UV treatment is that, unlike chemical biocide applications, no residuals are left behind. However, turbidity (such as that seen in some coastal ports) decreases the effectiveness of UV treatment. Furthermore, inactivation by UV of bigger, aquatic species seems to be restricted.

● Heat Treatment: This process entails raising the ballast water's temperature to a point where aquatic life becomes fatal. This can be accomplished by passing water through heat exchangers or by directly injecting steam. Numerous species, including bacteria, viruses, and larger creatures like larvae and zooplankton, are efficiently eliminated by heat treatment. [16] On the other hand, vessel-specific limitations and energy usage may need to be carefully taken into account while applying it. On board the Bulk Carrier Iron Whyalla, an experiment was conducted at sea utilizing hot water that was pumped through a ballast tank by the ship's main engine (Rigby et al., 1999). The researchers' microscopic examination of samples from heat-treated ballast tanks revealed as per Kazumi 11's findings, that heating ballast water to 38°C for multiple days was adequate to eradicate all zooplankton and a significant percentage of phytoplankton. Although there were initially some worries about how a greater temperature may affect the corrosion [9] of ballast tanks, the researchers discovered that the impact was negligible.

- Deoxygenation: By lowering the amount of dissolved oxygen in ballast tanks, deoxygenation seeks to make the environment uninhabitable for aquatic life. Inert gases, such as carbon dioxide or nitrogen, can be injected to do this. These gases displace oxygen and provide anoxic or hypoxic situations. Deoxygenation reduces the risk of corrosion and other negative impacts on vessel construction while efficiently suppressing the life of aerobic organisms. Deoxygenation as a possible ballast water treatment technology was shown to be technically feasible through shipboard trials where oxygen was removed from ballast tanks while a steady supply of nitrogen was provided (Tamburri et al., 2002). Within the lab, after subjecting three invasive invertebrates—the zebra mussel, Dreissena polymorpha, and the polychaete Ficopomatus enigmaticus—to hypoxic conditions (O_2 levels of 0.8 mg L^{-1}) for two to three days, the researchers found that only 20% of the invertebrates survived. Therefore, this technology would not be a good fit for ships that would be making short transoceanic voyages, but it might be appropriate for those that would be making longer ones.

Physical treatment is often considered [24] simple, sustainable, cost-effective, and environmentally friendly compared to other methods.

2.3.1.1 EFFECTIVENESS OF PHYSICAL TREATMENT

Processes like heat treatment, UV radiation, and filtration are examples of physical therapy approaches. These techniques effectively eliminate or destroy the organisms [9] found in ballast water without polluting the environment with hazardous chemicals or byproducts. By physically enclosing organisms and sediments, filtration systems can stop them from discharging into uncontaminated areas. It is well known that UV light has the power to damage microorganisms' DNA, making them dormant and incapable of procreating.

2.3.1.2 ADVANTAGES OF PHYSICAL TREATMENT

One of the key advantages of physical treatment is its simplicity. These systems are relatively easy [2] to install and operate compared to chemical or advanced treatment methods. They also have lower operational costs since they do not require the constant addition of chemicals or reagents. Furthermore, physical treatment methods are environmentally friendly as they do not introduce potentially harmful substances into marine ecosystems.

2.3.1.3 CHALLENGES AND LIMITATIONS

Physical treatment techniques can be limited when dealing with specific types of organisms or significant levels of contamination in ballast water, notwithstanding their general effectiveness. For instance, these techniques might not be sufficient to completely eradicate larger organisms or those that are resistant to physical therapies. Furthermore, variables like water temperature, [6] salinity, and ballast water composition can affect how successful physical treatments are. Because physical treatment is easy to use, affordable, and environmentally friendly, it is a valuable part of ballast water treatment systems. Combining physical treatments with other methods can improve overall efficacy in treating microorganisms in ballast water, even if it might not be a stand-alone solution in all situations.

