# Study on Ship Ballast Water Treatment Methods

Hangning Liu *

School of Southampton Ocean Engineering Joint Institute, Harbin Engineering University, Harbin, China

* Corresponding Author Email: lhn161@hrbeu.edu.cn

**Abstract.** With the rise of the world's maritime industry, the ecological and environmental concerns produced by ballast water discharges from ships are growing more and more significant, and can be hazardous to marine ecosystems, the marine economy, and human health. The ballast water management (BWM) convention from the International Maritime Organization (IMO) sets the rules for ballast water discharge and the two methods of ballast water exchange and ballast water treatment. Common types of ballast water management technology are introduced in this paper and the pros and cons of specific types of technology are explained. The research of this paper demonstrates that it is difficult for a single ballast water treatment system to achieve the D-2 discharge standard established in the BWM. More and more countries are increasingly supporting more efficient and environmentally friendly ballast water combination treatment systems. This paper may offer a reference for the development of ballast water treatment technology.

**Keywords:** Ballast water, Ballast water combined treatment, Marine ecosystem.

## 1. Introduction

Controlling the ship's trim, heel, stability, and other important factors requires the use of ship ballast water. Microorganisms, bacteria, eggs and larvae of other species, and even some large fish will invade the local ecosystem with the injection and discharge of ballast water, which will cause serious harm to the local marine ecosystem and the health of the residents. For example, Hallegraeff found that ballast water is one of the main ways of spreading harmful algae, toxic algae invasion, its reproduction, and secretion of toxic mucus will cause significant harm to local marine life, human accidentally eat contaminated shellfish and even affect health[1]. How to solve the ecological and environmental problems caused by ships' ballast water is a common problem all over the world.

The current basic ballast water technologies can be categorized into ballast water exchange(BWE) and ballast water treatment(BWT). Each ballast water treatment system has its own basic characteristics, so its efficiency is affected by different factors, that is, different ballast water treatment is adapted to different conditions. According to the BWT principle of ballast water management system(BWMS), BWT method can be divided into mechanical method, chemical method and physical method. Due to the difficulty of a single technology meeting IMO's ballast water D-2 discharge requirements, ballast water combined treatment technology is required[2]. The common ballast water combined treatment technology firstly separates and filters the ballast water by cyclone and then inactivates the harmful microorganisms in the ballast water using physical and chemical methods. Zhang found that the ballast water combined treatment technologies in China and South Korea mainly use filtration+electrolysis or filtration+ultraviolet (UV); the ballast water combined treatment technologies in Japan mainly use filtration+chemical; and the ballast water treatment technologies in Europe and the United States are more varied and innovative[3].

## 2. Classification of ballast water treatment methods

The BWM promulgated by IMO mentions the standards for installing BWMS, which stipulates two ballast water management methods: ballast water exchange (D-1 standard) and ship ballast water treatment (D-2 standard) [4].

Each ballast water treatment method has its own basic characteristics, that is, to a certain extent, impacts the application range and application effectiveness of the treatment system. The premise of

ship ballast water exchange is that the ship will remove and replace the ship ballast water with local seawater in the deep-sea area of the port of arrival in advance, so as to reduce the seawater pollution of the harbor. Ship ballast water treatment refers to the sterilization and inactivation of ballast water treatment using physical or chemical means.

### 2.1. Ballast Water Exchange

The method of BWE refers to the replacement of ballast water in waters deeper than 200 meters and more than 200 nautical miles offshore, where the ballast water exchanged in the deep sea from the ballast water loaded in ports is replaced with water from the deep sea. The BWM stipulates that when a ship carries out ballast water exchange, the volume of ballast water exchanged must be at least 95% of the amount of ballast water carried. The principle of sterilization is that organisms in offshore/far offshore waters cannot survive in deep/nearshore waters with different water quality, nutrient composition and other conditions[5]. Existing ballast water exchange methods is usually categorized into three types: flow-through method, empty refill method, dilution method.

