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Research paper

Quality Evaluation of Treated Ballast Seawater for Potential Reuse

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Abstract

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. 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. An exploratory study was conducted in Singapore as a case study as this country is facing water scarcity issues and a busy port in the world which received more than 28 billion m^3 of ballast water in 2015. Surprisingly the treatment technology between seawater toilet flushing and ballast water management has similarity. As both applications used screening and disinfection process and quality standard and analysis between treated ballast water with seawater applications found that seawater toilet flushing have the same quality parameter with treated ballast water. Thus, the treated ballast water can replace the raw seawater for seawater desalination. As such, with reduction of cost for screen unit, desalination water can exceed water production by NEWater in Singapore as the cost can recover the energy needed for desalination. It can conclude that treated ballast water has high recovery value and can be reused in seawater application.

Keywords: BWM Convention; Ballast water management; *Ballast water treatment; Desalination; Treated ballast water*

1. Introduction

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. 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 [1]. Ballast water, not just threats to the world's ocean but also affect human health and the economy [2], [3]. Roughly around 7000 of marine and coastal species moved throughout the world's ocean without been spotted every day [4]. These become a loss to the 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.

Previous studies have reported between 2004 till the end of 2009, not less than 50 billion USD losses were due to the damage that created by invasive species [4]. As reported by National Centers for Coastal Ocean Science, the government of United States lost around 138 billion USD 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 [5]. 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., 2000). 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 [6].

In recent years, the transport of invasive aquatic species in the other oceans has been categorized as one of the severe damages to the sea. This matter became a worry to the United Nations and was debated in the United Nations Conference on Environment and Development (UNCED). The first conference was held in 1992 and Rio de Janeiro was the host for that year. International Maritime Organization (IMO) had 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 standard 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 [7].

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 [8]. 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 will come into force a year after approval of the 30 States that constitutes 35% of the global gross tonnage. As of September 2016, 35% world gross tonnage has ratified the BWM Convention where 51 States has agreed with this convention. The BWM Convention will be implemented on 8 September 2017 [9].

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Up to now, IMO has tried to tackle on ballast water issue and trying to find a solution for the transporting invasive aquatic species into the world's ocean over the past 20 years.

However, ballast water treatment causes extra cost to ship owners or operators [10]. 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. In these applications, if sea water could be replaced by the treated ballast water due to higher quality is still unknown. Recently, the quality comparison between seawater and treated ballast water is not available. As such, there is a possibility to explore the potential of treated ballast seawater as there is present the real applications for seawater such as seawater toilet flushing, desalination and seawater cooling tower.

2. Regulations

2.1. The BWM Convention

Under BWM Convention, several ships need to comply with BWM Convention according to the year of constructed based on regulation B-3; Ballast Water Management for Ships [8]. For existing ships that were constructed before 2009, the ship with ballast capacity less than 1500 cubic metre (m^3) need to carry ballast water treatment onboard ship when the convention entry into force before 1 January 2017 after the delivery date of the ship in 2016 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 rectification of the BWM Convention [11]. 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 entry into force compliance by first IOPP renewal survey [8], [11].
Ship with ballast capacity between 1500 m^3 and 5000 m^3 that constructed before, in or after 2009 and in or after 2012 shall carry ballast water management accordance to first IOPP renewal survey after the BWM Convention come into force [11]. A ship with ballast capacity higher than 5000 m^3 if constructed in or after 2009 but before 2012 need to carry ballast water treatment onboard the ship when the convention entry into force before 1 January 2017 after the delivery date of the ship in 2016 associated with the first IOPP renewal survey. In the other hand, for the Convention that enter into force on 1 January 2017, it needs to carry ballast water management after the first IOPP renewal survey after entry into force [11]. Previous studies have reported ships that construct from 2009 until 2016 need to meet the regulation D-2 [12].
IMO have their standard for ballast water management under Section D – Standards for Ballast Water Management. Under regulation D-2 Standard there are several requirements need to be complied based on Table 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, minimize and constraint pollution that affects the marine environment and resulting in the present of new or alien species to that territory [8]. As referring to Article 196(1), each country is responsible to preserve marine protected areas.
Table 1 shows the ballast water performance standards by IMO and be compared with the standards that apply in California.