2.3.2 CHEMICAL TREATMENT

● BIOCIDES: are disinfectants that have undergone testing to see whether they can get rid of invasive species from ballast water. Marine life in 1 the ballast water is eliminated or rendered inactive by biocides. To avoid 4 discharge water from becoming naturally poisonous, biocides used as disinfectants for ballast water must be both effective against marine life and easily biodegradable or removable. Biocides are further divided into oxidizing and non-oxidizing

i. Oxidizing biocides: These are substances used to inactivate organisms in ballast water that are general disinfectants like chlorine, bromine, and iodine. Disinfectants of this kind work by eliminating the organic components of germs, such as nucleic acids and cell membranes. Among these are inorganic agents such as chlorine dioxide (ClO_2) and hypochlorites (e.g., NaOCl). Other oxidizing biocides include hydrogen peroxide (H_2O_2) and ozone (O_3). Oxidizing biocides are general disinfectants and act by destroying organic structures, such as cell membranes, or nucleic acids.

o Chlorine: Chlorine is a commonly used chemical method for treating ballast water to control and eliminate the transfer 6 of harmful aquatic organisms and pathogens. Chlorination involves the addition of chlorine-based chemicals to ballast water to disinfect and kill organisms present. Sano et al. (2004) reported that sodium hypochlorite was effective in freshwater against the oligochaete Lumbricus variegatus and the cladoceran, Daphnia magna.

o Hydrogen peroxide: is another chemical method used for treating ballast water to control the 27 transfer of harmful aquatic organisms and pathogens. A mixed assemblage of marine plankton, dominated by both planktonic adult and larval stages of benthic crustaceans, [19] was found to be fatally affected by hydrogen peroxide at concentrations of 1, 3, and 10 ppm by Kuzirian et al. (2001). The plankton was taken from the waters surrounding Woods Hole. MA. Depending on the H2O2 concentration employed, the period for 100% death, which was defined as [18] the point at which the organisms stopped swimming and did not respond to tactile stimuli, varied from 5 to 35 minutes.

o Ozone: is a powerful oxidizing agent that is commonly used as [2] a ballast water treatment method to control and eliminate the transfer of harmful aquatic organisms and pathogens. A 4-log inactivation of marine dinoflagellate cysts, Amphidinium sp. cysts, needed high ozone concentrations of 5 to 11 mg L–1 and up to 6 h of residual contact, according to an experiment. The scientists came to the conclusion that because ballast tanks have places with large levels of debris and locations where corrosion is present, "ozonation is likely to be a difficult technology to implement for organisms with this ozone requirement" [1] (Oemcke and van Leeuwen, 2005). According to the experiments mentioned above, extended contact times (hours to days) were necessary for ozone therapy of organisms in saltwater to be effective. These findings were surprising because ozone is a well-known strong oxidant—even more so than free chlorine. Its actions are biocidal and happen quickly.

ii. Non-oxidizing biocides: Non-oxidizing biocides are a class of disinfectants that, when applied, obstruct an organism's ability to reproduce, operate neurologically, or utilize its metabolism. Among these are glutaraldehyde and commercially available agents as Peraclean® Ocean and SeaKleen®. Non-oxidizing biocides work by disrupting an organism's ability to reproduce, operate neurologically, or utilize energy.

o Glutaraldehyde: In biochemistry, glutaraldehyde is employed as a fixative and amine-reactive Hom-bifunctional cross-linker. Through protein crosslinking, it rapidly destroys cells. Typically, it is used as the first of two fixative procedures along with formaldehyde to stabilize specimens like bacteria, plant matter, and human cells. Following tests using sediment samples from NOBOB (No Ballast On Board) ships, it was suggested that 90% of organisms might be killed by a glutaraldehyde concentration of at least 500 mg L-1 kept for 24 hours. Making use of this Sano et al. (2003) calculated the cost of treatment on the order of $5,000 per treatment (assuming a cost of roughly $17 per kg of glutaraldehyde), based on a concentration estimate and an assumed treatment volume of 200 metric tons (typical of a ship operating [2] in the Great Lakes). Other costs, such as hardware installation or field testing to demonstrate that biocidal concentrations were reached, were not included in this cost.

