Chapter

Oil–Water Separation Techniques for Bilge Water Treatment

Nurul Aini Amran and Siti Nor Adibah Mustapha

Abstract

Discharging accumulated bilge water from the ship is very important in order to maintain its stability and safety. However, the bilge water that contains contaminants, including waste oils and oily wastes, must be treated prior discharging to the sea. The International Convention for the Prevention of Pollution from Ships (MARPOL) has set strict oil discharge limit in order to minimize sea pollution. Thus, an efficient oil–water separator must be installed to separate the oil from the bilge water. This chapter introduces and discusses the working mechanisms, as well as advantages and disadvantages of the available oil–water separation techniques for bilge water treatment, which include gravitational, centrifugation, flotation, coagulation and flocculation, biological processes as well as absorption and adsorption.

Keywords: bilge water, oil/grease, oil–water separation, centrifugation, flotation, coagulation and flocculation, biological

1. Introduction

Shipping has a vital role in developing human society over the years, at which the shipping activities have linked the widely separated parts of the world through commercial relationships. In fact, the shipping industry is still developing from time to time with rapid industrial and digital economy growth. In Canada, the shipping industry has been established since 1840 and now undergone significant technological advances, where the size of ships that carry containers for international use continues to increase [1]. Even in Malaysia, the government has launched an initiative, namely, Malaysia Shipping Master Plan, that ensures the shipping industry is focused on developing itself and has a guide for future development. This initiative takes place from 2017 until 2022 with a “Revitalizing Shipping for a Stronger Economy” theme [2].

Generally, there are three main classifications for the global cargo shipping industry, which are:

i. Wet bulk: Transportation of crude oil and other petroleum products

ii. Dry bulk: Shipment of bulk goods

iii. Liners: Small shipments of general commercial goods

Each of wet bulk, dry bulk, and liner shipping needs their specialized vessels, which are tankers, bulkers, and container ships, respectively [3].

Firstly, for wet bulk shipping, approximately a quarter of the goods transported by sea is dominated by crude oil [4]. The oils are transported from its production point to the purchasers by the wet bulk shipping or known as tankers. Majority of the crude oil is moved from the most significant oil-producing region, which is the Middle East, to the dominant importers like the European Union, Japan and the United States of America. Other than that, North America imports oil from the Caribbean and West America meanwhile West and North Africa export their oils to Europe [4].

Next, the largest group out of these three classifications is dry bulk shipping, where more than 50% of all loaded goods are handled by the bulkers, while 30 and 16% are for tankers and containers, respectively [5]. There is a vast range of solid cargoes transported by containers. Generally, there are five primary crucial bulk goods, which are coal, grain, iron ore, bauxite, and phosphates, in which iron ore and coal are the two goods that are transported the most [4]. Meanwhile, chemical packages and steel products are the example of the shipped minor bulk goods [6]. The main routes for iron ore transportation are from Australia and Brazil to Japan as well as from Brazil to Western Europe. While for coal, which is commonly used as steam coal in power stations to generate electricity, the leading exporters are from South Africa, Australia, Colombia, the East and West Coast of the United States, as well as Indonesia. Moreover, Australia, South Africa, Colombia, and the East Coast of the United States export their coal to Western Europe, whereas Japan receives the coal from the West Coast of the United States, Australia, and South Africa [4].

Liner shipping, also known as container shipping, provides services by transporting goods in containers with scheduled sailings. The variety of goods transported by liner shipping are packed in a smaller unit. One of the contributors to the continuation and development of liner shipping is the increment of the digital economy. According to Ref. [7], companies that produce and process raw materials, commodities, and manufacturing goods are the previous world's fastest-growing and biggest corporations. However, currently, Internet-related service and technology-based manufacturers, such as Alibaba, Amazon, Apple, and Microsoft, have become the world's most valuable and most prominent companies, where e-commerce, online communication and cashless Business to Business (B2B) and Business to Consumer (B2C) transactions are practiced [7]. This development has contributed more to the growth of the shipping industry, where it is considered as a catalyst for economic development by facilitating world trade, due to the cheaper mode of transportation.

However, aside from on-the-ground activities such as lubricants, refineries, and petrochemical industries, it is undeniable that shipping activities have contributed to marine pollution, especially in this twentieth century where carriage of the cargoes by the ships is increasing. According to [8], millions of tons of oily wastes and waste oils are generated as the by-products of the ships, every year. One of the contributors to water pollution by the operating marine vessels is the discharging of oily bilge water. Typically for marine vessels, the oily wastes and waste oil that come from various sources accumulate in the bilge space, which is the lowest part of the vessel.

