Review article

Management of Wastewater From Ships and Options for Their Treatment

Vladanka Presburger Ulniković[1], Lidija Stamenković[2], Sanja Mrazovac Kurilić[1], Violeta Cibulić[1]

[1] Faculty of Ecology and Environmental Protection, University “Union-Nikola Tesla”, Cara Dušana 62-64, Belgrade, Serbia; E-mail: vladankap@gmail.com

[2] College of Vocational Studies, Filipa Filipovića 20, 17500 Vranje, Serbia

Abstract

Until recently, in the Republic of Serbia wastewater management of wastewater from ships has not been completely unregulated. There are several types of wastewater from ships, and each of them require specific treatment. In order to achieve satisfactory results in water pollution prevention from wastewaters originating from ships, one of perquisites is developed appropriate national regulations. Those national regulations harmonized with international laws in this field, can contribute to reducing the environmental pressure caused by this type of pollution. The subject of this paper is an overview of contemporary approaches to ship wastewater management, including advanced methods of their treatment.

Keywords: ships, water treatment, bilge water, sanitary wastewater, ballast water, monitoring.

Introduction

Waterborne transport is of enormous global economic significance regardless of whether it is freight or passenger transport. However, seas, rivers and the air are exposed to various negative effects of pollution produced by ships. The riskiest effects, ecologically, can be unintentional transport of foreign species to new environments and various waste materials which are produced by ships and discharged into the immediate environment. Additional adverse effects to the aquatic ecosystems are caused by the operation of the ship i.e. the ship hull movement, heat and noise, which are also significant. Discharge of wastewaters from ships has a wide range of short-term and long-term negative impacts on the environment, including on individual organisms, species or entire ecosystems (Jelavić and Kurtela, 2007).

For centuries, shipping, not only freight but also military and passenger, has represented a widespread mode of transport. Nowadays, a large number of travel agencies highlight nautical tourism as one of the most popular forms of tourism. The expansion of this type of tourism for the last 20 years has also influenced the development of nautical tourism in Serbia, especially over the past 10 years. The advantages of this kind of travel are many. First of all, the comfort, but also the safety and reliability of the trip are emphasized. However, this kind of travel has some disadvantages. The rapid expansion of this economic sector exerts pressure on the environment and natural resources. On the basis of sustainable development principles and adopted sustainable development goals, there is a need for protecting the environment and reducing the impact of pollution caused by ship transport and waste (Favro et al., 2010).

The quantity of wastewater produced by ships primarily depends on the type of ship. Accordingly, modern and recently made cruisers comply with environmental protection regulations. Modern cruisers have integrated systems for black and gray wastewater treatment, i.e. sanitary wastewater. These systems are called Advanced Waste Water Treatment Systems (AWTs), while older models of ships are required to pump out wastewater in port reception devices (EPA, 2008), or collecting wastewater in tanks from where it is transferred to wastewater treatment on floating facilities. These collecting tanks and devices are shall be constructed and tested in accordance with the provisions of the Technical Rules for Boats and Floating Facilities (Rulebook, 2017).

Three main groups of wastewater produced by ships are: bilge (oily), sanitary (black and gray), and ballast water. A large amount of wastewater is generated on passenger ships and large cruisers due to the extremely large number of people on board.

Bilge water on ships is oily water produced by different machine rooms, and also wastewater from ship warehouses, produced from the disposal of cargo residues and atmospheric precipitation. Information and data about the quantities of bilge water per vessel vary between 50 and 30000 liters of oily water delivered to a port reception terminal. According to some research, large ships produce 3-10 liters of oily water per day. However, the quantity of oily wastewater primarily depends on the type of ship, the size and engine condition.

Gray water represents water from sinks, baths, saunas, pools, laundry, galleys and water from the flushing of ship surfaces. Every passenger on a ship produces between 20 and 40 liters of black water, and about 120-340 liters of gray water daily. It is considered that wastewater generated per person on cargo ships is smaller - 20 liters of black water and about 115 liters of gray water per person per day (Presburger Ulnikovic et al., 2012).