o Peraclean® Ocean: It has been claimed that Peraclean® Ocean (Degussa AG, Germany), another commercial biocide, is efficient in destroying marine creatures. Peroxyacetic acid (PAA) is the primary bioreactive component, while hydrogen peroxide (H2O2) is the secondary active component with mild bacterial biocidal properties. Concentration vs. contact time graphs revealed that, starting at an initial 150 mg L-1 concentration of Peraclean® Ocean, PAA rapidly decreased during the first five hours and almost completely disappeared by ten. In contrast, H2O2 decayed more slowly and remained present at 50 hours (Veldhuis et al., 2006). These scientists discovered in large-scale experiments that the injection of Peraclean® Ocean destroyed ambient phytoplankton and prevented regeneration, even after 40 days. It was noted that phytoplankton and zooplankton be abruptly interrupted. While H2O2 was present, bacterial growth was reduced; however, when H2O2 was removed, bacterial growth quickly resumed. The researchers calculated that if the technology was used on a full scale, an extremely large storage capacity (> 120 m3) would be needed to hold the chemically treated effluents, noting that one limitation of this technology was the need to store the effluent for at least 6 days before discharge was deemed safe.

o SeaKleen®: Menadione, sometimes referred to as vitamin K3, naphthoquinone, and its bisulphite are combined to create SeaKleen® (Vitamar, Inc.). According to lab tests, SeaKleen® works well against the oligochaete Lumbriculus and the freshwater amphipod Hyalella Azteca

variegates, with a predicted 24 hour lower limit of detection (LC90) of less than 2.5 mg L-1 (Sano et al., 2004). According to Raikow et al. (2006), SeaKleen® was similarly hazardous to the eggs of [8] freshwater cladoceran Daphnia mendotae, marine brine shrimp Artemia sp., and marine rotifer Brachionusplicatilis. The least sensitive material was discovered to be daphnia eggs, which had a 24-hour LD90 of 8.7 mg L-1.

2.3.3 COMBINATION OF TREATMENT TECHNOLOGIES

A few large-scale experiments have been carried out to examine the effectiveness of several treatment technologies sequentially to eliminate or eradicate the wide group of organisms found in natural waterways, at water flows of about 300 m3 h-1. The basic idea behind these experiments was to first remove larger particles and creatures (like phytoplankton and bacteria) that pass through separation technologies, and then treat the remaining smaller organisms (like phytoplankton and bacteria) with a biocidal solution. For instance, Sutherland et al. (2001) assessed a cyclonic first stage that was followed by UV treatment. They found that after the separation phase, invertebrates were dead or moribund (though there were insufficient data for statistical analyses), and that phytoplankton "grow out" experiments revealed the lowest concentrations and growth rates in those samples that were subsequently treated with UV. Large-scale tests were carried out by [22] Waite et al. (2003) with water from Biscayne Bay (FL), employing a hydrocyclone or a self-cleaning 50 µm screen as the initial treatment step, followed by secondary UV treatment. [17] The majority of the zooplankton was removed by the 50 µm screen, while hydrocyclonic separation proved to be unsuccessful. Following UV treatment, [6] the number of viable microorganisms was initially decreased; however, in samples kept, bacterial growth was seen.

The treated water that resulted from testing [2] a ballast water treatment system that included a hydrocyclone, screen, and biocide (Peraclean® Ocean) complies with IMO criteria for species in both size classes, according to a recent study by Veldhuis et al. (2006). When Viitasalo et al. (2005) tested the biocidal efficacy of ozonation, UV, ultrasonication, and H_2O_2 individually and in combination against a naturally occurring assemblage of zooplankton from brackish waters, they discovered that the most successful treatment that complied with IMO regulations involved a combination of UV (at a dose of 140 mW s cm^{-2}) and exposure to 15 mg L^{-1} H_2O_2 for 48 hours. Nevertheless, they suggested that to maintain reasonable energy costs, a physical separation phase should be implemented to eliminate the larger organisms.

THEORETICAL FRAMEWORK

The search engines ISI Web of Science®, OCLC FirstSearch®, and Google Scholar® beta version were used to find publications with the term "ballast water treatment" to begin the review of technical literature published since 1996 when ballast water treatment options [10] were discussed in Stemming the Tide (National Research Council, 1996). After duplicate references were removed, a master list of 234 references was created as of January 2007.

