ANALYSIS OF TREATED BALLAST SEAWATER QUALITY FOR POTENTIAL REUSE

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MASTER OF SCIENCE
(MARITIME TECHNOLOGY)

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ABSTRACT

Ballast water is very important to provide safety for the ship and effect the efficiency of the ship's operation. 80% of the commodities are moving throughout the world by shipping and per annum, ballast water is being shifted for roughly 5 billion metric tonnes. Ballast water provides safety for a ship but on the other hand, cause a major problem to the environment through the introduction of the invasive aquatic species. The International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention) has already commencing on 8 September 2017 after ratified by 51 States represent 35% of the global gross tonnage in September 2016. However, there is no value recovered for the treated ballast water as it simply discharged during de-ballasting. The purpose of this project is to evaluate the quality of the treated ballast water and thus explore its potential for reuse to enhance environmental protection. In order to evaluate value creation of treated ballast water, three seawater applications which are seawater toilet flushing, cooling tower and desalination was studied and compared with treated ballast seawater. This project is approached by understand the treated ballast water and comparing treated ballast water and seawater at pre-treatment of desalination plant using portable WTW multi 340i pH/O^2/Conductivity meter, pH meter, turbidity meter, the spectrophotometric method and membrane filtration technique. Based on the results, the treated ballast water is suitable to remove the usage of the raw seawater for desalination. However, this research only covers temperature, pH, turbidity, conductivity, dissolved oxygen and *Escherichia coli*, and further analysis and technical development is require.

ABSTRAK

Air balast penting bagi menjamin keselamatan sesebuah kapal dan mempengaruhi kecekapan sesuatu operasi atau pelayaran. 80% daripada komoditi dunia digerakkan menggunakan kapal sebagai mod pengangkutan dan setiap tahun, lebih kurang 5 billion tan metrik air balast telah disalurkan. Air balast menjamin keselamatan sesuatu pelayaran tetapi dalam masa yang sama mendatangkan bahaya kepada alam sekitar melalui pengenalan spesis akuatik invasif. *International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention)* telah dilaksana pada 8 September 2017 setelah disokong oleh 51 negara yang mewakili 35% eksport-import dunia pada bulan September 2016. Walaubagaimanapun, air balast yang dirawat masih tidak mempunyai nilai pulang modal dan disalurkan kembali ke dalam laut selepas dirawat. Tujuan kajian ini dilakukan adalah untuk menilai kualiti air ballast yang dirawat dan mengenal pasti potensi untuk diguna pakai kembali bagi meminimumkan kos ekonomi dan meningkatkan perlindungan terhadap alam sekitar. Dalam mengenal pasti potensi air ballast yang dirawat, tiga (3) aplikasi air laut telah dikaji iaitu air tandas menggunakan air laut, menara penyejuk dan loji penyahgaram dan dibandingkan dengan air balast yang dirawat. Kemudian, projek ini dibandingkan dengan aplikasi air laut melalui ujikaji eksperimen. Melalui hasil daripada kajian ini mendapati bahawa air balast yang dirawat adalah sesuai untuk diguna pakai semula dan menggantikan penggunaan air laut mentah untuk proses penyahgaram. Walau bagaimanapun, kajian ini hanya merangkumi suhu, kekonduksian, kekeruhan, pH, oksigen terlarut dan *Escherichia coli* dan analisis yang lebih menyeluruh hendaklah dilakukan pada masa depan. Pembangunan teknikal juga mestilah dijalankan.

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APPROVAL

I certify that an Examination Committee has met on 22 January 2019 to conduct the final examination of Siti Nur binti Muhamad on her degree thesis entitled 'Analysis of Treated Ballast Seawater Quality for Potential Reuse'. The committee recommends that the student be awarded the Master of Science (Maritime Technology).

