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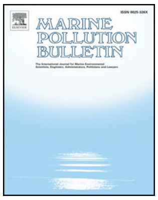

Management and environmental risk study of the physicochemical parameters of ballast water

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ABSTRACT

Shipping is a vital industry for the global economy. Stability of ships, provided by ballast water, is a crucial factor for cargo loading and unloading processes. Ballast water treatment has practical significance in terms of environmental issues, ecosystem, and human health, because ships discharge this water into the environment before loading their cargos. This study reviews the common methods for ballast water management – exchange, heating, filtration, ultrasonic treatment, ultraviolet irradiation, chemicals, and gas supersaturation – to select the best one. This study compares water temperature, salinity, dissolved oxygen, polycyclic aromatic hydrocarbons (PAHs), and heavy metals (Co, Cr, Ni, Pb) for ballast tanks of selected ships with the recipient port environment in the Persian Gulf as a case study. The exchange of ballast water in the ocean and/or its treatment on board to prevent inadvertent effects on the environment's physicochemical conditions is related to vessel characteristics, legislation, and the environmental condition. Ecological risk study showed that the salt content in ballast water is close to that of seawater, but the values of Cr (2.1 mg/l) and Ni (0.029 mg/l) in ballast water are higher than those in seawater (1 and 0.004 mg/l, respectively).

1. Introduction

Shipping is a vital industry for the global economy. The stability of ships is an important factor during the cargo loading and unloading processes. Stability of ships at the sea can be maintained by ballast water. Ships carry approximately 10–12 billion tons of ballast water across the oceans every year, in which thousands of aquatic species and heavy metals are being transferred (Tootsie, 2002). Ballast water treatments (BWTs) have practical significance in terms of environmental and health concerns for humans, because ships carry ballast water with different physicochemical parameters – temperature, salinity, dissolved oxygen (DO), polycyclic aromatic hydrocarbons (PAHs), and heavy metals (Co, Cr, Ni, Pb) – and transfer and discharge this water before loading their cargos.

It is impossible to neglect the harmful consequences of the physicochemical parameters of ballast water because of the presence of heavy metals that can negatively affect aquatic organisms and suppress the growth of marine life (Govind and Madhuri, 2014). Chinese and Russian industrial pollution events, such as discharge of heavy metals in the Amur River, have devastated fish stocks (Sharma, 2009). Besides being toxic to marine life, PAHs are very difficult to clean up and last for years in the sediment and marine environment (Panetta, 2003).

After identifying the adverse effect of transferring ballast water by ships across the world in 2004, the International Maritime Organization (IMO) accepted the International Convention on ballast water management for a safe and healthy environment (David and Gollasch, 2008). The Convention was set to come into force 12 months after being ratified by 30 states that cover 35% of the world merchant shipping tonnage. As of August 2, 2016, the convention has been ratified by 51 countries, but their contribution to the world merchant shipping tonnage is only 34.87%. Hence, it has not yet been implemented (International Maritime Organization, 2016).

The Persian Gulf has shallow water and thus has a high marine biodiversity and high temperature (Ngoka, 2015). The Gulf region is almost 241,000 km^2, surrounded by Iran, Qatar, Bahrain, Saudi Arabia, Oman, the United Arab Emirates (UAE), Kuwait, and Iraq. The marine life in this Gulf includes sea turtles, marine birds, dugongs, whales, dolphins, and over 500 fish species (Hellyer and Aspinall, 2005). Many of these species are native and highly dependent on the ecosystem of the Gulf (UNEP, 1999).

Several studies have provided possible solutions to mitigate the effects of ballast water on seawater (Bai et al., 2005; Balasubramanian et al., 2008; Bax et al., 2003; Costello et al., 2007; David and Gollasch, 2015; Delacroix et al., 2013; Dunstan and Bax, 2008; Firestone and Corbett, 2006; Gavand et al., 2007; Gonçalves and Gagnon, 2012; Liltved et al., 2011; Nanayakkara et al., 2011; Romero-martínez et al., 2014; Stehouwer et al., 2015; Tsolaki and Diamadopoulos, 2010;

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Werschkun et al., 2014; Williams and Grosholz, 2008; Zhang et al., 2005), but few of them have considered the effects of ballast water management on the physiochemical factors of water discharged into the port environment.

This study investigated the effect of common ballast water management on seawater by assessing the effects of chemical, physical, and mechanical treatments and exchange on the physiochemical factors of the ballast water discharged into the port environment to select the best of them. The choice of parameters to be investigated was made by those known to affect ballast water management, namely water temperature, salinity, DO, PAHs, and heavy metals in ballast water discharged into the port in comparison to the recipient port environment.

The common methods for ballast water management are described in the following section.

2. Ballast water management

Observing appropriate ballast water management is necessary to avoid problems through the invasion of species by ballast water. The methods of ballast water handling are ballast water exchange (BWE) based on D-1 standard and BWT based on D-2 standard (Germanischer Lloyd, 2013). The D-1 standard for water exchange specifies that 95% of ballast water should be exchanged or, when pumping is being used, that every tank should be pumped thrice. The D-2 standard for BWT is based on the maximum concentration of specified organisms (Gollasch, 2006).