#### 2.1.1. Flow-through method

It can also be considered as an injection method, the working principle is to pump clean seawater from the ship's bilge into the ballast tanks to discharge the original ballast water through the overflow, so as to achieve the purpose of ballast water exchange. The D-1 standard stipulates that at least three times the volume of the ballast tank must be excluded at the ballast water management convention. This method is simple to operate and does not easily change the ship's draught and therefore has a relatively small impact on the ship's stability. However, as this method puts a lot of pressure on pumps, water pipes and ballast tank plates, it is prone to the risk of damage to ballast tank related piping and structures.

#### 2.1.2. Empty refill method

The operating principle is to release the ballast water from the ballast tanks by pumps and reload clean seawater, therefore this approach can ensure the ballast water exchange thoroughly to the fullest extent.Compared to the flow-through method, the empty refill method is more susceptible to causing changes in the draft and stability of the ship during the discharge of ballast water. Moreover, this method usually involves emptying the water in a single ballast tank and reloading it, and then sequentially replacing the ballast water exchange in the remaining ballast tanks. Therefore, it will lead to changes in the local strength of the ship structure. This can lead to safety problems.

#### 2.1.3. Dilution method

It operates by pumping clean seawater into the ballast tanks from the top and discharging the ballast water from the bottom. Since the dilution method is a new sort of ballast water exchange technology, its connected ship structure and ballast tank pipes are different from those of previous ships, hence this method is only utilized on newly built ships and retrofitted old ships.

According to the relevant research found that when the ballast water is fresh water using ballast water exchange method can be achieved to a significant degree to reduce the risk of invasion of foreign organisms, however, for the same in the seawater environment of microorganisms. However, for microorganisms in the same seawater environment, the effect of this method may be difficult to meet the expected standard, and this method will also cause safety hazards to the ship. Therefore, for the ballast water exchange method itself needs to find a way to avoid the ship stability, draft difference, hull strength and other factors have an impact, but also will not impose additional water pressure on the hull structure of the innovation; Briski E et al. believe that BWE is difficult to meet the BWM stipulates the D-2 standard that is not able to meet the current demand for efficient treatment of ballast water on board ships, can only be used as a kind of transitional measure, and therefore other more efficient ballast water treatment methods are needed.

### 2.2. Ballast water treatment

According to its concept, BWT can be divided into mechanical, chemical, and physical methods. These methods treat ballast water as is required to ensure that it meets the D-2 discharge standard set by the BWM. As there are various types of ballast water treatment technologies, different ballast water treatment methods have distinct properties and are suitable for different settings.

#### 2.2.1. Mechanical methods

The principle of mechanical methods is to remove suspended solids from ballast water by means of sedimentation, filtration and separation. Two common methods of mechanical methods are filtration and rotary separation. The filtration method refers to the removal of particulate impurities through filtration devices, so it is usually considered to be the most environmentally friendly ballast water treatment method, but for microorganisms similar to viruses and bacteria should reduce the aperture of the filter and increase the filtration pressure and other means, which is easy to cause clogging of the filter resulting in reduced filtration efficiency and increased maintenance costs[6].

Cyclone separation method refers to the use of a specific device to make the fluid rotate internally, the centrifugal force generated by the high-speed water flow can throw out large particles with different specific gravity and microorganisms, which can remove majority of the microorganisms in ballast water, but it is not possible to separate microorganisms that have specific gravity comparable to that of seawater. However, according to Ren, it was found that the ballast water treatment system with a single rotary separation function has limited ability to remove harmful microorganisms from the water[7]. Therefore, mechanical methods have limited efficiency and cannot address ballast water treatment alone, but are frequently used in combination with other technologies such as physical or chemical approaches to achieve the D-2 discharge level of the BWM.