Of these references, 16 were reports from government and institutional bodies, while about 25 dealt with [4] ballast water treatment methods that were published in peer-reviewed journals. Conference proceedings accounted for around half of the references; the other references comprised patents, news stories, editorials, and peer-reviewed literature on relevant subjects (such as invasion biology and risk assessment). Additional sources of information included [28] the National Oceanic and Atmospheric Administration (NOAA) website, which listed projects funded under the Ballast Water Technology Demonstration Program from 1995 to 2006, and the International Maritime Organization (IMO) Globallast R&D Directory, which listed 66 projects worldwide. In an effort to reduce prejudice regarding the technology's efficacy, an effort was made to concentrate mostly on [4] ballast water treatment systems as they were described in the peer-reviewed literature using these information sources.

[25] The US Coast Guard Research and Development Center (USCG RDC) conducted a scientific assessment of four distinct ballast water treatment systems that were supplied by suppliers. According to the ensuing study, "the test programs lacked the level of rigor indicative of a scientifically sound test program, controls, sufficient replication, appropriate test protocols, and adequate experimental design" (Roderick, 2004). Therefore, assessing [26] ballast water treatment systems that were published in peer-reviewed journals was the main focus of this white paper. Ship operations depend on ballast water. Ballast water is necessary for both fully loaded and unladen ships to maintain proper trim during choppy seas and for stability and trim on unladen ships (Goncalves & Gagnon, 2012). Ballast tanks have the capacity to pump more than 150 000 metric tons of fresh or salt water, possibly containing live things, in one operation (Dunstan and Bax, 2008; Ruiz et al., 1997). There is a chance that numerous species will be carried and remain viable in the destination waters [16] as a result of the massive volumes of water being moved from one location to another (Ruiz et al., 1997). Usually referred to as non-native, invasive, or alien species, the broad definition of these species "includes any species reported to have become established."

Although the kind and route of the vessel [8] have a significant impact on the dispersion risk, ballast water on ships is thought to be the primary vector in the global spread of these invasive species (Seebens et al., 2013). Invasive alien species may affect [6] marine and estuarine ecosystems in ways that are ecological, economic, and health-related. The invasion of zebra mussels in the Great Lakes, as mentioned by Ruiz et al. (1997), is an example of an ecological problem that resulted in expenses of between 1,8 and 3,4 billion US dollars by the year 2000. Given that the Vibrio cholera infection can spread through ballast water, cholera is one illness that is indirectly brought on by ballast water (Ruiz et al., 1997). The Ballast Water Convention was accepted in 2004 by [1] the Marine Environment Protection Committee of the International Maritime Organization (IMO-MEPC) in an effort to curb the spread of invasive species. The treaty, which is expected to come into effect twelve months after the ratification of nations accounting for 35% of global merchant shipping tonnage, is still awaiting ratification by a few nations as of April 2014. In the meanwhile, local regulations have been implemented by certain nations, ports, or areas to stop the spread of exotic species by ballast water discharge. The United States Coast Guard (USCG) released stronger guidelines on March 23, 2012, to stop the discharge of untreated ballast water along American coastlines. This was a momentous occasion. The three main methods of managing ballast water that are often covered by these international and national rules are installing ballast water.

Because of the salinity, this water exchange lowers the amount of viable freshwater organisms in the ballast tanks (Briski et al., 2013). Exchange of ballast water is not always feasible due to primarily geographical reasons (certain shipping routes do not operate in mid-ocean).Consequently, BWTS offer a second option for bringing the number of organisms down to a level that poses little damage to the ecosystem or public health. Before ballast water is discharged into the harbor, ships must have technology that can clean it completely. Certain port-based system prototypes do not require the installation of a treatment unit on board; instead, they receive the ballast water from the vessel (King and Hagan, 2013).

CHAPTER 3

METHODOLOGY

The Study Involves;

a) Regulations and Requirement.

b) Proposed concepts.

c) Selected treatment system.

d) Design and Fabrication of Selected treatment system.

e) Monitoring and Maintenance

3.1 REGULATIONS AND REQUIREMENTS

The IMO’s BWM Convention requires ships [2] to install and use approved ballast water treatment systems that meet certain performance standards (see section 2.2) for reducing the number of [5] organisms in ballast water.
These regulations outline the standards that ballast water treatment for invasive species.