Ballast water is a special type of vessel water that can generate pollution. However, the role of ballast water on ships is significant. Namely, ballast water is inserted into ships to save its elementary operation, namely, hull stress, which means better transverse stability and improve maneuvering characteristics. However, ballast water discharged by ships has a number of shortcomings which can have negative impacts that are reflected in aquatic pollution and disturbances of the natural balance in aquatic ecosystems. Ballast water discharge into the marine ecosystem contains various biological organisms, including different plants and animal species, and, when ballast water is discharged, under appropriate condition they may begin to dominate in the new ecosystem, and, consequently reproduce and become invasive species. This process leads to degradation of the natural balance and ratio of organisms in such an ecosystem. The negative impacts of this process can have harmful consequences on humans and the environment. In addition, it is estimated that passenger ships with a passenger capacity of 3000 people, produce between 55 and 85 liters of hazardous waste per day (Endresen et al., 2003). Many research studies address the issue of monitoring wastewater from ships, the quality of their treatment and their discharge (IMO-MEPC, 2008; Perić, 2016; China National Standard, 2018).

Serbia experience rapid growth of nautical tourism, which include ship transport on inland waterways, includes rivers, channels and lakes. Vessels used can be divided into: vessels owned and operated by private individuals consisting of small boats for 2 to 4 persons; charters i.e. motor boat and sail boat rentals for navigating rivers and lakes with small and medium vessels for 4 to 12 persons; river cruises – packages organized by tour operators and destination management companies consisting of larger vessels for groups from 20 and up to 300 passengers (Hrabovski-Tomić, 2008). A large number of foreign tourists visit Belgrade during organized Danube cruises. According to official data, Belgrade is visited by more than 400 cruise ships with about 50,000 tourists a year (Belgrade Port, 2019).

Potential Environmental Hazards From Ships

Ship pollution emissions have local, regional, and global impacts (Corbett and Koehler 2003). Many studies indicate that marine diesel engines are among the most fuel-efficient combustion sources for moving global resources and products. (Corbett, 2002; European Commission, 2002).

The expected environmental hazards from ships fall into the following categories: physical, thermal, chemical and biological. Noise will be a hazard on certain areas of the ship (e.g., the engine room). The potential thermal hazards are significant as wastewater from dishwashers and laundry is typically between 70°C to 80°C. Also, graywater pipes may become heated when they run next to steam pipes. Chemical hazards can be caused by the existence of noxious fumes, such as paint storage and chemical storage areas, or unsafe environments, such as the rope storage and chain lockers, but also from high amounts of soiled bilge water which have toxic, corrosive and

inflammable / explosive characteristics. Biological hazards can occur due to the presence of large amounts of different types of wastewater. For example, sanitary water, which is formed by mixing gray and black wastewater (sewage), may potentially contain blood or other potentially infectious material (EPA, 2017).

Shipping represents a source of growing environmental concerns both for inland waterways and oceans. These problems come from six major origins: routine discharges of oily bilge and ballast water from marine shipping; dumping of non-biodegradable solid waste into the ocean; accidental spills of oil, toxics or other cargo or fuel at ports and while underway; air emissions from the vessels' power supplies; port and inland channel construction and management; and ecological damage in consequence of the introduction of outlandish species transported on vessels (OECD, 1997).

Discharges at sea, whether legal or not, are unlikely to be detected by authorities. To limit them, a combined approach has been developed, that on one side seeks to prevent ships from discharging waste and on the other, makes ports provide adequate facilities to collect all sorts of waste from ships at reasonable cost (European Parliament, 2019).

Shipping also causes more invisible types of pollution. Recent concerns include the harmful environmental effects of species (often invasive) which are transported from one water area to another in ballast water tanks. Also, the bilge water includes high amounts of pollutants which have toxic, corrosive and inflammable / explosive characteristics. Untreated oily bilge water discharged directly into the ocean can damage marine life and a number of cruise lines have been charged with environmental violations in this regard elsewhere (Olorunfemi et al., 2015).

Methods for Ship Wastewater Treatment

UV treatment and electrochlorination have been the dominant technologies for ballast water treatment since long before the IMO Ballast Water Management Convention entered into force. UV treatment uses ultraviolet light to inactivate organisms as they pass through a reactor, whereas electrochlorination passes an electric current through saline water to produce oxidizing disinfectants. These disinfectants are active substances that inactivate the organisms in turn. Both technologies are proven and simple in principle. However, electrochlorination involves a wide range of safety, logistical and cost considerations that UV treatment does not. As UV solutions continue to grow smaller and more cost-effective, these considerations are leading many to re-evaluate electrochlorination's merits – even for large flows (Alfa Laval, 2018).

A sequential method - in this method the ballast water tank is first emptied and refilled with fresh ballast water to achieve at least 95% efficiency of exchange by volume.