Routinely, the accumulated oily bilge water must be discharged out of the bilge spaces to maintain the stability of the vessel, hence eliminating the possibility of the ship to be in the conditions that can cause a hazard to it [9]. The wastes discharged can eventually cause water pollution, which leads to many negative impacts on the human, environment, and marine populations. Oily bilge water may poison marine organisms because it might cover plants and tiny animals when it floated on the surface of the water and is carried into the shoreline, causing life cycles of the plant and the respiration of the animals be interfered [10].

Hence, many governments and international industries are working on the marine pollution issue, mainly originated from the shipping industry, such as the Marine Environmental Protection Committee (MEPC), the International Convention for the Prevention of Marine Pollution from Ships (MARPOL), and the Department of Environment (DOE), Malaysia. In order to solve the problem, oily wastewater separator is essential and needs to be installed and operated effectively to prevent the pollution as well as to ensure that the water discharged overboard is within legal limits.

The lowest compartment of the vessels and directly above the keel is known as bilge, where water that drains off from various sources is captured. The water might be originated from rain, interior spillage, rough seas, or minor leakage in other main parts of the vessel. Depending on a few factors such as ship size, design of engine room, and components' age, the amount of accumulated bilge water onboard varies from one to another. In order to maintain the stability of the vessel and to avoid conditions that can cause hazard (such as vessel's propulsion systems and ancillary machinery damage and fire hazard) due to too much of bilge waste accumulation, it is crucial to remove the bilge water into a holding tank, periodically [9]. There are two options to manage the bilge water, which are whether installing bilge separator to treat it onboard or holding it in a tank on the vessel before discharging it to the shore's treatment facility. Somehow, treating it onboard has an advantage where a smaller volume of oily bilge water has to be stored in the vessel. Meanwhile, the treated wastewater can be removed according to the related regulations and standards.

The composition of bilge water depends on the design and function of the ship. The wastewater is commonly comprised of water, oily fluids, cleaning fluids, lubricant, and grease as well as other wastes that originated from piping, engines, and other operational and mechanical sources in the vessel's machinery spaces [9] as well as urine and chemicals. Other than that, extra waste streams in massive vessels contain sludge, waste oil, and oily water mixtures. Sludge is formed from the continuous fuel purification to remove contaminants in order to enhance low-quality fuels as well as to avoid ship's engines and highly machined components from being damaged.

2. Impact of bilge on marine pollution

The regulation stipulated by the International Maritime Organization (IMO) highlighted on the oil content of the bilge water discharged to the sea. The International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) has set the maximum limit of 15 mg/L for the oil content in the wastewater to be discharged to the sea. According to the US EPA (2008), passenger ships produce the highest amount of bilge water with huge difference as compared to the other types of ships. This is due to their more complex constructions and support for crowds of passengers [9].

Typically, the small volumes of treated bilge water are released above the water line and instantly diluted in the sea water. Hence, the obvious effects of oil spill is most likely not going to occur. However, a long-term effect might happen to the marine living organisms around the shipping lanes. The negative consequences that will take place may be due to the excessive concentration of biodegradable compounds, including oil, as well as continuous increment of nondegradable compound concentration such as metals [11].

Other than that, surfactant is one of the significant chemicals contained in the bilge water. The mixtures of oil and surfactants may cause higher toxicity since the oil and surfactants alone are toxic themselves. This may be due to the synergistic effects or the crude oil that has been dissolved, causing it to be consumable for the exposed organisms [12–15].

3. Current oil–water separation techniques

Typically, OWS is made up of three segments, which are separator unit, filter unit, and oil content monitor and control unit. The separator and filter units are included as treatment units, where many designs and different principles are applied. The gravity and centrifugal separators are commonly used as the first stage of the treatment, followed by other separation techniques, which is called as polishing treatment. The examples of the polishing unit are flotation, coagulation and flocculation, filtration, biological treatment, as well as absorption and adsorption [16]. Normal techniques, such as gravitational and centrifugation, are used for oily wastewater that has two distinct phases; meanwhile, addition of chemical or biological de-emulsification is required for separation of emulsified oily bilge water [17].

3.1 Gravitational method

Typically, oily bilge water treatment onboard starts with a gravitational method in order to remove heavy fractions and lighter fractions based on density difference. In this method, coalescing materials made of oleophilic polymer in the form of loose-packed media or parallel plate are used to attract the oil droplets to adhere to the plate [16]. Examples of oleophilic polymer used as the coalescing plate separators are polyethylene, fiberglass, and nylon [18].