#### 2.2.2. Physical methods

The common physical methods are heating method, UV method and deoxygenation method. The working principle of heating method is to use high temperature to kill microorganisms[8]. At present, the main heating method is to heat the ballast water through the ship's power system directly or indirectly by using the waste heat generated by the ship, steam and other ways to heat. The use of the heating method will affect some of the water-cooled cooling system of the ship, and will have a negative impact on some of the ship's structure, pumps and pipelines[9].

The ultraviolet method utilizes ultraviolet light to kill microorganisms in the ballast water of ships, and studies have shown that the ultraviolet method can cause mutation of microbial DNA molecules and hinder the synthesis of microbial proteins. The UV method can kill most of the microorganisms in seawater, and it has obvious effect on the inactivation of bacteria, viruses and zooplankton. However, the inactivation effect of ultraviolet light is poor for algae, and the inactivation effect of ultraviolet light is greatly affected by the turbidity of seawater.

Deoxygenation method mainly uses nitrogen or carbon dioxide and other inert gases to expel the oxygen in the ballast tank, because the solubility of inert gases in seawater is greater than the solubility of oxygen, so it will produce a low-oxygen bad situation to achieve the purpose of microbial inactivation. However, carbon dioxide will modify the pH of the ballast water causing corrosion in the ballast tanks and so endangering the safety of the ship's hull construction.

#### 2.2.3. Chemical methods

Common chemical methods are electrolysis and ozone. Electrolysis works on the principle that the characteristic equipment electrolyzes seawater to produce chloride for ballast water microbial inactivation.Matousek et al. electrolyzed seawater by electrolysis to obtain a concentration of 3 mg/L NaOCl, and found that the removal rate of bacteria, phytoplankton, and medium-sized zooplankton was higher than 99%. Zhang found that when the effective chlorine concentration in seawater reaches 5mg/L, it can kill 99.85% of heterotrophic bacteria, 100% of Vibrio and 85.2% of E. faecalis; when the effective chlorine concentration reaches 20mg/L, it can kill almost all the bacteria in seawater; however, for killing the planktonic algae, it needs a higher concentration of effective chlorine[10].

However, the process of ballast water electrolysis produces many highly polluting and relevant chemical compounds, as well as erosive effects on the ship's hull.

The ozone method works by using the strong oxidizing properties of ozone to inactivate microorganisms in ballast tanks. Ozone is easily decomposed to produce a single oxygen atom can penetrate the cell membrane to decompose proteins, lipids and other macromolecules, destroying the growth and reproduction of bacteria and viruses[11]. However, ozone will aggravate the corrosion of the ship hull and cabin, and excessive ozone concentration will also have an impact on the health of the crew.

In summary, it can be seen that each treatment system has its own characteristics, such as freshwater ballast water can not use electrolytic seawater treatment device; turbidity ballast water can not use ultraviolet light treatment; the use of chemical killers and deoxygenation method is usually by the spring flow rate is not too great, but mainly to let the ballast water in the cabin preservation time to achieve the expected kill rate, this method may not be suitable for shorter voyage ships. Since it is difficult for a single technology to meet the IMO requirements for ballast water D2 discharge, studies using multiple technologies for combined treatment have emerged.

## 3. Combined treatment technology and application

Combined technology is the most effective method in ballast water combined treatment technology, and the current combined technology is generally based on mechanical treatment as the primary treatment, combined with physical, chemical or physical/chemical technology as the secondary treatment technology. Ballast water combination treatment can boost the inactivation efficiency of ballast water microorganisms, and can lower the cost of ballast water treatment, lessen the impact of ballast water on the environment.For example, Meng Chengxin and coworkers used a UV treatment system in combination with chlorine dioxide. They found that chlorine dioxide would photolyze with ultraviolet light and generate active substances that can inhibit algae cells; The Norwegian Optimarin ballast water treatment system, which is type-approved by the United States Coast Guard (USCG), adopts the "membrane filtration + ultraviolet" treatment method, which can effectively kill microorganisms, viruses and bacteria in seawater. This system has the advantages of being more environmentally friendly, low noise, light weight, and small footprint; China's BalClor ballast water treatment system adopts the "filtration + electrolysis + neutralization" combination, and it is Asia's first ballast water combined treatment system to be approved by the USCG type. Its workflow is to first use filters to flush seawater to remove particulate contaminants; then go through an electrolysis device to inactivate harmful microorganisms; and the final step is to use a 'neutralization' system to decrease the residual chlorine concentration in ballast water below the IMO value and discharge.

