BACHELOR THESIS – ME141501

# EXPERIMENTAL STUDY ON THE COMBINATION OF UV RADIATION AND CRUMB RUBBER FILTRATION FOR BALLAST WATER TREATMENT

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DEPARTMENT OF MARINE ENGINEERING
FACULTY OF MARINE TECHNOLOGY
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SKRIPSI – ME 141501

# EKSPERIMEN PADA KOMBINASI RADIASI UV DAN FILTRASI SERBUK BAN PADA SISTEM PENGOLAHAN AIR *BALLAST*

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## APPROVAL SHEET

**Experimental Study on the Combination of UV Radiation and Crumb Rubber Filtration for Ballast Water Treatment**

**BACHELOR THESIS**

Submitted in fulfillment of the requirement for the degree of Bachelor in Engineering
at
Marine Operation and Maintenance (MOM) Laboratory
Bachelor Program (S-1) Department of Marine Engineering
Faculty of Marine Technology
Institut Teknologi Sepuluh Nopember

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**Experimental Study on the Combination of UV Radiation and Crumb Rubber Filtration for Ballast Water Treatment**

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## Abstract

Ballast water discharge could be the suspect of dangerous bio-invasion and also pollution. The bringing of other species from the origin port to the destination port can be harmful to the ecosystem. Phenomenon such as bio-invasion happens because there are no predators for the species brought by the ballast water. This concern leads to the making of regulations inside the International Convention for the Control and Management of Ships' Ballast Water and Sediments delivered by IMO. Stated in the regulation, point D-2 is the limitation of the number of pathogenic bacteria and microorganisms that are allowed to be in the ballast water when being discharged.Along with the implementation of the ballast water management regulation, several types of ballast water treatment were introduced, giving people option on how they should treat their ballast water before discharging. A study proposed that crumb rubber has the potential to be a good filtration for ballast water treatment. Waste-tire-derived crumb rubber was utilized as filter media to develop an efficient filter for ballast water treatment (Tang et al., 2009). Previous experiments have been done by Fauzi et al. in 2017 and Puspitasari et al. in the same year with a ballast water management prototype using a filter and UV radiation. Crumb rubber has the potential to be a good filter media but until now it has not been well developed. By using a smaller size of crumb rubber, the experiment of using 10 lpm as flow rate and 4 UV lights, resulted on a positive result. The findings in this research show 0 cfu/ml of bacteria in $10^{-2}$dilution factor. The repetition of the cycles also contributed on improving the ability to remove bacteria. Based on the results on $10^{-2}$dilution factor the repetition of the cycles/loops resulted in better filtration, respectively. The optimum result is shown after 5 cycles in the experiment without UV radiation, and for the experiment using UV radiation, 2 cycles is enough to filter microbes to 100%.

Keywords: ballast water treatment, D-2 Regulation of IMO, crumb rubber, bacteria, dilution, UV radiation, and filter.

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Surabaya, July 2018

Author

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# CHAPTER 1
# INTRODUCTION

## 1.1 Background

Ballast water technology was found since thesteel-hulled vessel was introduced to the marine industries. It is used for several purposes such as the vessel’s stability, balance,and trim. Placed in ballast tanks which is located on the double bottom and/or on the outboard area from keel to deck (wing tanks), ballast water is taken up or discharged when cargo is unloaded or loaded. Ballast water is taken up when thevessel is on empty (unloaded) condition, and so it is discharged when the vessel is ina loaded condition. This mechanism is also to ensure that vessels stay on their sufficient draft and therefore propeller can be fully immersed. Ballast water can be taken from anywhere, meaning on the spot wherever that vessel needs to take up ballast water, but on the contrary discharging ballast water is not a simple matter.

The introduction of non-native species from ships’ ballast water, in addition to other sources, is a matter that is causing increasing concern and is a potentially serious, but highly unpredictable problem, in all coastal marine ecosystems (Carlton 1996). A JNCC (Joint Nature Conservation Committee) review of non-native marine species in British waters estimates that around a third of the 51 non-native animals and plants found in British waters have been introduced by shipping, both in ballast waters and on ship’s hulls (Eno *et al* 1997).