Table 1: Ballast Water Performance Standards of IMO Regulation D-2 and California

Organism Category	IMO Regulation D-2	California
> 50 µm in minimum dimension	< 10 cells/m^3	No detectable living organisms
10-50 µm	< 10 cells/ml	< 0.01 living organisms/ml
Toxicogenic Vibrio cholerae (O1 and O139)	< 1 colony forming unit (cfu)/100 ml < 1 cfu/g (wet weight)	< 1 cfu/100ml or < 1 cfu/g (wet weight) zoological samples
Escherichia coli	< 250 cfu/100 ml	< 126 cfu/100 ml
Intestinal Enterococci	< 100 cfu/100 ml	< 33 cfu/100 m

2.2 The United States Coast Guard (USCG) Regulations

National regulations such as United States Coast Guard (USCG) has established the same performance standard; regulation D-2 by IMO. USCG has implemented the regulatory of Standards for Living Organisms in Ships since 28 August 2009 [13]. On 23 March 2012, USCG has issued the final discharge standard for ballast water management [14]. As such, the ships with approved ballast water management system by USCG must comply with paragraph (a) of the ballast water discharge standard (BWDS) [14]. In paragraph (a), there is a description for organisms greater than or equal to 50 µm, organisms between 10 µm to 50 µm and the indicator for the microorganisms which include Toxicogenic Vibrio cholerae (O1 and O139), Escherichia coli and intestinal enterococci. Up to now, a number of studies have reported the performance standard of ballast water management will become more stringent than regulation D-2 if there are an improvement of current technologies for ballast water management [13], [15].
Thus far, previous studies have indicated that the discharge standard of ballast water in California for organisms that larger than 50 µm is no detectable living organism [16], [17]. There are several differences between Ballast Water Performance Standard between IMO Regulation D-2 and California based on Table 1. For zero detectable living organisms in California, the treaty entered into force for all organism categories on 1 January 2020 [18].
In California, ballast water performance standard shall be implemented based on the year of the ship constructed and the ballast water capacity of the ship [19]. For a vessel that carries ballast water less than 1500 MT (metric tonnes) that construct on or after 1 January 2016, the ships shall meet the ballast water standard as soon as the ship ready for her voyage. For ships that constructed before 2016, the implementation of ballast water standard shall begin on 1 January 2018. A Ship that carries ballast water between 1500-5000 MT, the performance standard has come into force since 1 January 2016. Vessel with ballast capacity more than 5000 MT, that built on or after 1 January 2016 started to meet the performance standard on 1 January 2016. While for existing vessels, she should meet the requirement starting on 1 January 2018.
Ballast water management is not applied to several types of ships. These types of ships can neglect this Convention which are ships that not designated or built to carry ballast water, ships that only navigate and perform in water of the States and ships of a party that only carry task in waters under the control of another party with permission and authorization of the Administration. To add up, ships that only employ in waters of the State and the high seas, warship, naval auxiliary and government-owned ships and ships that fitted with permanent ballast water tank that will not conduct discharging of ballast water [8] are allowed to neglect this Convention. For a ship that only navigate in water of the States, the reason why she does not conduct ballast water management onboard the ship is discharging the ballast water will not introduce any new species to the ecosystem as they carry the water from the same area.

2.3 European Union Regulations

The European Commission has published a statute that related with invasive alien species that transport by the ballast water which is the Regulation 1143/2014 on invasive alien species accordance to BWM Convention in 2004. This rule has been implemented since 1 January 2015 to control and prevent the problem that results from the invasive alien species. The statute covered three types of involvement which are prevention, prior identification, and fast action. There is a list of invasive alien species that caught the attention of the Union under Commission Implementing Regulation 2016/1141 adopting a list of invasive alien species of Union concern. 37 species listed under this regulation which is adopted from a list of invasive alien species of Union concern under Regulation (EU) No 1143/2014 of the European Parliament and the Council. This regulation has entered into force on 13 July 2016 and relevant to all Member of the Union (EUROPA).