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Academic session : 2017/2018

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LIST OF ABBREVIATIONS

FDA	Food and Drug Administration
CDC	Centers of Disease Control and Prevention
IMO	The International Maritime Organization
UNCED	United Nations Conference on Environment and Development
BWM Convention	The International Convention for the Control and Management of Ships' Ballast Water and Sediments
Escherichia coli	*Escherichia coli*
m^3	Cubic meter
UNCLOS	United Nations Convention on Law of the Sea
USCG	United States Coastal Guard
BWDS	Ballast water discharge standard
MT	Metric tons
BWMS	Ballast water management system
BWSRP	Ballast Water Strategic Research Program
ICBWM	International Conference on Ballast Water Management
BWT	Ballast water treatment
UV	Ultra violet
DNA	Deoxyribonucleic acid
RNA	Ribonucleic acid
SWRO	Seawater reverse osmosis
GNI	Gross National Income

CHAPTER 1

INTRODUCTION

1.1 Background

Ballast is a method to increase the draft, change the trim, to provide the stability or to maintain the load line by using either solid or liquid in a ship. Ballast water is very important to provide safety for the ship and effect the efficiency of the ship's operation. For a decade, the old ship used solid like sand and rocks to maintain the stability. Since the 1950s, with changing in technology recently, the ship used water as a mechanism for the ballast system (Satir & Doɬan-Saɬlamtimur, 2014). 80% of the commodities are moving throughout the world by shipping and per annum, ballast water is being shifted for roughly 5 billion metric tonnes (Tsolaki & Diamadopoulos, 2010). Ballast water provides safety for a ship but on the other hand, cause a major problem to the environment through the introduction of the invasive aquatic species. The invasive aquatic species is transported when the ballast tank is occupied with the water that contain marine and freshwater fish larvae, small fish, crustaceans, algae, invertebrates, viruses and bacteria are discharges when the ship arrives at the next port or to load cargo (Battle, 2009).

Ballast water, not just threats to the world's ocean but also affect human health and the economy (Ibrahim & El-naggar, 2012; Jing, Chen, Zhang, & Peng,

2012). Roughly around 7000 of marine and coastal species moved throughout the world's ocean without been spotted every day (Battle, 2009). These become a loss to economy because the marine and coastal species had turned to invasive where the species started to compete with the local environment and evolve inhabitant flora and fauna. In addition, the invasive species also harm the ecological system. It had been reported that between 2004 till the end of 2009, not less than USD 50 billion losses were due to the damage created by invasive species (Battle, 2009). As reported by National Centers for Coastal Ocean Science, the government of United States loss around USD 138 billion due to the present of 50,000 invasive species in their coastal area every year for damages and to control the population from breeding. European Commission reported, losses due to the alien species is approximately around €12 billion per annum (EUROPA, 2016). Human health also affected by the transport of the ballast water due to the present of the microorganisms and bacteria like Vibrio cholera O1 and O139 which resulting in human epidemic cholera (Ruiz et al., 2002). Vibrio cholera in shellfishes was detected by the Food and Drug Administration (FDA) and the Centers of Disease Control and Prevention (CDC) of the USA in 1992 (Takahashi, Lourenço, F. Lopes, Rall, & Lopes, 2007).

In recent years, the transport of invasive aquatic species to the other oceans has been categorized as one of the severe damage to the sea. This matter becomes a worry to the United Nations and was debated in the United Nations Conference on Environment and Development (UNCED). This conference was held in 1992 and Rio de Janeiro was the host for that year. The International Maritime Organization (IMO) has started looking for an action about the transferring of invasive aquatic

species before it was debated in Rio de Janeiro in 1992. The first action that was taken by IMO has published the Guidelines for Preventing the Introduction of Unwanted Organisms and Pathogens from Ship's Ballast Waters and Sediment Discharges in 1991. Later, the guidelines were updated in 1993. Then, IMO comes with another guideline in 1997 which were the Guidelines for Control and Management of Ship's Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens (Resolution A.686(20)) (IMO, 1997).

