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Review study of ballast water treatment system: Review of ballast water treatment system technologies.

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ABSTRACT

The transfer of ballast water is considered the major global pathway for spread of invasive spices and sediments in the aquatic environment, resulting to devastating impact in the coastal waters. There have been various technologies and studies been conducted to provide solutions on the problems caused by the ballast water. This review study discusses the various ballast water treatment system techniques and their applications been applied in the maritime industry. The physical treatment is most simple, sustainable, cost effective, and environmental-friendly technique among all others, and chemical methods always generates its relevant disinfection by-product, while treatment system employing both heating and electric field technology, are more expensive but their effectiveness is not affected by the ballast water composition, salinity, or temperature level of their surrounding waters. As each treatment technology has its strength and weaknesses, it can be concluded that no particular treatment technology has total efficiency in managing the microorganism, but the combination of various treatment techniques will be highly effective and efficient. There is a need for further research, and practical implementation towards improving the existing technology and obtaining a sustainable maritime ecosystem.

1. Introduction.

Ballast water from one country and discharge into a new country have been identify as a major pathway for the transfer of invasive species and introductions of pollutant sediments (Wang et al., 2021; Outinen et al., 2021). Around 84% of global ecosystems are affected by invasive species discharge through ballast water transfer (Molnar et al. 2008 ; Gollasch et al., 2007). The impacts of the spread of non-invasive species through ballast waters of ships include predation, water quality alteration, and spread of diseases like paralytic poisoning, cholera outbreak on human health and marine ecosystem (Strayer 2010; Gollasch and David, 2018). In managing this problem, IMO has adopted the international convention for control and management of ships' ballast water and sediments (Sukizaki et al., 2013; Jang et al., 2020). The convention was designed along with management standards such as the D-1 and D-2 discharge standards for both new and existing ships, with the aim of managing the spread of non-indigenous invasive species in the maritime ecosystem (Saebi et al., 2020; Lakshmi et al., 2021). While the D-2 regulation standard envisaged the long-term management solution which involves, the installation of ballast water treatment system, for the management and control of the spread of invasive species (Herdzik, 2018; Chen et al., 2021). In response, different vendors are rapidly pursuing extensive development of ballast water treatment system and research employing variety of techniques in the removal of microorganisms inside ballast water are being proposed constantly (Summerson et al., 2019; Apetroaei et al., 2018). As of February 15, 2022, a total of n ballast water management systems, involving mechanical methods (e.g., include filtration and separation), physical methods (e.g., includes ultraviolet light, ozone, heat, ultrasound), and chemical methods (using biocides) has been granted final approval by IMO has been published by Class-NK as approved ballast water management system in the market, (Class NK 2022). However, there are still some challenges with the current ballast water treatment technologies, affecting

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their efficiency in the treatment of ballast water qualities and resulting to environmental risk. In-line with this background, this study discusses the various ballast water treatment methods, examining their principles, system requirements, system advantages, technical challenges as well as assessing their efficiency.

2. Technologies applied for ballast water treatment.

2.1. Filtration technique.

Filtration is the process of passing the ballast water through disc or screen filters to remove organism and suspended solid particles settling in the ballast water. The filtration technique is mostly affected by the drops in pressure and reduced flow rate of the ballast water system due to the resistance in the filter elements during self-cleaning process. (ABS 2011). While these techniques have been proven to be efficient, other studies has also discovered their limitations. It was observed that more than 70% of phytoplankton and 90% of zooplanktons were removed from a crumb rubber/sand dual-media filtration system. It can be concluded that filters are prone to blockages and require regular replacement and back flushing. The effectiveness of filtration will not be influenced by the salinity of the water. As long as no ice is formed, it is unlikely that the performance of screen or disc filters will be affected by the water temperature. Crumb rubber filters might be more sensitive to arctic conditions as it can be expected that low temperatures will reduce the flexibility of the filtering material.

2.2. Hydroclone technique.

Hydro cyclones employs centrifugal forces for the separation of particles with specific gravity greater than water. Several studies have investigated the effectiveness of the hydro cyclone ballast water treatment technology and it has seen that this technique are easy to operate and maintain and are capable of removing larger organisms from ballast water due to the (Taylor and Rigby, 2001) The study conducted by Parsons & Harkins, 2002 shows that hydro cyclone process was unable to remove smaller biota organisms lesser than 20 µm including viruses, protozoa, bacteria, phytoplankton, chaetognaths and jelly fish. Recent developments aimed at improving the physical treatment techniques have resulted to the design and application of a variety of filtration and hydro cyclone techniques, such as slow and rapid sand filtration, screen filtration, cloth screens/filters, pre-coat filtration, disk filtration, crumb rubber filtration, membrane filtration, well filtration, and cyclonic separation are integrated into the treatment systems (Gregg et al., 2009; Kumar et al., 2021). Hydro clone could be considered to be an effective cost alternative to filtration in the treatment of ballast water. However, they can be said to be less effective than simple self-cleaning filtration techniques. Also, since hydro cyclones are designed to separate particles based on their masses, they are highly ineffective at removing organisms that have specific gravities very close to that of their liquid environment and particles smaller than 100 µm. The effectiveness of the hydro cyclone treatment system depends upon the difference in density and size of the particles contained in the ballast water, the speed of rotation and residence time and are less effective with an increasing salinity as this increases the specific weight of the water but may not affected by water temperature as long as no ice is formed.