3.2 PROPOSED CONCEPTS

3.2.1 CONCEPT ONE: TREATMENT WITH UV LIGHT

FIG. 3.1 Proposed concept design for the treatment of ballast water treatment using Ultraviolet

3.2.1.1 CONFIGURATION

● Ultraviolet lamp: The UV treatment system's main parts are the UV lamps. They release UV light that is useful for disinfecting at particular wavelengths, usually in the UV-C region (around 254 nanometers). The lights are contained within UV-transmitting protective sleeves composed of quartz or related material that shields the bulbs from impurities and moisture.

● Ultraviolet treatment chamber: A specialized technology called an ultraviolet (UV) ballast water treatment system is used to treat bilge water aboard ships and other vessels. Water that ships take on board to help with stability and balance while cruising is known as ballast water. It is frequently absorbed from one place and released at another. But when introduced into unfamiliar habitats, a variety of organisms—including bacteria, viruses, algae, and even invasive species—can be found in this water and represent a threat to the environment.

● Filter: A crucial stage in ballast water treatment systems is filtering. These systems are intended to eliminate or neutralize chemicals and possibly hazardous organisms from ballast water, which ships absorb to remain stable.

● Ballast pump: The ballast pump is a vital part of a ballast water treatment system that handles the intake, circulation, and release of ballast water. Transferring ballast water into and out of the ship's ballast tanks is its main duty.

3.2.1.2 LIMITATIONS

● Limited penetration: Because UV light can only penetrate so far, it might not be able to properly cure water that contains a lot of suspended particulates or turbidity. The 5 water may not be sufficiently disinfected by UV light if it is murky or has a high particulate matter concentration. Generally speaking, UV treatment works well against bacteria, viruses, and certain kinds of algae and plankton, but it might not work as well against larger creatures like zooplankton, larvae, and cysts of particular species. Certain organisms might be protected from UV radiation by other 2 particles in the water or might have built-in defenses against it.

● Energy Consumption: To produce and sustain UV light, UV treatment systems need energy, which can raise operating expenses and energy consumption on board ships. Even with recent improvements in energy economy, UV systems still need a certain level of power to function properly.

● Maintenance Requirements: To maintain optimal performance, UV bulbs need to be updated and monitored regularly because they deteriorate over time. UV bulbs that have been fouled by biofilms, mineral deposits, or other materials may become less effective and need to be cleaned or replaced.

● Safety Concerns: When installing, operating, and maintaining UV treatment systems, safety measures must be taken because exposure to UV light can be hazardous to human health. 9 To reduce the risk of exposure, personnel handling UV lamps and equipment must be properly trained.

● Regulatory Compliance: Although regulatory organizations like the IMO acknowledge UV treatment as a valid method 4 for treating ballast water, different jurisdictions may have different requirements and particular norms. To comply, ship operators must make sure that their UV treatment systems adhere to all applicable laws and guidelines.

3.2.2 CONCEPT TWO: HEAT TREATMENT

Fig 3.2 Proposed concept design [8] for the treatment of ballast water using heat

3.2.2.1 CONFIGURATION

Similar to the configuration of the Ultraviolet treatment, but with the presence of a heating element and the absence of the Ultraviolet chamber. This method depends on the Filter to remove [1] the majority of the organisms present in the water and utilizes heat to finish off any organisms that manage to pass through the filtration process.

3.2.2.2 LIMITATIONS

● Energy Consumption: Heat treatment needs a substantial amount of energy to bring ballast water's temperature up to the required levels for efficient treatment. It may be expensive to operate due to its high energy consumption, particularly for big boats.

● Time-consuming: It can take some time to heat [6] ballast water to the proper temperature and keep it there long enough to guarantee efficient treatment, particularly for ships with big ballast tanks. This may cause ballast operations to be delayed, which may affect vessel timetables.

● Heating Uniformity: [2] It can be difficult to heat ballast water uniformly across its volume, particularly in big tanks with intricate geometries. Temperature variations inside the tank could lead to some parts not receiving enough treatment, making them vulnerable to invasive organisms.

● Resistance of organisms: Different organisms may be more or less resistant to heat treatment. To effectively eradicate an organism, it may be necessary to expose it to greater temperatures or longer periods if it is dormant or encysted.