- Flow through method - in this method the substitution of water is based on the process of pumping water into the ballast tank and allowing it to overflow in some other way. Three times the volume of the tank is the smallest volume of water that must flow through the tank.
- Dilution method - in this method the replacement ballast water is pumped into the tank through the top opening while simultaneously flowing out through the other opening at the bottom of the tank. During this process the same rate of water flows in and out of the tank is kept. Three times the volume of the tank is the volume of water that must flow through the tank.

The methods described have some specificities and those characteristics must be considered depending on the type of vessel selected. Vessel construction as well as the year of production influence what type of method is being used. The open sea replacement of ballast water is done in order to minimize the impact of ballast water in the ports. This method is effective because the marine organisms taken on in coastal sea waters are unlikely to survive when discharged into the open sea or ocean and vice versa. However, there are some disadvantages of this method, which are:

1. The process to remove the sediment and residual water from the bottom of the ballast tank is difficult,
2. The organisms that are adhered along the sides of the ballast tank or the other structural elements are difficult to completely remove and
3. Storms and unstable weather conditions lead to the question of the safety of ballast water replacement (Balaji et al., 2014).

There is a large number of various research methods for water treatment but, a scientifically grounded conclusion about the final method that can fully satisfy requirements and would find wider application on ships has not yet been established. Methods such as hydrocyclone separation and UV radiation have significant prospects for application on ships (Kurtela and Komadina, 2010). The combination of these two methods is based on treatment applications that can be performed during all stages of water ballast handling i.e. during ballast loading at the port of origin, the "en route" process, and ballast discharge at the destination port. The operational benefits of hydrocyclone and UV radiation on shorter routes, as well as in closed seas, can be decisive for the application of these methods.

One of the contemporary solutions for treatment of bilge water, sludge and ballast water is based on a membrane bioreactor system (MBR). MBR is used to separate purified water from the activated sludge. In this system, there is no need for a precipitator, which is an ideal solution for cruise ships. There is a large number of modern biological wastewater treatment plants, but most of them are based on the extended aeration process (Molland, 2008).

In the case of ballast water, there are two types of technological processes used for treatment: solid-liquid separation, which is based on the separation of suspended solids from ballast water by sedimentation or surface filtration, and disinfection aimed at the removal of microorganisms using physical or chemical methods.

One of the useful methods in the case of ballast water treatment is also the filtration process, which is performed prior to being stored in ballast tanks or discharged it into the waterway. This method is very useful and has a number of advantages.

One of the advantages is that during the process of filtration, retained organisms, which are potential pollution, can be returned to their natural habitat. However, with all the advantages, there are certain disadvantages when it comes to the filtration of ballast water. One of the major disadvantages of this method is that the process requires special devices which are expensive to install.

The treatment system for sanitary (black and gray) wastewater consists of five basic phases:

1. Pre-treatment phase,
2. Biological treatment of microorganisms,
3. Flocculation and flotation,
4. Fine filtration phase,
5. Final treatment with ultraviolet rays (Jelić and Mage, 2013).

The anticipated end result of implementing all of above-mentioned treatment phases is that the purified wastewater fully complies with the regulations and that it is absolutely safe for discharging into the environment. The sludge remaining after the flotation process goes to further processing in the appropriate plant.

Pre-treatment Phase

This phase of wastewater treatment is applied as a pre-treatment in order to protect and/or facilitate further purification phases. This purification phase includes methods of removal of bulk materials from wastewater, suspended particles, oils and fats (Rajaković and Rajaković, 2003).

Shipboard wastewater pre-treatment phase means mechanical purification and selection, or separation, where large particles are removed (papers, blankets as well as pieces of plastic) and solid fats. Pre-treatment of wastewater from ships is very important, because this prevents mechanical damage of equipment, as well as, clogging and blocking parts of the purification system in the following phases. The process of pre-processing is based on coarse filter meshes that are constantly rotating. Large particles in wastewater come to the grid on which large particles and solid fats remain and only the liquid part of the wastewater passes. The particles collected on the mesh are removed by a scraper and automatically lead to the sludge container.

Biological Treatment of Microorganisms

After the pre-treatment phase, wastewater goes to the mixing tank foreseen for biological degradation of organic matter. The mixing tank contains microorganisms that degrade organic matter under aerobic conditions. This phase of wastewater treatment facilitates the degradation of most of the organic matter contained in sanitary (black and gray) wastewater (Jelić and Mage, 2013).