The International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention) was adopted into practices by the IMO in February 2004 (IMO, 2004). This regulation is a way to manage ballast water discharge from the ship to a sea and to decrease the possibility of introducing of alien species or non-native species that exporting from the ballast water. BWM Convention have come into force a year after approval of the 30 states that constitutes 35% of the global gross tonnage. In September 2016, 35% world gross tonnage have ratified the BWM Convention where 51 states has agreed with this convention. As for now, the BWM Convention has been implemented the BWM Convention commencing on 8 September 2017 (IMO, 2017). Up to now, IMO has concentrate on ballast water and trying to find a solution for the transporting invasive aquatic species into the world's ocean over the past 20 years. The significant of the commencing of BWM Convention is not only can reduce the spreading of invasive aquatic species but also mark a global benchmark for worldwide shipping, comprehensible and strong guideline related to the management of ballast water onboard ships (IMO, 2017).

However, ballast water treatment increase operational cost to ship owners or operators (UK P&I Club, 2013). Meanwhile, the treated ballast water is just simply discharged into the sea without any value recovered. Seawater is widely being used in industries as a coolant, toilet flushing and desalination for the production of fresh water. Recently, the quality comparison between seawater and treated ballast water is not available. As such, there is a possibility to reuse treated ballast seawater as the present of real applications for seawater.

1.2 Problem Statement

The International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention) have commencing on 8 September 2017 after ratified by 51 states represent 35% of the global gross tonnage in September 2016. However, there is no value recovered for the treated ballast water as it simply discharged during de-ballasting. The cost to implement BWM Convention is starting from half a million to four million dollars for developing a ballast water management plan, dry docking and installation per ship (UK P&I Club, 2013). Based on previous research, estimated the ship owners need to bear the initial cost to install ballast water treatment system for the ships are higher than 70 billion dollars and after a few years of enforcement of BWM Convention, the installation costs are assumed to be around 10 billion dollars per annum (King et al., 2013).

Besides that, there is no present literature that related to the potential reuse of treated ballast water currently. Other than that, the availability of the information

related to the topic is limited and very constraint. Insufficient information such as value recovery, quality parameters and reuse of treated ballast water also included in the issues of treated ballast water in this research. To add up, in Malaysia, ballast water discharge has no specific guideline and not been supervised by Malaysia authority (Kaur, 2014).

1.3 Objectives

The aim of the study is to evaluate the quality of the treated ballast water and thus explore its potential for reuse to enhance environmental protection. The objectives of the study consist of the following:

i. To evaluate the potential area for reuse of the treated ballast water.
ii. To analyse the suitability of the treated ballast water for reuse in seawater application; desalinated water in Singapore.
iii. To propose a requirement standard for treated ballast water for general ship in Malaysian water.

1.4 Scope of Study

This study is conducted to evaluate the potential area of the reuse of the treated ballast water. Three potential areas in seawater applications have been identified which were coolant, toilet flushing and desalination for reuse of the treated ballast water as these three areas are the major users of the seawater (Copper Development Association Inc., 2017). Furthermore, this study is to propose a requirement

standard for discharging treated ballast water. This study will only focuses on a standard for Malaysian water bodies. Six water qualities standard had been studied which are temperature, Turbidity, pH, conductivity, dissolved oxygen and *Escherichia coli* (*Escherichia coli*).

1.5 Significance of Study

As mentioned earlier, there is no study have been conducted in investigating the potential reuse of treated ballast water. Therefore, this study fills the gap in treated ballast water for reuse literature by giving current evidence on development of ballast water management to the maritime world. Besides that, strategy for water reuse is really important to tackle water scarcity problem. As pointed out by Angelakis and Gikas, 2014, water reuse development and strategy is still not present and conducted in Europe. Secondly, the study contributes to the limited and inconclusive literature on treated ballast water. Most important, the study contributes to give recent evidence on treated ballast water as very little research has been carried out over the past ten years. Furthermore, treated ballast water is really important to maritime activities and industry as BWM Convention already enter into force after ratification of 35% of world tonnage (IMO, 2016). The introduction of invasive species may jeopardise the security and safety of Malaysian maritime environment.