Ballast water discharges are recognized as critical sources of pathogens, harmful algae blooms and Non-Indigenous Species (NIS) introduction (Aguirre-Macedo et al., 2008; Drake and Lodge, 2004; Hallegraeff, 2007; Molnar et al., 2008). To prevent potential environmental, human health and socioeconomic impacts of these introductions, the International Convention for the Control and Management of Ships' Ballast Water and Sediments (referred after as “BWM Convention”) was adopted in February 2004 by the International Maritime Organization (IMO, 2004). The Convention aims to prevent the spread of harmful aquatic organisms from one region to another and halt damage to the marine environment from ballast water discharge, by minimizing the uptake and subsequent discharge of sediments and organisms ("BWM Convention" International Maritime Organization).

Along with the implementation of the ballast water management regulation, several types of ballast water treatment were introduced, giving people option on how they should treat their ballast water before discharging. In general, ballast water treatment can be done by; filtration systems (physical), chemical disinfection (oxidizing and non-oxidizing biocides), ultra-violet (UV) radiation, deoxygenating treatment, heat (thermal treatment), acoustic (cavitation treatment), electric pulse/pulse plasma systems, and magnetic field treatment.

A study proposed that crumb rubber has the potential to be a good filtration for ballast water treatment. Waste-tire-derived crumb rubber was utilized as filter media to develop an efficient filter for ballast water treatment (Tang et al., 2009). Though result shows that crumb rubberdecreases the amount of microorganism content on filtered ballast water, crumb rubber alone is still not enough to filter the microorganism content to meet the requirement from Ballast Water Management Convention. It is suggested to combine crumb rubber filtration and chemical/physical disinfection (e.g., UV radiation) to meet the ballast water treatment criteria. Other research on crumb rubber as filtration media also states that crumb rubber has toxic content in it and that might be the reason why crumb rubber is a good ballast water filter due to its ability to kill microorganisms in ballast water(Burleigh et al., 2011).

Previous experiments have been done by Fauzi et al.in 2017 and Puspitasari et al.in the same year with a ballast water management prototype using a filter and UV radiation. The latest experiment done by Puspitasari et al scales up the original prototype made by Fauzi et al to see if microorganism content decrease or even meet the regulation criteria. Results from the latest experiment showed that microorganism content still hasnotmet the criteria, therefore using smaller crumb rubber as the filtration media will be the alternative used in this research and expected to meet the requirement.Furthermore, repetition of the cycle/loop of ballast water treatment will be done to check if it impacts the amount of microorganism content on the treated ballast water.Crumb rubber has the potential to be a good filter media but until now it has not been well developed. This research aims to exploit the benefits of crumb rubber as a filter media for ballast water treatment and apply it to the prototype.

## 1.2 Research Question

The study shall answer the following questions:

1. Does the size parameter of the crumb rubber as the filter media have any impacts on the filtration efficiency?
2. What are the chemical contents of crumb rubber and which of the chemical contents hasthe ability to inactivate or terminate the microorganism contained in the ballast water?
3. Does the repetition of the cycle/loop of ballast water treatment have any impact on the amount of microorganism content on ballast water which had been treated?
4. How does the filter affect the ballast water treatment process?
5. What does the result of this experiment showcompare to the previous experiments?

## 1.3 Research Limitations

Limitations of this study are as follows:

1. Ballast water sample is taken from Kenjeran
2. The ballast water prototype is a laboratory-scale prototype and currently belongs to the 4$^{th}$ Level of “Technology Readiness Level” (TRL).

3. Flow rate tested are only on 10 lpm referring to the optimum flow rate of previous studies.
4. Regulation used to evaluate treated ballast water is based on the Ballast Water Management Convention – IMO, but only *Enterobacter* will be considered.

## 1.4 Research Objectives

The objectives of this thesis are as follows:

1. To identify the efficiency of smaller size-crumb rubberon the ballast water treatment process.
2. To identifythe chemical contents of crumb rubber and which of the chemical contents has the ability to inactivate or terminate the microorganism.
3. To determine the impact of repetition on the cycle/loop of the ballast water treatment system on the amount of microorganism content on ballast water which had been treated.
4. To determine the impact of the filters on the ballast water treatment process.
5. To compare the result to previous experiments.

## 1.5 Project Deliverable

Specification of the filters(crumb rubber) that can eliminate the number of microorganisms. Note that the prototype in this research is still a laboratory-scale prototype.

## 1.6 Benefits of Research

Benefits taken from this thesis when it is done are as follows:

1. As a base research to reach TRL-9 and enter mass production.
2. As a recommendation for the upcoming research on ballast water treatment using UV and crumb rubber filtration.