3. Technology for Ballast water Treatment and Discharge

3.1. Port-Based Treatment

Port-based treatment is divided into two parts which is a treat after de-ballasting and uptake ballast water with treated water. Treat after de-ballasting is dependent on the facilities of the port where ballast water from the ship is moved to the treatment tank [1]. The treatment plants depend on the traffic at the port. The benefit of the port based treatment is, a ship that not treated the ballast water onboard can exchange with treated water at the harbor due to the availability of the stored tank. The Valdez Marine Terminal (Prince William Sound) in Alaska is an example of the port that provides ballast water treatment on shore [1].
While for uptake ballast with treated water is the method using clean seawater that has been treated at the port. The seawater must be treated before use to prevent the present of impurity. The advantage of the ballast water to be treated onshore is Port State can monitor the efficiency of the ballast water management and meets the standard [20]. Besides that, ballast water treatment also being conducted by the professional who are expert in the ballast water treatment standard and the maintenance will be executed by them [21].

3.2. Onboard Treatment

Treatment of ballast water onboard ship encompasses two types of process which are solid-liquid separation and disinfection [22], [11]. Fig. 1 presents the technology that is used to treat ballast water on board vessel.
Solid-liquid separation can be executed through the process of hydrocyclone or surface filtration to segregate the solid particles and resulting in the production of a waste stream where can be discharged at the particular collecting point [1], [11]. Hydrocyclone or surface filtration is considering as a primary step of the treatment which eliminates larger particles with diameter 40 µm [23]. Disinfection is the way to remove microorganisms using one or combination of the process which are chemical inactivation, physicochemical inactivation or deoxygenation [11]. There are two possible ways to inactivates microorganism via chemical inactivation; oxidising biocides or non-oxidising biocides. Oxidising biocides are the process of present in chemicals in the ballast tank to eliminate the organism through Solid-liquid separation: -Hydrocyclone -Surface filtration Disinfection: -Chemical inactivation -Pysical inactivation –Asphyxiation Onboard Treatment the destruction of the cell wall, alteration of cell permeability, change of the protoplasm alteration of DNA or RNA and inactivate enzyme activity [24]. Advanced Environmental Technologies define non-oxidising biocides as chemical agents that react with the microorganisms and resulting in changes in cell metabolism and structure. The process that categorises under physicochemical inactivation can be class into chemical and physical treatment. Chemical treatment including chlorination, electrochlorination or electrolysis, ozonation, peracetic acid, seakleen and chlorine dioxide while physical treatment consists of UV irradiation, deoxygenation, gas injection, ultrasonic treatment, cavitation, heat and pressure vacuum disinfection [1], [11].

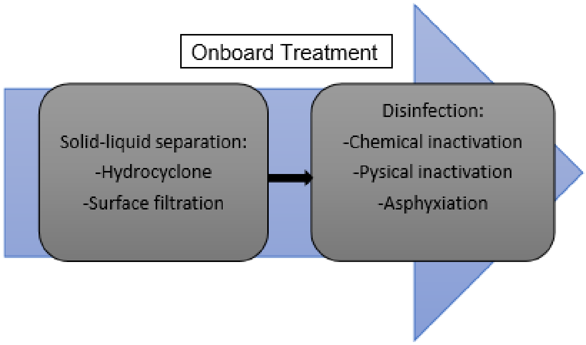

Fig. 1: Ballast Water Treatment Onboard Ship

4. Ballast Water in Singapore

An exploratory study was conducted and Singapore has selected as a case study. Singapore is known for their global hub port, shipping, and maritime services. Historically, Singapore has turned into world's busiest port by shipping tonnage since 1982 when they succeed to achieve one million TEUs a year. Then, Singapore continues their success in the maritime industry in 1990 when they made five million TEUs per year and managed to become the world's largest container port. To date, Singapore is growing their maritime industry day by day [25].

With a Gross Domestic Product (GDP) worth US$292.739 billion in 2015 [26], the maritime industry contributes around 7% to the country GDP or 10% from the service sector which helps in Singapore's growth [27]. As a maritime hub, Singapore is known for their expertise in ship repair. Besides that, Singapore also provides services for shipbuilding and offshore structures, vessel design and engineering and supply marine equipment and services to the shipping industry either for the ship or offshore structure [25]. As reported by INSIS, due to Singapore's capability in supply services and port facilities, Singapore has grown into an International Maritime Centre (IMC).