The free-moving dispersed oil droplets continue to adhere to the plate or media until it can break from the coalescing material and float up to the surface of the tank. The presence of the oil detected by the sensors then automatically triggers the OWS to remove the collected oil to a waste oil tank. However, this method can only be effective when the phase of the oil and water is separated distinctively [19]. In other words, in some instances, the gravitational method is not suitable since the bilge water typically consists of emulsified oil formed due to the chemical emulsifiers (solvents and cleaning agents) as well as mechanical means such as ship's motion and transfer system pump [16]. **Figure 1** shows the gravitational separator process.

As can be seen from the figure above, as the oily bilge water flows through the parallel plate, oil globules are formed and float up to the surface to form oil layer. Oil skimmer is used to skim off the oil layer. Then, oil discharge valve and purge water valve are opened, where the oil is removed from the unit by the purge water.

3.2 Centrifugation method

Centrifugal separators are the alternative option for the gravity separators. The same principle is applied, in which the oil is separated based on the different density of oil and water as well as coalescence of the oil droplets. Somehow, the centrifugal acceleration causes the gravity to increase more, and the coagulation and flocculation processes are enhanced in order to separate the emulsified oil. This type of separator has many advantages as compared to gravity OWS. Since it can separate more oil from the bilge water, including emulsified oil, less oil content is loaded to the next treatment step, which is usually called a polishing unit. Thus, the polisher's

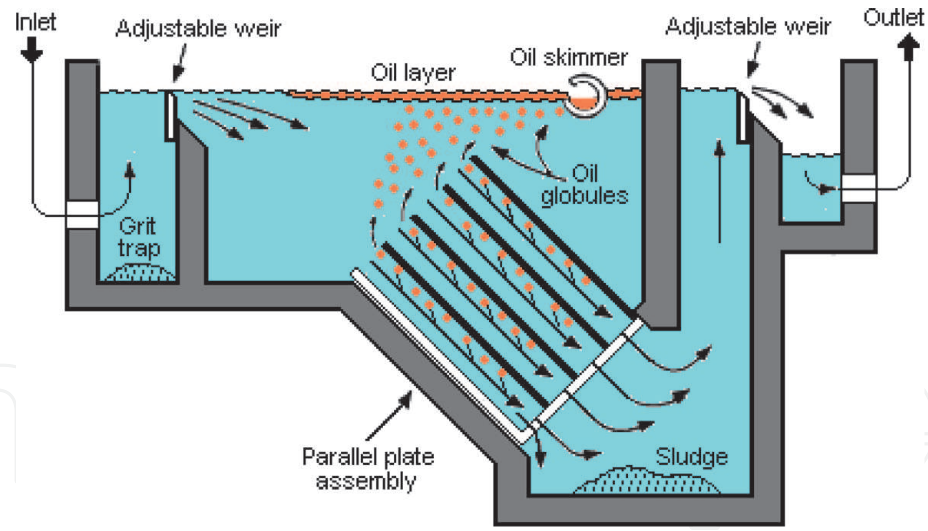

Figure 1.
Gravitational separator [20].

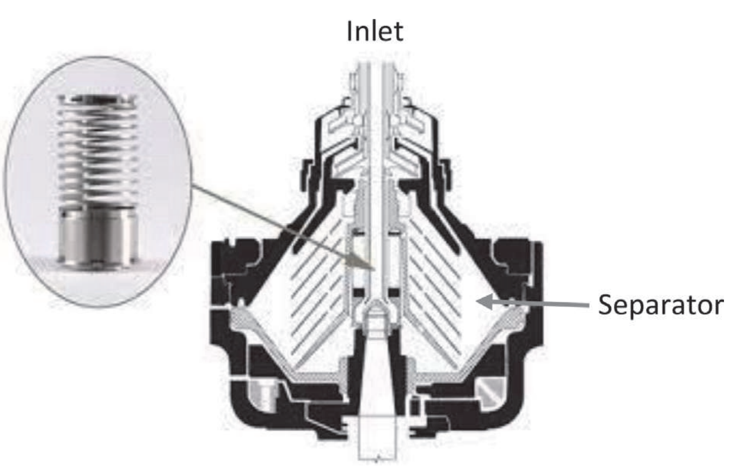

Figure 2.
Patented Alfa Laval XLrator [21].

service life might last long, reducing the cost of maintenance and repair. Centrifugal separators are also more compact and require smaller bilge water holding tanks [16]. However, high capital cost is needed for the centrifuges, and regular maintenance must be done since large horsepower motors are used during the process.

Figure 2 shows an example of manufactured separator (PureBilge by Alfa Laval).