Flocculation and Flotation

The wastewater from the mixing tank is further forwarded to the flocculation module. With the aid of flocculants and coagulants during the flocculation process, fine particles of organic matter and fat are aggregated into larger particles. These particles will be removed from the wastewater during the flotation process. During the flocculation process it is very important to constantly monitoring the pH value of wastewater. The optimum pH value for this part of the process must be between 6 and 9. In order to discharge wastewater from the ship after purification it is necessary to maintain this pH value. In order to control the pH value, a flotation tank is equipped with pumps that dispense the appropriate chemicals. The device on the flotation tank reads the values of the pH and sends a signal to the pumps that automatically dose the required amount of chemicals (Kolarec, 2017).

The next module in this phase is the flotation module. Therefore, wastewater then goes further into the flotation module. Flotation represents a physical treatment for the removal of solid particles and fats. During the process, an aqueous dispersion is created in the air drum from the mixing of air and water at a certain pressure (from four to six bars). The water saturated with air bubbles, is returned to the flotation module reappears, where the pressure rapidly reduced. This results in the formation of a micro balloon that is caught for previously concentrated particles of organic matter and fat in the flocculation chamber. The particles of organic matter and fat surrounded by these microbubbles float to the surface of the flotation chamber and can be removed from the surface as a precipitate.

Fine Filtration Phase

In the fine filtration process, residual particles from the water are removed using a filter mesh size of 40 to 60 μm. The particles and fats remaining on this filter are automatically removed using a device that is placed inside the drum and acts by twisting the filter mesh. In order to improve the entire process, a nozzle is installed from the outside of the filter, and it constantly cleans the filter with clean water. The fine filtration process may also include additional chemical treatment of wastewater. If the fine filtration phase does not produce good results, wastewater will be restored to the pre-processing process (Kolarec, 2017).

Treatment with Ultraviolet Rays

At the end of the process, purified water reaches the UV lamps. This is a water disinfection unit used to remove residual bacteria and viruses. The effectiveness of this phase of treatment inactivates 99.9% of bacteria and viruses. This purification method is environmentally acceptable, because it is not based on the addition of different types of chemicals such as, for example, chlorine. UV irradiation is performed either by low pressure (LP) or medium pressure (MP) UV lamps (Oguma et al., 2002; Werschkun et al., 2012). The advanced oxidation processes (AOPs) with UV-C can be a good alternative to managing the problem of ballast water, primarily for microorganisms. However, for larger organisms, there is more resistance, and, a filtration stage (by physical filtration or hydrocyclone) is usually required (García-Garay et al, 2018). Also, there is no change in the composition of the water and UV lamps have low power consumption (Kolarec, 2017).

Purified wastewater passes through a TSS (Total Suspended Solids) module prior to being discharged from the ship. According to the TSS index value, and the adopted regulations in this field, purified wastewater can be discharged from the ship, or returned again to the purification process. Also, the produced sludge is in the further processing process, which has two phases: dehumidification and sludge drying.

Conclusions

Vessels traffic is of enormous global economic significance regardless of whether it is freight or passenger transport. There are three main groups of wastewater produced by ships: bilge (oily), sanitary (black and gray), and ballast water.

The expected environmental hazards from ships fall into the following categories: physical, thermal, chemical and biological. The potential thermal and biological hazards can occur due to the presence of large amounts of different types of wastewater, for example, sanitary water. Recent concerns include the harmful environmental effects of species (often invasive) which are transported from one water area to another in ballast water tanks. Also, the bilge water includes a high amounts of pollutants which have toxic, corrosive and inflammable / explosive characteristics. Untreated oily bilge water discharged directly into the ocean can damage marine life and a number of cruise lines have been charged with environmental violations in this regard elsewhere.

One of the modern solutions for treatment of bilge water, sludge and ballast water is based on the membrane bioreactor (MBR). There is a large number of modern biological wastewater treatment plants, but most of them are based on the extended aeration process. One of the primary methods in use for treatment of ballast water is also the filtration process. The treatment system for sanitary (black and gray) wastewater, consists of five basic phases: pre-treatment phase, biological treatment of microorganisms, flocculation and flotation, fine filtration phase, final treatment with UV rays.

The results of implementating all of the above mentioned treatment phases for all types of wastewater from ships, fully complies with the regulations and it is absolutely safe for discharging into the environment. The results of applying the treatment of wastewater from ships, which are listed in this paper, are purified wastewater, fully compliant with the regulations and absolutely safe for discharging into the environment. With the application of legal measures and regular monitoring, the aforementioned wastewater treatments from ships will be a major advance in the preservation of clean water bodies and aquatic ecosystems.

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