2.1. Ballast water exchange

BWE is the most practical and prevalent method, because the translocation of species cannot occur through this method (David and Gollasch, 2008). The three methods of exchanging ballast water are as follows: (i) to discharge the tanks and subsequently refill, (ii) to discharge and refill simultaneously, and (iii) to release water through the bottom of ship and simultaneously pump water into the tank, which is known as the dilution method (Gollasch, 2004). Despite the fact that BWE would be the most cost-effective and time-saving process, it is impossible to ignore the following risks to the vessel and crew with regard to BWE: loss of stability, overstress, sloshing loads, torsional loads, reduction in maneuverability, reduction in draughts, icing, occupational hazards and fatigue of crew, and excessive forces on securing arrangements of containers or special cargo.

2.2. Ballast water treatments

BWT is divided into three major categories (Airahuobhor, 2010): mechanical, physical, and chemical treatments. A single method usually cannot meet the requirements of the International Maritime Organization in a way that is safe, effective, and economic (Wu et al., 2011). Thus, combining two or more treatment systems of ballast water is usually more practical and efficient. Some of these treatment systems are introduced in more detail in the following section.

2.2.1. Mechanical and physical treatment

Among mechanical treatments, filtration is effective in removing cloudy particles, viruses, bacteria, and parasites (Nasser et al., 2002; Tang et al., 2009), and hydrocyclone technology is also of interest (Lloyd's Register Group, 2010). Exposing microorganisms to ultraviolet radiation is a practical and effective way to inactivate microorganisms (Tang et al., 2009). However, when particles are suspended, the effectiveness of ultraviolet radiation is diminished through the attenuation of the radiation. Hence, a combination of filtration and ultraviolet methods can be used (Perakis and Yang, 2003; Tang et al., 2009). Another physical method is to use ultrasound (Holm et al., 2008). Zooplankton and phytoplankton also decrease when heated water is added to the ballast water tanks in ships (Acomi et al., 2012; Avenue and Wales, 1999; Bolch and Hallegraeff, 1993; Hallegraeff et al., 1997; Quilez-Badia et al., 2008). Ozone is widely used for water disinfection, but marine microorganisms have shown resistance to ozone treatment (Liltved et al., 2006), and sometimes this treatment causes corrosion (Oemcke and Hans van Leeuwen, 2005; Wu et al., 2011). In this case, TiO_2 photocatalyst can be added to ozone because it is an effective and safe material to destroy bacteria (Benabbou et al., 2007; Yao et al., 2007).

2.2.2. Chemical treatments

Electrochemical oxidation has been used in recent years for the treatment of a wide range of industrial wastewaters as well as for disinfection of drinking water, swimming pool water, and seawater. For example, sodium hypochlorite has been shown to be an effective chemical to destroy bacteria and viruses (Tsolaki et al., 2010). The gas supersaturation method causes bubble formation and results in cell damage that kills the organisms (Takahashi et al., 2001). Chemical biocides, in particular SeaKleen (Granitto, 2006; Stimson et al., 2010), PERACLEAN Ocean, and the chlorine dioxide biocide VIBREX, as a BWT have restrictions for use because of their chemical nature, biological effectiveness, and possible residual toxicity of the discharged ballast water, although PERACLEAN Ocean has the highest potential to inhibit microbial growth (de Lafontaine et al., 2008; Gregg and Hallegraeff, 2007). Peracetic acid (PAA) can sterilize process vessels and tanks to control microbial growth (Profaizer et al., 1997). Chlorine dioxide destroys microorganisms by disrupting the transfer of nutrients through the cell wall, not by disrupting the metabolic process. Stabilized chlorine dioxide is ClO_2-buffered in an aqueous solution (LENNTECH, 2014). Although chlorine dioxide has a half-life of 6–12 h, it can be safely discharged within 24 h as recommended by the suppliers (Lloyd's Register Group, 2007).

3. Materials and methods

3.1. Location of study and surveyed material

Kharg Island is situated in the northern part of the Persian Gulf. It has a somewhat triangular shape, with length and average width of about 4 and 2 miles, respectively. Kharg Island's oil terminal is one of the largest oil terminals in the world. Kharg Island serves as a seaport for exporting petroleum and oil products (Norouzifard, 2011). There are two different types of ports in Kharg Island (Norouzifard, 2011): (i) for oil tanker below 500,000 dead weight (DWT) and (ii) for vessels above 500,000 dead weight (DWT).

3.2. Survey of oil tankers

>796 ballast water reports of oil tanker by pilot office of Ports & Maritime Organization in the Gulf, collected over an 8-month period from 31 October 2012 to 25 June 2013, was checked, of which 356 were without ballast water on boards. The remaining 440 oil tankers carried ballast water and discharged 617,625,754 m^3 into the Gulf from other ports. The origin and quantity of ballast water discharged by these 440 oil tankers are listed in Table 1. On the basis of the ballast water report forms, the most common last ports before reaching the port in the south of Iran were, in order of the number of oil tankers, the United Arab Emirates, India, Saudi Arabia, and Japan, as shown in Table 1.

3.3. Oil tankers selected for analysis

In this study, 14 oil tankers were selected on the basis of their type of management and evaluated. The samples for the physicochemical analysis were taken from 9 suitable vessels of various types ranging from small cargo vessels with dead weight of <1000 tons to very large crude carriers (VLCCs) of >300,000 tons dead weight. Their combined quantity of discharged ballast water was found to be 600,382 tons, and the origin of most of them were Asian countries; their respective capacity, type of management, season of sample collection, estimated distance, and port of origin are shown in Table 2. Both treatment and

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