● Corrosion and Material Compatibility: Because heat treatment systems involve high temperatures, there may be a risk of corrosion to the ballast tanks and related equipment. Maintaining the integrity of the ballast system and preventing damage need compatibility with vessel materials and coatings.

● Safety Concerns: Managing high temperatures when operating heat treatment equipment can put crew members and the ship itself in danger. It is necessary to have the right tools and safety procedures in place to reduce these hazards.

3.2.3 CONCEPT THREE: CHLORINATION

Fig 3.3 Proposed concept design for the treatment of ballast water by chlorination

3.2.3.1 CONFIGURATION

This concept consists of the following configurations:

● The injection system: The injection system, which may include pumps, flow meters, and injection points placed strategically throughout the ballast water piping system, is in charge of adding chlorine to the stream of ballast water at a prescribed dosage rate.

● Stirrer: Enough mixing and contact time are needed following chlorination to guarantee that chlorine is evenly distributed throughout the ballast water and that target organisms are exposed to enough of it. To help with mixing, agitation devices or ballast water circulation systems can be employed.

● Filter: A crucial stage in ballast water treatment systems is filtering. These systems are intended to eliminate or neutralize chemicals and possibly hazardous organisms from ballast water, which ships absorb to remain stable.

3.2.3.2 LIMITATIONS

- Management of Residual Chlorine: Ballast water treated with chlorine treatments may include residual chlorine. If residual chlorine is released into delicate habitats, it may be detrimental to marine life. Consequently, to avoid detrimental effects on marine life, residual chlorine levels must be properly managed.

- Disinfection byproduct formation: When chlorine disinfects ballast water, it may react with the organic stuff in the water to generate disinfection byproducts (DBPs). Certain DBPs, such as haloacetic acids (HAAs) and trihalomethanes (THMs), can be hazardous to aquatic life and endanger human health if released into the environment.

- Limited Efficacy against Some Organisms: Chlorine is a powerful disinfectant against [24] a wide range of microorganisms, although some species of algae, protozoa, and encysted organisms may be resistant to it or require greater dosages to be effective. This may lead to insufficient therapy and the possible persistence of resistant microorganisms.

3.2.4 CONCEPT FIVE: MULTI-BARRIER APPROACH (FILTRATION + CHLORINATION + HEATING)

Fig. 3.4

3.2.4.1 CONFIGURATION

- Filtration: a backflush filter is implemented [8] to eliminate the need to keep stopping to change the filter when clogged.

- Chlorination: a chlorine dispenser is implemented to discharge a set amount of chlorine needed for the treatment of the water.

● Heating: a heater set [5] to the required temperature is implemented, to raise the temperature of the water to the set amount. For this reason, a temperature sensor is required to detect [21] the temperature of the water to raise or reduce the temperature.

3.2.4.2 LIMITATION

● Effects of Residual Chlorination: If treated ballast water is released into delicate environments, residual chlorine from chlorination may remain and pose a threat to marine life. It might be difficult to control residual chlorine levels to meet legal requirements without harming the environment.

● Organism Resistance: Over time, some organisms, including some kinds of bacteria, parasites, and algae, may become resistant to chlorination. This may make other methods of therapy necessary and less successful than chlorination as a treatment.

● Energy Consumption: Heating [6] ballast water to the necessary temperatures can be a significant energy use, especially when heating huge amounts of water. Excessive energy use can have a negative influence on the environment and operational costs related to energy production.

3.3 SELECTED TREATMENT METHOD

We selected concept five (combination of chlorination, filtration & heating) as the method to fabricate for various reasons including

● Its ability to combine the effectiveness of [9] both physical and chemical treatment systems into a single system.

● Its ability to be effective in regions where either of the single treatment systems would have been ineffective without combining with another system.

3.3.1 BREAKDOWN OF SELECTED METHOD

The selected method comprises three different systems (chlorination, heating & filtration) which are all 4 treatment systems on their own. The efficiency is therefore greatly increased because some limitations of one system can be handled by another system. Here is a breakdown of each system:

3.3.1.1 Filtration

This Process uses filters to physically remove organisms from the ballast water. The filters can be made of various materials, such as sintered metal, ceramic, or other filtration media. This method can be effective in removing large and medium-sized organisms from ballast water, such as phytoplankton, zooplankton, and some larvae.