Singapore has a total of 3.39 % of terrestrial and marine protected areas from the total territorial area in 2014. It has increased 0.8% compared in 1990 [26]. From 2007 to 2015, Singapore receives more than 120,000 vessels per year with a total of 1.2 million within nine years [28]. In 2015, MPA reported around 132,922 vessels has arrived at their port in 2015. 43% of the ship arrivals are from tankers, containers, and bulk carriers indicate that Singapore port received more than 28 billion m^3 of ballast water as these types of ships has ballast capacity more than 5000 m^3 [29]. The Fig. 2 below shows the breakdown of the number and vessels type that have arrived in Singapore for the year 2015.

Thus, it is vital for Singapore to maintain their total protected areas as they received vessel from 700 ports around the world. To overcome problems that related with ballast water and to preserve their marine biodiversity, Singapore has come out with a strategy that related to this issue in 1990's. Besides that, this approach also can reduce its consequences towards shipping industry and trade. The method is known as the Ballast Water Strategic Research Program (BWSRP) and come out with six objectives which involve new technologies for treatment, preparing the shipyards, monitoring, actively participate and support any IMO - Globallast Programme associated with ballast water [30].

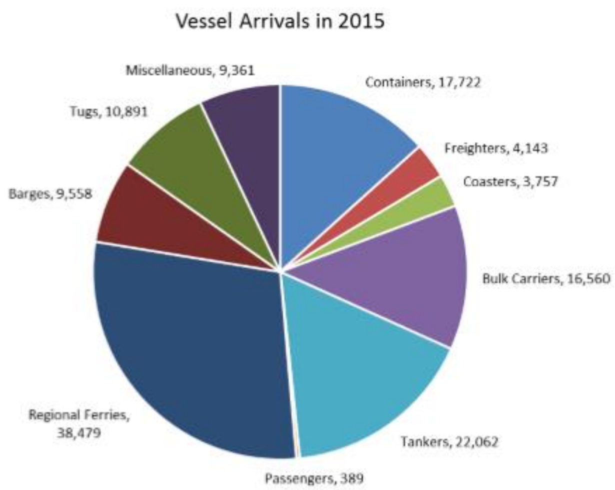

Fig. 2: Vessel Arrival in Singapore Port

Besides that, Singapore has been engaged in the international conference related to ballast water issues. Singapore has succeeded in hosting International Conference on Ballast Water Management (ICBWM) with a total of 40 countries participated. The topics that have debated by more than 40 countries were IMO regulations and standard, ballast water issues from public health perspectives, technologies to treat ballast water, safety and economics measures related to ballast water management, best ship designs, monitoring technologies for ballast water management, risk assessment and global issues [30].

4.1. Treated Municipal Waste Water

Singapore is known as a country with limited fresh water supply as this country has no natural lakes, large rivers or any groundwater resources. Thus, this turns Singapore into a country with water scarcity. In Singapore, each day 430 million gallons of water is used per day. 45% is used by domestic sector which is homes consuming, and another 55% of the demand is from the non-domestic sector. This water demand is assumed to be around 860 million gallons a day which are double of current water demand in 2060 [31]. Singapore predicts the water demand for domestic sector will decrease by 5% in 2030. However, the demand for the non-domestic sector will be increased to 60% in 2030. Water demand for the non-domestic sector will remain increase by 2060 to 70% per day [31].

In order to overcome this problem, Singapore imported water from Malaysia. Singapore and Malaysia have endorsed four water agreements which were in 1927, 1961, 1962 and 1990. For the first agreement that have signed in 1927 between the Singapore City Council and the Sultan of Johor, Sultan Ibrahim where in this agreement, Singapore is allowed to draw water for free from Sungei Pulai and the charged was only applicable for the rented of 2,100 acres' land with annually only cost 30 cents per acre and this agreement has ended in 1961 [32]. Deals in 1961 for 50 years has expired in 2011 where Singapore can take the water for 88 million gallons a day from the Pontian and Gunung Pulai Reservoirs, as well as the Tebrau and Skudai Rivers with the cost of 50 cents per 1,000 gallons. Agreement in 1962 was agreed on 29 September 1962 which allowed Singapore to extract 250 million gallons a day with the contract of 99 years. These two agreements; the 1961 and 1962 agreement were signed between the city council of the state of Singapore and the government of the state of Johor. The 1990 agreement was agreed on 24 November 1990 between the Public Utilities Board (PUB) of Singapore and the Johor state government and will be terminated in 2061 where Singapore was authorized to build a dam at Sungei Linggui. These three agreements have fulfilled almost half of the Singapore's needs for the water [32].