In the inlet stream of the unit, the bilge water is accelerated by the XLrator with less shearing and foaming in order to prevent the oil drops from separating and further emulsion formation. Then, it flows into the separator, in which coalescence occurs due to high centrifugal force. Flocculation of small oil drops takes place and flocculants is added to promote bigger flocs for easier separation [21].

3.3 Flotation

Separation of oil by flotation occurs due to the difference in density of oil and water, where water is denser than oil, forming a scum layer on top of the water. Floatation technique can be divided into many different techniques, including electroflotation, froth flotation [22], and dissolved air flotation (DAF). Electroflotation separates oil from water through electrochemical reactions by electrolysis, where tiny bubbles produced from electrolysis will cause the pollutants to float to the water body surface [23]. In froth flotation, the separation takes place when the oil adheres onto the fine bubbles generated when air is introduced into the system. Surfactant is added to adsorb the air or water interface of the bubbles of air with the head groups (hydrophilic) in the water and the tail groups (hydrophobic) in the air. Hence, when the bubbles rise through the solution, the oil will concentrate on the bubble surfaces and foam is formed [24].

Meanwhile, dissolved air flotation (DAF) introduces micro gas bubbles into the flotation chamber that has been formed when water is saturated with gas under pressure [25]. The oil droplet will spread around the gas, and conglomerate will continue to rise to the surface of the solution. The advantages of flotation treatment are the following: less investment needed, low energy consumption, and easy to maintain [26]. However, the statement contradicts with Yu et al. [27] who stated that flotation requires high energy consumption and has repairing and maintenance problem as well as issue in manufacturing of the device.

3.4 Coagulation and flocculation

According to Yu et al. [27], coagulation process is a robust oil–water separation technology because it is able to separate dissolved and emulsified oil; hence, it is vastly applied in the latest oily wastewater treatment method [28]. In the coagulation process, coagulant, a chemical substance, is added to the wastewater to destabilize the charge of colloidal particles in the solution [29] which is too tiny for gravitational settling. When the particles are destabilized, larger flocs are formed making it easier to settle and then are skimmed off to the clarifier or sludge thickener.

Anyhow, many experiments might be needed if the coagulation method is going to be used in treating oily wastewater. This is because of the complexity of oily wastewater, making it hard to choose the most suitable coagulants for effective separation of oil and water to take place [27]. In a study done by Zeng et al. [30], oil removal efficiency is improved up to 99% when aggregation of poly-zinc silicate (PZSS) with anionic polyacrylamide (A-PAM) is used as the coagulating and flocculating chemicals. Somehow, higher costs are needed, and it could cause water bodies' secondary pollution and difficulties to the next process [27].

3.5 Biological

Some bilge water treatment units include biological treatment, which is called as a bioreactor. In this method, microorganisms are used to eliminate or reduce the organic and inorganic compounds before the treated wastewater being discharged to the sea or to a collection system [29]. The microorganisms convert the dissolved and particulate carbonaceous organic matter, including oil, in the bilge water into simple end products through the oxidation process. The equation below is representing the aerobic biological oxidation of organic matter [29].

$$\text{Organic material} + O_2 + NH_3 + PO_4{}^{3-} \rightarrow \text{new cells} + CO_2 + H_2O \qquad (1)$$

As can be seen from Eq. 1 above, the oxidation process needs oxygen (O_2) and nutrients, which are nitrate (NH_3) and phosphate ($PO_4{}^{3-}$), in order to convert the organic matter to carbon dioxide (CO_2) and water (H_2O). Other than that, the new cells generated are referring to the biomass produced after the oxidation of organic matter takes place.

There are two principals of biological processes used to treat wastewater, which are suspended growth and attached growth, or also known as biofilm, processes.

Suspended growth process maintains the microorganisms in liquid suspension by proper mixing methods. Meanwhile, attached growth attach the microorganisms to an inert packing material, where the wastewater will flow past the biofilm to remove the organic materials [29]. For OWS onboard, biofilm is used, in which the bacteria are attached to a synthetic support media. In this bioreactor, aerators are installed under the media to supply oxygen to the bacteria for bacterial growth as well as for oxidation of the organic contaminants to take place. Other than that, a clarifier is needed in order to remove the biomass formed at the end of the processes [16].