Implementation

This will be first stage of treatment as it will remove organisms of a set size before moving to other treatments, it will have a backwashing ability to prevent clogs in the long run.

Filtration is effective against:

- Sediment and particulate matter
- Larger organisms like zooplankton and algae
- Some bacteria and viruses (depending on filter pore size)

Advantages

- High removal efficiency for larger organisms and sediment
- Can be 16 used in combination with other treatment technologies
- Relatively low energy requirements

Disadvantages:

- May not be effective against smaller microorganisms
- Requires regular filter maintenance and replacement

- Can be affected by water quality and sediment load

Regulatory compliance:

- [1] The International Maritime Organization (IMO) and the US Coast Guard have approved filtration as a ballast water treatment method.
- The IMO's Ballast Water Management Convention requires a minimum filter pore size of 50 microns to achieve the desired level of disinfection.

Overall, filtration is a crucial step [4] in ballast water treatment, helping to remove larger organisms and sediment, and can be used in combination with other technologies to achieve optimal results

3.3.1.2 Chlorination

This process uses chlorine-based solutions to disinfect and deactivate marine [1] organisms, such as bacteria, viruses, and algae that may be present in the ballast water. It is one of the most widely accepted ballast water treatment technologies that have gained regulatory approval from the International Maritime Organization. The chlorination method of ballast water treatment system is a chemical treatment process that uses chlorine or its compounds to disinfect and oxidize organic matter, bacteria, viruses, and other microorganisms in ballast water. This method is widely used due to its effectiveness and relatively low cost.

Implementation into selected system

- Chlorine addition: Chlorine gas or hypochlorite solution is added to the ballast water [17] depending on the nature of the water.
- Mixing: The chlorine is mixed [19] with the ballast water to ensure uniform distribution.
- Reaction time: The chlorinated water is [26] held in a tank or pipeline for a specified time (usually 1-2 hours) to allow the chlorine to react with the organic matter and microorganisms.

● Neutralization: After the reaction time, [5] the water may be neutralized with a reducing agent like sodium bisulfite to remove excess chlorine.

● Disinfection: The chlorinated water is then discharged into [18] the environment, where the residual chlorine continues to disinfect and oxidize any remaining organic matter.

Chlorination is effective against

- Bacteria (including Legionella)
- Viruses
- Fungi
- Algae
- Zooplankton

Advantages

- High disinfection efficiency
- Relatively low cost
- Well-established technology

Disadvantages

- Toxic to aquatic life if not properly neutralized
- Can react with organic matter to form harmful byproducts (e.g., trihalomethanes)
- Requires careful handling and storage of chlorine
- May not be effective against all types of microorganisms

Regulatory compliance

- The International Maritime Organization (IMO) and the US Coast Guard have approved chlorination as [2] a ballast water treatment method.
- The IMO’s Ballast Water Management Convention requires a minimum residual chlorine level of 0.5 mg/L for discharged water.

Overall, chlorination is a widely used and effective method for ballast water treatment, but it requires careful handling and monitoring to ensure environmental safety and regulatory compliance.

3.3.1.3 Heat treatment

A ballast water treatment system that uses heat is known as a thermal ballast water treatment system. This system heats the ballast water to a temperature high enough to kill most organisms that may be present in the water, without using chemicals or UV light. The heated water is then circulated through a heat exchanger or a thermal reactor to achieve the desired temperature. Heat treatment is a ballast water treatment method that uses heat to kill or inactivate organisms and pathogens in ballast water. This method is also known as thermal treatment or pasteurization.

Process of implementation

The ballast water is heated to a temperature of typically between 35°C to 50°C. The heated water is held at the elevated temperature for a specified time, usually around 30 minutes to 1 hour. The treated water is then cooled before discharge. Heat treatment is effective against Bacteria, Viruses, Fungi, Algae, and Zooplankton.

Advantages:

High disinfection efficiency

No chemicals or residues

Low maintenance

Environmentally friendly

Disadvantages:

Energy-intensive

Requires careful temperature control

May not be effective against all types of microorganisms

Regulatory compliance: [1] The International Maritime Organization (IMO) and the US Coast Guard have approved heat treatment as a ballast water treatment method. The IMO's [2] Ballast Water Management Convention requires a minimum temperature of 38°C (100°F) for at least 30 minutes to achieve the desired level of disinfection. Overall, heat treatment is a reliable and effective method [9] for ballast water treatment, offering a chemical-free solution that meets regulatory requirements.