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# CHAPTER 2
# LITERATURE REVIEW

## 2.1 Problem Overview

Ballast water discharge could be the suspect of dangerous bio-invasion and also pollution. The bringing of other species from the origin port to the destination port can be harmful to the ecosystem. Phenomenon such as bio-invasion happens because there are no predators for the species brought by the ballast water. This concern leads to the making of regulations inside the International Convention for the Control and Management of Ships' Ballast Water and Sediments delivered by IMO. Stated in the regulation, point D-2 is the limitation of the number of pathogenic bacteria and microorganisms that are allowed to be in the ballast water when being discharged.

Since September 2015, Indonesia became one of many ratifying countries of Ballast Water Management Convention and therefore has the responsibility to obey the regulations. This is quite new for the Indonesian ship industry and until now there are still no products of ballast water treatment originally made by an Indonesian company. This leads to new studies and research on ballast water treatment in Indonesia. As a matter of fact, research about ballast water treatment is until now a topic that still needs improvement.

Fauzi et al., 2017 have conducted an experiment over ballast water treatment prototype with a combination method of UV radiation and filter. He managed to design and built a prototype for ballast water treatment using one filter and two UV lights. For the filtration media, he uses crumb rubber and then activated carbon compares the result. It is stated in his conclusion that the prototype could remove 99% of microorganism content, and it is also mentioned that using carbon as a filtration media works better than crumb rubber. This experiment is continued by Puspitasari H., from 2017 to validate the value of theprevious result. It was found later on byPuspitasari that microorganisms from Fauzi'sexperiment died during dilution and not by the treatment. The solution used for the dilution killed microorganism by hemolysis.

Puspitastasari H.scaled up to two times of the original prototype and thus the current prototype has two filters and four UV lights. With smaller size of crumb rubber, it shows abetter result than on the earlier experiment. Eventhough the result was better;still, the result did not meet the requirement of BWM IMO. This has become the root problem of this thesis.

## 2.2 Ballast Water System

Ballast water is used on a vessel for the purpose of its stability, balance, trim and to maintain stress loads within acceptable limits. It is taken up (from thesea or another source) to fill the designated tanks that could be located on several areas such as the double bottom, the wing tanks or hopper tanks (occupying the upper corner section between thehull and main deck). According to American Association of Port Authorities (AAPA), in general, a vessel takes on ballast water as it unloads cargo and discharges ballast water as it loads cargo. In addition, a vessel may take on ballast water as it enters a harbor to safely pass under bridges and discharges ballast to safely cross shoals on the bottom of the waterway. This mechanism is also to ensure that vessels stay on their sufficient draft and therefore propeller can be fully immersed.

Ships are designed to carry passengers or cargoes such as oil, aggregates, grains, products in containers, fish, cars, and so much more from one place to another. Some ships could only transport goods from one place to the destination and then head back to its initial port empty loaded. An example of this is oil tankers, each of an oil tanker are designed to load specific type(s) of cargo, therefore density becomes an issue when cargo is changed. This gives impact to the stability of the ship if the ship is loaded with another type of oil with a different density. When an oil tanker is designed to carry marine diesel oil with the density offor example 0.86g/m3and then forced to carry heavy fuel oil with the density higher than that, the ship will reach its draft before the cargo hold is full. This leaves void space inside the cargo, disturbing the stability of the ship due to the movement of fluid causes by external factors. This could also put the safety of its crews in jeopardy. Therefore if a ship is travelling without cargo or without full cargo, ballast water is needed to fulfill the vessel's draft when cargo hold is empty and also to achieve the required safe operating conditions. Figure 1describes the mechanism of ballast water intake and discharge.