NEWater is the 3rd National tap is high quality reclaimed water. NEWater comes from the treated used water or treated municipal wastewater is decontaminated via advanced membrane technologies and ultra-violet disinfection. This water is clean and pure and meets the WHO standards for drinking water. The idea for the NEWater was debated in the 1970s to overcome water scarcity. However, during that time membranes technology was very expensive and difficult to predict the result. With continuous of research, the study of NEWater was managed to discover as the new source of raw water to meet Singapore's water demands in 1998. The first NEWater plant was operated in May 2000. Up to now, Singapore has four NEWater plants which supply 30% of water to meet national demand. The total of water supply by NEWater will increase to 55% in 2060 as a better technology present in the future [31].

Wastewater is collected from the consumer into underground sewer pipes. In Singapore, the total volume of used water treated in the year 2015 is 575 Mm^3 [31]. Up to now, a number of studies have reported the treated water attains up to 30% of national water consumers [33], [31]. There are four water reclamation plants in Singapore which are Ulu Pandan, Jurong, Kranji, and Changi. Ulu Pandan water reclamation plant contributes to 121 Mm^3 of treated water, both Jurong and Kranji plants contribute to 69 Mm^3 of used water treated. As can be seen from the Fig. 3 below the largest plant that contributes to the used water treated is Changi with 316 Mm^3 which equivalent to 55% of overall water treated [31].

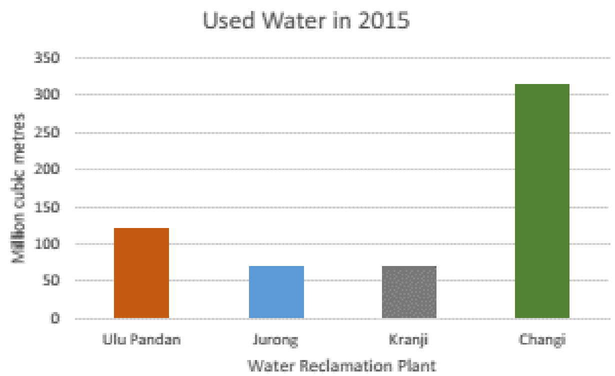

Fig. 3: Volume of Treated Water by WRPs in Year 2015

4.2. Reuse/ Value Creation

Treated ballast water can be reused for the industrial purpose [34]. Besides that, water that is treated onshore can be reused by other ship [21]. Seawater systems are widely being used in the industries like shipping, offshore oil and gas production, coastal industrial plants and power plants [67]. This shows there are possibilities for the treated ballast water to be reused rather than simply discharge to the sea.

The possibilities reuse of ballast water is for toilet flushing. In Hong Kong, seawater is being used for toilet flushing, and almost 80 % of the area was supplied by the seawater [35], [36]. The present of dual water supply system either using fresh or sea water system with different pipelines in Hong Kong has started since the 1950's [37]. Each day in 2015, the amount of the seawater being supplied to the citizens is approximately around 746,240 m^3 for toilet flushing [35]. By 2030, the estimation population in Hong Kong is increasing by 8.9 million and seawater demand for toilet flushing will increase to 1.1 x 108 MI/year [35]. Thus, reuse of treated ballast water might be the best solution for the country that utilizes seawater like Hong Kong and Singapore.

Desalination through the thermal process is where the seawater is heated to a high temperature and resulting in the evaporation of the seawater then is condensed and produce the fresh water [38].

Unfortunately, desalination via thermal process is inefficient as it required high energy during the process and corrosion is easily taking place [39]. Reverse osmosis (RO) is the type of membrane processes [40]. RO contribute about 59.85% of global desalination which is the highest compared to another process [41]. RO membrane can separate the small size of contaminants and requires combined method which are nanofiltration (NF), ultrafiltration (UF), and microfiltration (MF) to eliminate larger particles [42]. Spiral wound modules with high-permeability membranes are the type of RO process that will be used for desalination [43]. RO Improvement of the membrane process has resulted in the increasing of salt rejection which has a linear relationship with the recovery ratio; 35,000 mg/L of salinity [40]. Desalination of the treated ballast water via RO might be useful and a way to decreased water scarcity.

Seawater sources normally have contaminants like hydrocarbons and biological contaminants which including microorganism [42]. Eliminating or reducing the pre-treatment stage which including coagulation, filtration and membrane-based will reducing the energy consumption, capital cost and environmental impact of desalination plants [43].