2.3. Ultraviolet technique.

The ultraviolet (UV) treatment is based on sterilization process, by using UV lamps in providing photons which can attack and break down cell membranes of aquatic micro-organisms and pathogens, or destroying their ability to reproduce (ABS 2011, Lloyd 2010). As the ballast water passes through chambers that contain the lamps, the ultraviolet light is highly sensitive to many organisms, impacting the DNA of the organisms and renders them non-viable, or incapable of reproduction. The two basic types of UV-lamp technology include the low-pressure (LP) UV lamp which can emits UV-C radiation causing DNA damage, and the medium-pressure (MP) UV lamp emits UV-A, -B, and –C radiation resulting in damage to DNA, proteins, and enzymes (Rivas-zaballos et al., 2021; Romero-martínez et al., 2020). The major drawback facing the effectiveness of UV treatment technology consist of several physical and technical conditions, including the UV lamp source and its wavelength, the radiation dose, exposure time, light or dark storage conditions, temperature distance between applied field and light source, and the treatment conditions, such as the microbiological content, turbidity , salinity, and absorbing matter of the ballast water. However, UV can be affected by waters with low TSS (total suspended solids), as larger aquatic organisms limit its effectiveness but exhibits higher disinfection efficiency for smaller organisms such as bacteria and viruses compared to bigger organisms like microalgae (Gregg et al., 2009; Čulin and Mustać, 2015). The UV can cause degradation of suspended organic matter into dissolve organic matter (DOM), resulting to higher turbidity which can impair the UV transmission and becoming less effective. Also, formed by the ballast water disinfection using UV light irradiation are by-products such as aldehydes, carboxylic acids, organ halogens, nitrite, and bromate, while its success depends largely on the quality of the filtration system that precedes the treatment.

2.4. Heat treatment technique.

This technique involves the heating of ballast water until any organisms present inside of the ballast water are killed by the heat of the water. The technique is very convenient because it does not require any complex components that can generate harmful byproducts and has exhibited a higher efficiency even for moldy seawater (Wang et al., 2018). It has been observed that higher temperatures between the range of 40–55 °C has high efficiency and inactivation capability for killing microorganisms such as bacteria, phytoplankton, and zooplankton, as such aquatic microorganisms are highly sensitive to significant change in the ambient temperature of their environment. There are common ways to complete heating process, involves, heating the ballast water in their tanks or heating the water by running it past the ship's engines. The limitation involve in this technique is that they are only suitable for short distance voyage as a longer operating times is needed for heating up the ballast water. Also, an increasing energy demand is required to perform this process and possibility of corrosion on the surface of the ballast tank, due to the high heat generated.

2.5. *Ultrasound technique.*

The Ultrasound treatment technology uses high energy ultrasound to eliminate organisms in the ballast water. It is also referred to as cavitation treatment and are among the recently developed technologies that utilized ultrasonic resonator-based ballast water disinfection and anti-fouling applications for ballast water treatment systems. The high pressure caused by the ultrasound ultimately breaks down organisms' cell walls and killing them. Ultrasonic treatment is an attractive choice because it is having a lower maintenance cost and involve the use of non-chemical; however, research indicates that this ballast water treatment system works best when combine with other treatment methods like ultraviolent (U.V) or biocides method.

2.6. *Microwave treatment technique.*

This technique has been identified for solving the limitation posed by longer heating operating time in heat treatment method. Experimental studies have been used to show that microwave treatment technique can attain a higher heating temperature within a very shorter time range. Boldor et al. 2008 in his study has investigated the efficiency of a microwave treatment system in killing specific microorganisms, using a continuous microwave system and the result observed shows that the targeted microorganisms were inactivated at 55 °C in 200 seconds. Balasubramanian et al., 2008 has shown in his study on the efficiency using continuous microwave system with heat recovery to remove Artemia Salina cysts. The results obtained shows that the inactivation of Artemia salina cysts was achieved at 64 °C with 100 s holding time. However, all the results were obtained on a pilot-scale test condition at very low flow rates between 2 L/mins to 3L/mins. Its major limitation is that it requires higher energy and fuel consumption are required.

2.7. *Ozone technique.*

Ozone is one of the known chemicals' biocides, commonly used as ballast water treatment for killing living organisms by oxidation process. The use of ozone in the treatment of ballast water has shown to be unstable in different water condition because they react differently in seawaters as well as in freshwater. In seawater the ozone converts bromide, that is naturally present in seawater, into hypobromite ions and hypobromous acid, which is less effective, but longer lasting disinfectant (Kazumi 2007). As a result, ozone might thus be even more effective as disinfectant in marine water than in fresh water. The study, conducted by Oemcke and Van Leeuwen, 2005, confirms that the reason was because of the presence of bromide, Br^-, in seawater. further investigation on the effects of pH, presence of iron, and bacterial has shown that these environmental conditions can affects the efficacy ozone in seawater. Wright et al., 2007 and de Lafontaine et al., 2008 carried out an investigation using Bacillus subtilis spores as an indicator, under different simulated ballast conditions to test for the environment effects on the ozone treatment system. Their results confirms that ozone treatment technique is not a good choice for the control of spore-forming organisms in ballast water but may be suitable for the controlling other species. The main environmental drawback observed using ozonation techniques, include the uneven distribution of ozone in the ballast tanks, corrosion of ballast tanks, and regrowth of microorganisms. The residual chemicals and by-products generated are discharged into the environment and may cause residual toxicity at discharged waters.