3.4 FABRICATION PROCESS

The prototype was fabricated based on the chosen concept.

Firstly a frame was built to carry all the components of the system, then the filter was attached, for the sake of cost management a regular 5μm was used in place of a backwash filter.

Next a 50 liters clear plastic storage box, fitted with a backnut to simulate sea water is placed above the frame to serve as the supply of sea water through the system. It is connected to the filter by half inch pipes and elbows, and a ball valve is placed in between to shut off and on the supply to the system. The ballast pump in the concept diagram is removed as the system is expected to flow by gravity

The chlorine addition was done manually with the aid of a graduated syringe, thereby the chlorine dispenser was replaced to save cost. The stirrer was fabricated from iron rod firmly welded to a motor to perform the rotary motion for stirring.

A 20 liters electric water heater was used as the heating chamber for the system. The stirrer is mounted to the cover of the heater and the heater is to be the ballast tank.

The heater has an outlet to serve as the outlet for de-ballasting of the system. This setup allows for the testing of each individual treatment systems and also the combination of the systems.

3.5 Testing

The system was tested against parameters from existing systems to prove it's effectiveness in treating ballast water to international standards. These parameters include:

- Filtration efficiency: the International Maritime Organization recommends that the benchmark for Filtration of ballast water be at least 90% for particles larger than 50μm.

● Chlorine efficacy: Successful chlorination should result in residual chlorine concentrations 21 less than or equal 10µg/L of chlorine.

● Heat treatment effectiveness: Heat treatment processes typically aim to achieve temperatures of at least 50-60°C for 1 hour.

● Overall treatment performance: Reliable systems should demonstrate consistent performance over extended periods with minimal maintenance requirements.

CHAPTER FOUR

RESULT

4.1 TEST PARAMETERS

● Filtration efficiency

● Chlorine efficacy

● Heat treatment effectiveness

● Overall treatment performance

4.2 RESULTS ACQUIRED FROM TEST

Lab results detected the presence of both vibro cholerae and zooplankton in the water source.

Here is the breakdown of the lab result gotten from test 16 with respect to the laid out parameters:

Vibro cholerae

Zoo plankton

Verdict

Filtration (5µm mesh diameter)

organism was found in large quantity after filtering

Organism was not found in the filtered water

Filtration is effective on zooplankton but ineffective against vibro cholerae due to its size being smaller than the filter pores

Chlorination (5mg/L for 1 hour)

Organisms appears to be dead

Some Organisms appears to be dead, while some are still alive

Chlorination is effective more effective on vibro cholerae than on zooplankton

Heat treatment (60ºC for 1 hour)

Organisms appears to be dead

Organisms appears to be dead

Heat treatment is effective against both organisms at that temperature

Treatment

Vibro cholerae

Zooplankton

Verdict

Combined system (filtration + chlorination + heating)

Present in water but appears to be inactive

Absent in water

The combined system is more efficient as both organisms are dead and absent from water respectively

4.3 DISCUSSION

The table above shows that filtration with a 5μm filter was not as effective as chlorination and heat treatment on vibro cholerae, but was more effective on zooplankton due to its size which is larger than the filter pore diameter. This information provided above shows that the combined system of Filtration, chlorination, and heat treatment is more efficient than each individual systems as the discharge water possesses less discharge of organisms as required by regulatory authorities.

CHAPTER FIVE

CONCLUSION

5.1 CONCLUSION

[6] The International Maritime Organization Convention for the Control and Management of ships ballast water and sediments stated that the allowable size of organisms be < 10 live organisms per mm of between 10 - 50µm. Utilizing a combination of chlorine, filtration, and heating is an efficient approach [9] for ballast water treatment. This system [23] has the potential to effectively remove harmful organisms and meet the necessary regulations for maintaining marine ecosystems, protecting human health, and supporting economic activities in the shipping industry. It is cost effective as it is an efficient system that can be applied in any vessel type or size.

CHAPTER FIVE

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