5. Quality Parameters

5.1. Seawater Toilet Flushing

Recent developments in toilet flushing in Hong Kong have heightened the need for water quality standard. There are five key parameters of water quality standard that set up by Hong Kong Government for distribution to consumers which are *E. Coli*, total residual chlorine, dissolved oxygen, total suspended solids and colour spectrum [44]. The key parameter for *E. Coli* is to determine the number of bacteria for ensuring the safety of the users.
Total residual chlorine is essential to control the growth of bacteria in the reclaimed water. Dissolved oxygen can result in the present of odour in toilet flushing system. Low oxygen environment can cause the pungent smell and to avoid this from happening, the organic materials must be eliminated and control in the system. While for the total suspended solids and colour spectrum, it is general water quality parameters to ensure the water system is suitable for the public uses. The Table 2 below illustrates some requirements by the Environmental Protection Department of Hong Kong Government for application of sea water at sea water intakes.

Table 2: WSD Standards at Sea Water Intakes

Key Parameter	Water Quality Standard
Colour Spectrum	< 20 Hazen
Turbidity	< 10 NTU
Threshold Odour Number	< 100 odour unit
Ammoniacal Nitrogen	< 1 mg/L
Suspended Solids	< 10 mg/L
Dissolve Oxygen	> 2 mg/L
Biochemical Oxygen Demand	< 10 mg/L
Synthetic Detergents	< 5 mg/L
E. Coli	< 20,000 cfu/100 ml

Then, the seawater as shown in Table 2 will go through the treatment process to meet the quality standards of reclaimed water in Hong Kong, and the treatment process is way too much simpler rather than fresh water treatment [37]. The treatment process only consists of screening and disinfection process and only conducted in the pumping station [37], [45], [35]. After completed the treatment process, the treated seawater is pumped to the service reservoirs [45], [35]. Table 3 shows the key parameters of water quality standards for the toilet flushing in Hong Kong [46].

Table 3: Intakes Key Parameters of Water Quality Standards of Toilet Flushing in Hong Kong

Key Parameter	Unit	Standard
E. Coli	colony forming units/100mL	Not Detectable
Total Residual Chlorine	mg/L	After treatment > 1; At point of use > 0.2
Dissolved Oxygen	mg/L ≥ 2	≥ 2
Total Suspended Solids	mg/L	≤ 5
Colour spectrum	Hazen unit	≤ 20

5.2. Cooling Tower System

Facilities performance can be influenced by the cooling water quality. The sources of the water must strictly examine for their chemical properties and content. Cooling tower operation and performance have closely affected by the general mineral component that contains in the water. Minerals component in the water not only effect the operation of the cooling tower but also create environmental problems. Biological activity also has the direct effect towards the operational activity. Hence, the key parameter for water quality of power plant cooling towers is very crucial and tabulated in Table 4 [47].
Langelier Saturation (LSI) is necessary to detect scaling and corrosion disposition that will occur in the cooling tower. LSI is imperative in measuring the pHs – CaCO3 saturation pH. Calcium hardness, alkalinity, temperature and TDS will affect the concentration of the pHs – CaCO3 saturation pH in the cooling water. When CaCO3 present in the cooling water, the reading will have positive values and scaling might be taking place [47]. Ryznar Stability (RSI) is developed based on LSI calculations. The advantage of the RSI is it will the prediction of the scaling and corrosion is more accurate compared to the LSI calculations. The best value of RSI is between 6 – 7. The corrosion tends to occur in the cooling water if the values exceed 7. On the other hand, scaling will happen if the results show values less than 6. Puckorius Scaling Indices (PSI) almost have similarity with the RSI system. PSI will determine the system pH rather than verify the actual pH in the system. PSI is a type of modified system which will give a good estimation of the scaling and corrosion probability that present in the cooling water. The evaluation is made by indicating the real alkalinity of the environment [47].