## 4. Conclusion

The ecological problems caused by ship ballast water are becoming more and more obvious, and the existing ballast water management methods are mainly categorized into BWE and ship BWT, and different technologies are adapted to different application environments and conditions. This paper provides a comprehensive overview of common ballast water exchange and ballast water treatment technologies. With the adoption of BWM announced by IMO, ballast water exchange technology can no longer meet the standards of ballast water discharge regulations, and it can only be used as a transitional measure.

Depending on the basis of ballast water treatment in BWMS, treatment methods can be classed into mechanical, chemical and physical methods. Ballast water treatment is an efficient approach to limit the spread of biological invasions and pollution caused by ship transit. With the adoption of the ballast water management convention, the diversity of ballast water treatment methods has risen rapidly and each has its own advantages. However, a single ballast water treatment technology has some drawbacks, such as the corrosion of the treatment technology on the ship, the safety of the

related equipment, etc. These drawbacks need to be further researched and solved. Therefore, many countries have started to promote ballast water combined treatment technology. Combined treatment technology has more safety, environmental protection, high efficiency and can be applied to different working environments.

## References

[1] Hallegraeff, G.M., 1992. Harmful algal blooms in the Australian region. *Marine pollution bulletin*, 25 (5-8), pp.186 - 190.

[2] Zhang Siyuan. The application research on ballastwater combined treatment system (Doctoral dissertation, Harbin Institute of Technology), 2015.

[3] Liu, Y., Jin, Y., Song, C., Wang, H., Wang, T. and Yang, Y., 2007. Environmentally sound ballast water treatment and resource utilization of ship ballast water sediments. *Journal of Dalian Maritime University: Natural Science Edition*, (S2), pp.167 - 168.

[4] Huang Jialiang and Li Pinfang, 2006. Introduction to the IMO International Convention on the Control and Management of Ships' Ballast Water and Sediments. *Maritime Technology*, (1), pp.46 - 49.

[5] Taylor, M.D., MacKenzie, L.M., Dodgshun, T.J., Hopkins, G.A., de Zwart, E.J. and Hunt, C.D., 2007. Trans-Pacific shipboard trials on planktonic communities as indicators of open ocean ballast water exchange. *Marine Ecology Progress Series*, 350, pp.41 - 54.

[6] Hou Yuehui, Feng Lijuan, Zhang Dahai, Yao Shuo and Li Xianguo. Research progress and application of ship ballast water treatment methods. *Environmental Science Survey*, 2018, 37 (S1): 90 - 94.

[7] Ren Fuan and Yin Peihai, 2005. Ship ballast water cyclone separation device. *Modern Ship Mechanical and Electrical Maintenance Technology* (2005).

[8] Thornton, G., Prentice, R. and Watson, M. The safe reuse of water using heat disinfection. *In Conference paper Enviro*, 2006 (Vol. 6).

[9] Li Bin and Sun Peiting. Feasibility Study on Ballast Water Heating by Waste Heat of Diesel Engine. *Journal of Dalian Maritime University: Edition of Natural Science*, 2001, 27 (2): 50 - 53.

[10] Zhang Shuohui and Guo Hao. Effects of Chlorination on the Survival of Alien Organisms in Ballast Water of Ships. *Environmental Protection in Transportation*, 1999, 20 (4): 14 - 15.

[11] Zhang Handong. Principle and Application of Ozone Disinfection. *Anhui Architecture*, 2000, 7 (6): 116 - 117.