Biological treatment, with flexible operation, simple maintenance and management, as well as stable effluent quality [26], is indeed a suitable method since no waste oil is produced by the process [16]. Small oil droplets of emulsified oil, which are hardly removed by physical and chemical treatment, can be degraded easily by the bacteria [31]. However, CO_2 will be produced from the process, resulting in increment in greenhouse gases. Even though the operating cost is low, the capital

Techniques	Advantages	Disadvantages	References
Gravitational	Effective for discrete phases of oil and water	Not effective to separate emulsified oils from water	[16, 19]
Centrifugation	1. More compact 2. Do not require large bilge water holding tanks 3. Produce small amount of waste 4. Can be run without continuous man-hours operation and supervision	1. Use huge horsepower motors 2. Require frequent maintenance 3. High capital cost for centrifuges	[16]
Flotation	1. Less investment needed 2. Low energy consumption 3. Easy to maintain 4. Produce less sludge	1. Repairing and maintenance problem 2. Issue in manufacturing of the device	[26, 27]
Coagulation and flocculation	1. Can remove emulsified oil and dissolved oil 2. High adaptability	1. Need to be operated by skillful operator 2. High operating cost 3. Produce high amount of sludge which then needs to be disposed 4. A lot of experiments might be needed due to complexity of wastewater composition	[16, 27, 28, 33]
Biological	1. Able to effectively degrade organic pollutants including emulsified oil 2. Can remove other organic pollutants 3. No waste oil produced 4. Mechanically simple 5. Low operating cost	1. Loading spikes can occur 2. High capital cost 3. Need to be operated by skillful operator	[16, 27]
Absorption and adsorption	1. Suitable for less than 400 GT vessels 2. Relatively compact 3. Low capital and operation costs 4. Require low maintenance	1. Need to replace the media frequently (if necessary)	[16]

Table 1.
Comparison of the separation techniques.

cost needed is high and skillful personnel to be in charge is required to ensure the treatment functioned well.

Basically, there are three stages involved in the process [32]. The first stage is heavy phase separation, where separated oils and solids are removed. In the second stage, the bacteria are used to convert the emulsified oil into non-harmful end products. This stage is known as emulsified oil degradation stage. Then, the third stage contains clarifier in order to remove the remaining solids and water.

3.6 Absorption and adsorption

Physicochemical sorption involved in absorption and adsorption processes can eventually separate the oil from the bilge water. Absorption occurs when two discrete physical states of substances are fused together. Meanwhile, in adsorption, molecules adhere onto the surface of different phase [16]. Both absorption and adsorption involved absorbent sorption media and adsorbent, respectively. The oil is separated by pumping the bilge water through these media until their maximum sorption capacity is achieved, which then the oil is removed. Certain used media are possible to be regenerated onboard; meanwhile, some are regenerated or disposed of onshore. Somehow, the regenerated media is replaced once it is exhausted, where it can no longer absorb or adsorb the oil molecules. Having a few advantages which include low capital and operating cost as well as compact treatment unit, these two sorption techniques are suitable for vessels with less than 400 gross tonnages [16]. **Table 1** summarizes the comparison of the oil–water separation techniques.

4. Commercial OWS for bilge water treatment

Currently, many types of OWS for bilge from different manufacturers are available in the market. The separators consist of a number of separator units that

No.	Manufacturers	Name of the products	Separation techniques applied
1	Alfa Laval	PureBilge	Centrifugation
2	EnSolve Biosystems, Inc.	PetroLiminator OWS	Biological
3	Village Marine Tec.	Village Marine Tec. Oily Water Separator (VMT OWS)	Adsorption
4	Separator Spares & Equipment, LLC.	ULTRA-SEP Bilge Water Separator	Ultrafiltration (membrane)
5	Compass Water Solutions	CRP-SEP	1. Gravitational 2. Centrifugation
		ULTRA-SEP	1. Centrifugation 2. Filtration 3. Ultrafiltration (membrane)
		VG-SEP	1. Centrifugation 2. Adsorption
6	Recovery Energy, Inc.	BOSS Oily Water Separators	1. Filtration 2. Centrifugation

Table 2.
Examples of commercially available bilge water separator.

use different separation techniques. **Table 2** shows examples of companies that produced commercially available bilge water separators.

5. Conclusions

Different techniques are available and being used in the oil–water separation techniques for bilge water treatment. Typically, more than one unit of separators is needed to meet the minimum allowable discharge limit value set by the regulatory bodies. Gravitational and centrifugal methods are said to be the first technique before undergoing further polishing separation. Polishing treatment unit caters smaller droplet of oil, or emulsified oil, which cannot be treated by gravitational and centrifugal methods. To conclude, oily bilge water can be treated with proper separation techniques so that the treated bilge water discharged to the sea comply with the limit and marine pollution can be minimized and prevented. Any other treatment techniques can as well be tested and introduced to enhance the oil–water separation process in treating bilge water.

Acknowledgements

The authors would like to acknowledge the Centre for Biofuel and Biochemical Research (CBBR) and Chemical Engineering Department, Universiti Teknologi PETRONAS for the support.

Conflict of interest

The authors declare no conflict of interest.

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