Table 4: Cooling Tower – Water Quality Parameters (Vivian Li, 2012)

Key Parameter	Units	Standard
Ca	mg/LCaCO$_3$	value was given
Ca x SO$_4$	(mg/L)2	500,000
Mg x SiO$_2$	mg/LCaCO$_3$ x mg/LSiO$_2$	35,000
M Alkalinity	mg/LCaCO$_3$	No value was given
SO4	mg/L	No value was given
SiO2	mg/L	150
PO$_4$	mg/L	No value was given
Fe (Total)	mg/L	< 0.5
Mn	mg/L	< 0.5
Cu	mg/L	< 0.1
Al	mg/L	< 1
S	mg/L	5
NH3	mg/L	< 2
pH		No value was given
Total dissolved solid	mg/L	-
Total suspended solid	mg/L	< 100 with film fill < 300 with open fill
Biochemical oxygen demand	mg/L	--
Chemical oxygen demand	mg/L	--
Langelier SI		< 0
Rysnar SI		> 6
Puckorius SI		> 6

5.2. Cooling Tower System

Seawater reverse osmosis (SWRO) facility is designed according to the quality of the seawater, the origin of its uptake and its variation [48]. Open surface seawater has greater potential for membranes fouling and the process for pre-treatment also required several levels of treatment compared to the beach well water [48]. One of the greatest challenges associate with SWRO desalination is biofouling of the RO membranes which resulting in low productivity of the SWRO facility [49]. Biofouling can be referred as a deposition, growth and metabolism of bacteria cells on the membrane [49], [50] have reported the membrane fouling have exerted influence on the performance of giant desalination facilities at Carlsbad, California.
In order to decrease the effect of biofouling is by eliminating the nutrients that help bacteria to growth like dissolve organic carbon (DOC), extracellular polymeric substances (EPS) or transparent exopolymer particles (TEP) in the seawater [51]. Granular activated carbon (GAC) can be used as a pre-treatment process before SWRO take place [52].
A number of researches have reported for lab-scale treatment type with GAC filter bed as a pre-treatment have the impact on water quality. The combination of GAC biofiltration and membrane bioreactor (MBR) as a pre-treatment before RO take place has removed about 70% of DOC [53]. While, GAC biofiltration with RO process has decreased SDI and resulting in a reading of turbidity level below 0.3 NTU [54]. While when the GAC biofiltration process is undergoing about 20 days, almost 70% of DOC have been removed, and 80% of TEP has been eliminated [55]. On the other hand, for 75 days of GAC biofiltration process the value of DOC removal has decreased to 39% [56]. Table 5 shows the key parameter for seawater quality for a desalination plant in Singapore as reported by Water Supply (Plant).

Table 5: Quality Parameter of Seawater Desalination Plant in Singapore

Parameter	Standard
Temperature	40°C
Fluoride	0.40 - 0.70 mg/L
Total Residual Chlorine	0.50 - 2.00 mg/L
Free Residual Chlorine	≤0.12 mg/L
Chlorine Combined (Monochloramine) Residual	0.80 - 2.00 mg/L
Conductivity	≤ 378.0 µS/cm
pH	≤ 9.0
Total Dissolved Solids (TDS)	≤250.0 mg/L
Turbidity	≤ 3.0 NTU

The quality of seawater desalination also depending on types of application. As such, application for crop irrigation, the quality parameters might have slight differences but still referring to the standard of the desalination plant. Desalination for agriculture purpose can be considered as an expensive method [57] but it is widely being used in Spain [58], [59] and Israel [60], [61]. Besides that, DSW for agricultural irrigation is also emerging to Florida [62]. The application also expanding to the Canary Islands, Spain where it is only the available choice for agriculture purpose [63], [64].
To date, there are no specific water quality parameters for DSW agricultural application [57]. Israel is the only country that has specific standard for desalination as required by the Israeli Ministry of Health [65]. There are 10 quality parameters that can be used for agricultural and municipal DSW standard which are pH, electrical conductivity, concentration ranges for a number of ions (Cl^-, Na^+, Ca^{2+}, Mg^{2+} and SO_4^{2-}), concentration ranges for boron, alkalinity, and Calcium Carbonate Precipitation Potential (CCPP) [57]. Table 6 shows the standard for desalinated water for domestic and agricultural usage in Israel [60] and crop irrigation standard [66]. Meanwhile, Table 7 and Table 8 shows the risk in the reuse water application.