2.8. *Electrochlorination (EC).*

The efficacy of electro-chlorination (EC) has been proven to can meet the IMO discharge standard for viable smaller plankton and bacteria in rivers and brackish water (Echardt and Kornmueller, 2009). The shipboard trial conducted in several studies, has shown that this technique has a higher rate of inactivation for different planktonic fractions (First et al., 2015; Tsolaki et al., 2010). However, major limitation of the electrochlorination (EC) is its higher cost when compared to others treatment system and their use of quenching agents to reduce the high levels of total residual oxidant (TRO). In his study, Gray et al., 2006 and Jang et al., 2020 in their separate studies, had used the electrochemical treatments in the removal of plankton from ballast water and the results shows an efficiency greater than 99%.

2.9. *De-Oxygenation.*

This treatment methods involve the installation of de-oxygenation plants on board ship, used in removing dissolved oxygen in the ballast water and injecting inert gases, such as nitrogen into the tank to asphyxiate the organisms. The removal of oxygen kills the aerobic organisms present in the ballast water, as well as reducing corrosion rates, provided that the oxygen content is maintained at the correct levels. This system is effective and can be used for both fresh or salt water as well as clear or turbid water. However, it requires a prolonged period of treatment time, as it takes two to four days for ensuring that the organisms and pathogens are rendered harmless to the receiving waters. Several studies have shown that the time required for achieving hypoxia is inversely related to temperature with much longer times needed in cold water. Hence, deoxygenation technique is not recommended for short transits voyages. The challenges encounter in this system is that the ships ballast tanks have to be sealed against atmospheric oxygen for it to be highly effective and low temperatures reduce the metabolic rate of organisms enabling them to cope better with low oxygen levels.

3. Discussion.

Physical and mechanical methods have a high level of efficiency, but for the removal of microorganisms, additional chemical methods are preferred. The short- and long-term effects of many system characteristics, especially those using active substances, are of greater concern, regarding their effects relate health risks**.** As majority of ballast water treatment using chemical methods always generates its relevant chemicals in varying amounts when discharged, which affects the coastal waters due to the accompany disinfection by-product. The release of certain disinfectant by-product (DBP) from treatment system employing the chemical method have been reviewed to be highly toxic and can result to the adverse problems to the marine organism leading to carcinogenicity, genotoxicity, cell cytotoxicity, and acute toxicity, to aquatic organisms. As for treatment system employing heating and electric field technology, there effectiveness is not affected by the composition, salinity, or temperature level of the ballast waters and maybe considered to be more suitable, but they still require higher energy for operations and may be feasible for shorter distance voyage. The deoxygenation technique is not dependent on water composition but at low temperatures it takes longer time for this treatment to become effective and are only applicable during longer voyage travels. The UV radiation, which is not influenced by salinity, but their performance is reduced in turbid water or water that is rich in (dissolved) organic matter which might cause problems under specific circumstances. The release of effluent into the coastal waters, the high energy consumption, cost of OPEX and CAPEX are also important issues been considered by in most of Ballast water treatment technologies. Based on our studies review, all treatment techniques are to some extent, effectiveness but has their pros and cons, and it can be concluded that the combination is necessary to cope with all conditions for providing a more effective result. Further studies and research are still needed to be carried out on improving the ballast water treatment system detection methods, post-treatment effects of the ballast water treatment organism and the improvement the chemical disinfectant on their impacts to the coastal waters.

Conclusions.

This study has reviewed the ballast water treatment technology and provides understanding on their operational mechanism, efficiencies, as well as their limitations. The assessment carried out on the current list of sixty-five approved ballast water treatment systems shows that 52% employs the Ultraviolence technology, 29% utilize electrochemical treatment, while the remaining 19% uses technological processes such as ozonation, ultrasound, the addition of biocides, or deoxygenation. As the qualities and constituents' particles of the ballast water to be treated, in terms of organic and inorganic matter, organisms, physical and chemical parameters are different, it can be concluded that, the effectiveness of each ballast water treatment depends on the application of the appropriate treatment technology. The use of physical method like filtration and hydro cyclones techniques has always results to a better primary treatment system as they effectively removing larger microorganism and sediments when applied at all maritime environmental conditions but since their performance are affected by smallest organisms, so additional treatment methods are always required to compensate their weaknesses. More studies and research in technology improvement is still needed to be carried out on the currently used ballast water treatment system as there has been instances, where certain type-approved ballast water treatment systems have been reported being noncompliant to the IMO discharge standards.

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