1.6 Thesis Organisation

Chapter 1 Introduction describe about the introduction of the research topic inclusive of background, problem statement, objectives, scope of study, contribution and implications of the study and thesis organisation. **Chapter 2 Literature Review**, will discuss ballast water development and seawater applications. An overview of the regulations that related to ballast water is provided. Technologies for ballast water treatment are described, with particular attention given to the onboard treatment. Problem related with BWM Convention that covers international and Malaysia also being covered. Then, ballast water in Singapore is studied. Subsequently, seawater applications that have potential for reuse and the quality standard among the seawater applications are discussed. While in **Chapter 3 Experimental Methods**, an overview of experimental methods is given. Experimental methods are separated into the field work and the laboratory analysis. Six quality standards of water are studied and tested. In order to ensuring the reliability of the water samples, preservation of the samples is required. Then in **Chapter 4 Results and Discussion**, the results for the experimental works is discussed in this chapter. The characteristics of water are explored which are physical characteristics, chemical characteristics and biological characteristics. Both ballast water and seawater for pre-treatment of desalination plant is compared and analysed. Lastly in **Chapter 5 Conclusion and Future Work**, the conclusion, the results, proposed model and contributions of this study are summarised. Suggestions for future work are made.

CHAPTER 2

LITERATURE REVIEW

A lot of literatures have been used to understand the quality evaluation of treated ballast seawater for potential reuse. To identify the potential reuse, many research has been conduct on seawater application to evaluate the possibility of the treated seawater to be supplied for the application. This chapter explains many research and reviews on the quality standards of treated ballast water, seawater application, and desalinated water in Singapore have been carried out and be used to answer the objectives in previous chapter.

2.1 Regulation

2.1.1 The BWM Convention

Under BWM Convention, there are several ships that need to comply with BWM Convention according to the year of constructed based on regulation B-3; Ballast Water Management for Ships (IMO, 2004). For existing ships that constructed before 2009, the ship with ballast capacity less than 1500 cubic meter (m^3) need to carry ballast water treatment onboard associated with the first International Oil Pollution Prevention Certificate (IOPP) renewal survey. If the convention entry into

force after 31 December 2016, the ship shall carry ballast water management accordance to first IOPP renewal survey after ratification of the BWM Convention (Lloyd's Register Marine, 2015). For the ship with ballast capacity less than 1500 m^3, the ship constructed in or after 2009 but before 2012 and constructed in or after 2012 shall meet the regulation D-2; Ballast Water Performance Standard after the convention enter into force compliance by first IOPP renewal survey (IMO, 2014; Lloyd's Register Marine, 2015).

Ship with ballast capacity between 1500 m^3 and 5000 m^3 that constructed before or after 2012 shall carry ballast water management accordance to first IOPP renewal survey after the ratification of the BWM Convention (Lloyd's Register Marine, 2015). A ship with ballast capacity higher than 5000 m^3 if constructed in or after 2009 but before 2012 must carry ballast water treatment onboard after the convention enter into force accordance to the first IOPP renewal survey (Lloyd's Register Marine, 2015). Previous studies have reported ships that construct from 2009 until 2016 need to meet the regulation D-2 (Gollasch et al., 2007).

IMO have their standard for ballast water management under Section D – Standards for Ballast Water Management. Under regulation D-2 Standard there are several standards that needs to be achieved based on Table 3.1 before discharging of the ballast water. Hence, with all the guidelines that provided by IMO, BWM Convention are reliable with Article 196(1) of the United Nations Convention on Law of the Sea (UNCLOS). According to Article 196(1), all the country that registered under IMO must conduct all the possible ways to avoid, minimise and

constraint pollution that affects the marine environment and resulting in the present of new or alien species to that territory (IMO, 2004). This is because each country is responsible to maintain marine protected areas.

Table 2.1: The IMO D-2 for Ballast Water Discharge

Organism Category	Regulation
> 50 µm in minimum dimension	< 10 cells/m^3
10-50 µm	< 10 cells/ml
Toxicogenic *Vibrio cholerae* (O1 and O139)	< 1 colony forming unit (cfu)/100 ml < 1 cfu/g (wet weight)
Escherichia coli	< 250 cfu/100 ml
Intestinal Enterococci	< 100 cfu/100 ml

Source: IMO, (2014)