Table 6: Quality Standard for the Desalinated Water for Domestic and Agricultural Usage in Israeli and Crop Irrigation Standard

Key Parameter	Israel	Crop irrigation Standard
pH	< 8.5	6.5-8.4
Electric conductivity	(ds/m) < 0.3 dS/m	< 7.0
Chloride (mg/L)	< 20 mg/L	See Table 7
Sodium (mg/L)	< 20 mg/L	See Table 7
Calcium(mg/L)	32-48 mg/L	--
Magnesium (mg/L)	12-18 mg/L	--
Sulphate (mg/L)	> 94 mg/L	--
Boron (mg/L)	0.2-0.3 mg/L	< 0.75
Alkalinity (mg/L CaCO3)	< 80 mg/L CaCO3	--
CCP (mg/L CaCO3)	3-10 mg/L CaCO3	--
SAR (Sodium Adsorption Ratio)	--	

Table 7: Toxicity Risk from Sodium (Na+) and Chloride (Cl-) in Water for Irrigation

Ion Concentration	Low risk	Moderate risk	High risk
Cl− (mg L−1)	< 140	140-350	> 350
Na+ (mg L−1)	< 70	70-210	> 210

6. Results and Discussion

The current study found that the similarities of the quality parameters between each application respectively (reuse, desalination, ballast treatment) were total suspended solids. The value for total suspended solids for toilet flushing is below 5 mg/L, for the cooling tower are less than 100 with film fill and less than 300 with open fill. While for seawater desalination plant, the value of total suspended solid is less than 2 mg/L. Surprisingly, for treated ballast water the discharge standard only has similarity with toilet flushing application which the quality parameter is the organisms. The quality of treated ballast water is organism category where referring to D-2 Ballast Water Performance Standard where includes bigger than 50 µm in minimum dimension, between 10-50 µm in size, Toxicogenic Vibrio cholerae (O1 and O139), Escherichia coli and Intestinal Enterococci.
It also found that treated ballast water standard is too limited, and the value creation is still not complying with the quality standard for the seawater toilet flushing. Treated ballast water can replace the raw seawater that is used for seawater toilet flushing due to the treated ballast seawater has passed decontaminated process through two types of process which are solid-liquid separation and disinfection. This can reduce the cost and time for the pre-treatment process. An advanced analysis should be conducted as both applications has the same treatment process but different quality parameters. The current study found that the standard for E. Coli in seawater toilet flushing is not detectable whereas for the treated ballast water is less than 250 cfu/100 ml.
Another significant finding was that the both seawater application used almost similar treatment technology but produced different results, especially for the standard parameters. Besides that, the standard for seawater toilet flushing is much better compared to treated ballast water. This was proven by looking at the quality standard for seawater toilet flushing and treated ballast water as laid out by IMO and the USCG regulations.
In addition, the treatment process of desalinated water has similarity between treatment process of treated ballast water which is screening with filtration and disinfection process. At screening process, the raw seawater is the screen with a mechanical rake, and chlorine is used to remove marine growth. This process has a close relationship with ballast water treatment as the purpose of

filtration and disinfection are the same which to eliminate marine organism. There are three standard manufacturers for the water before undergoing reverse osmosis system which is the temperature must be maintained at 25°C, 60 pounds per square inch (psi), and TDS at 500 parts per million (ppm). The standard of the water has a very dependent relationship with volume of production treated water. However, for treated ballast water these three parameters are still unknown.

The screening process for the desalination can be replaced with treated ballast water due to the similarity in the treatment process of treated ballast water. As Singapore port received more than 28 billion m^3 of ballast water in a year, this volume can meet up Singapore's desalinated water which is 448,500 m^3 per day which is equivalent to 164 million m^3 yearly. This volume is enough to cover the needs of water required by Singapore to reduce water scarcity in this country. This can increase water production in Singapore which may be one of the useful results to reduce water scarcity in this region and meets national water demand as currently, desalination meets 25% of Singapore's water demand.

7. Conclusion

To conclude, the treatment process of desalinated water has similarity between the treatment process of treated ballast water which is screening process with filtration and disinfection process. As the Singapore Port received more than 28 billion m^3 of ballast water annually, this volume can be assumed to fulfil the demand for desalinated water in Singapore. As such, the ballast water received is sufficient to cover the needs of water to reduce the water scarcity that faces by Singapore.

Next, based on this study, treated ballast water can be used for seawater toilet flushing as the treated ballast water has passed through similar treatment process. However, an advance analysis should be conducted as both applications undergo the similar treatment process but the quality standard is different.

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