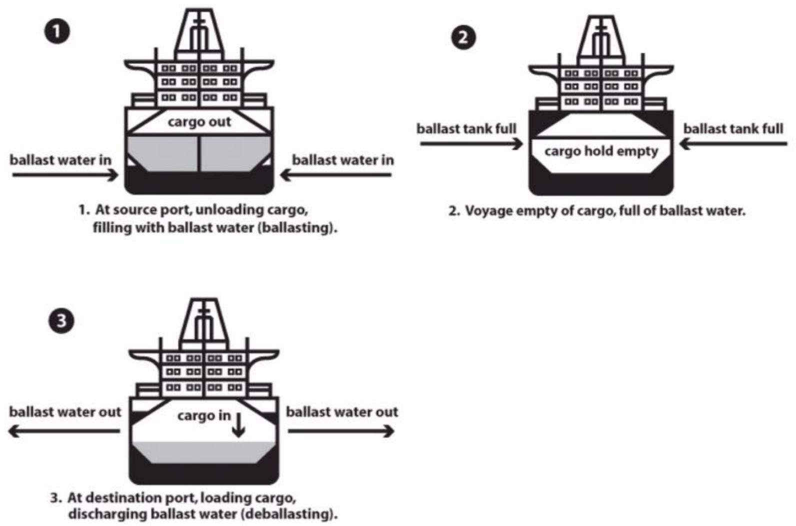


Figure 1 Ballasting and deballasting mechanism

*Source:[https://www.tc.gc.ca/eng/marinesafety/oep-environment-ballastwater-defined-249.htm](https://www.tc.gc.ca/eng/marinesafety/oep-environment-ballastwater-defined-249.htm)*

## 2.3 Regulations on Ballast Water Management

Shipping moves over 80% of the world's commodities and transfers approximately three to five billion tonnes of ballast water internationally every year. Ballast water is essential to the safe and efficient operation of shipping, but it also poses a serious ecological, economic and health threat through the transfer of invasive aquatic species inadvertently carried in it (Understanding Ballast Water Management, Lloyd's Register, 2016). Many cases of bio-invasion happen due to ballast water discharge. Foreign species are carried to another place where natural predators do not exist. This has caused the foreign species to overpopulate and endangered the local species.The impact of bio invasion could be very severe; an example is ared tide. A red tide refers to an algae bloomof several species of dinoflagellates which appear red. A bloom of *Karenia brevis* (one of the dinoflagellate species that causes red tide) poses danger to marine life and human health. *Karenia brevis* produces a potent neurotoxic which could harm or even kill fish, seabirds and marine mammals in a large amount. A fish kill due to red tides happens along a six-county stretch that includes Pinellas, Sarasota, Manatee, Charlotte, Lee and Collier counties in Florida shown inFigure 2. Meanwhile, Figure 3shows the map of the red tide concentration along the Florida counties.

Figure 2 Thousands of fish wash up on shores from Pinellas and Manatee counties to Sarasota south to Collier.

*Source:[https://patch.com/florida/bradenton/florida-gulf-coast-red-tide-concerns-prompt-call-research-funding](https://patch.com/florida/bradenton/florida-gulf-coast-red-tide-concerns-prompt-call-research-funding) (Courtesy of Manatee County Public Safety Department)*

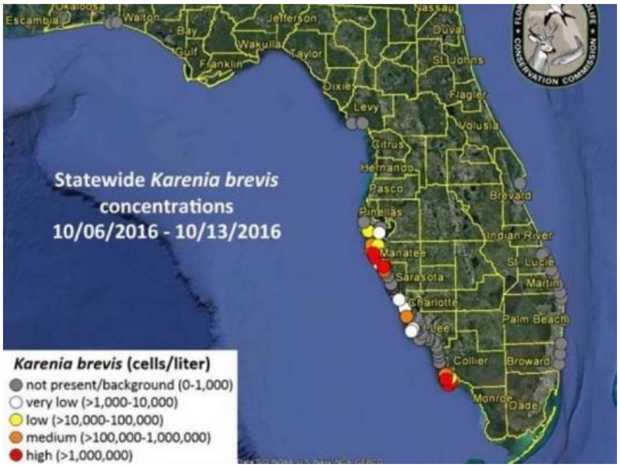


Figure 3 Map showing the concentration *Karenia brevis* as the cause of red tide along the countiesin Florida.

*Source: https://patch.com/florida/sarasota/red-tide-continues-cause-problems-sarasota-pinellas-manatee-counties (Courtesy of Florida Fish and Wildlife Conservation Commission)*

Negative impacts of ballast water discharge became a concern and later on,regulations over ballast water management start to rise. The “International Convention for the Control and Management of Ships' Ballast Water and Sediments” (BWM) is adopted on 13 February 2004 and entered into force on 8 September 2017. Since November 2015, Indonesia became one of 68 countries that ratify this convention, and therefore from then Indonesia shall follow the regulations on the BMW Convention and do its obligation as a ratifying country. Ratifying to this convention also means that Indonesia will have legal protection from *Invasive Alien Species* (IAS) or *Harmful Aquatic Organism and Pathogens* (HAOP) carried with ballast water by ships.

Under the Convention, all ships in international traffic are required to manage their ballast water and sediments to a certain standard, according to a ship-specific ballast water management plan. Regulations regarding the ballast water and sediments according to “International Convention for The Control and Managementof Ships’ Ballast Water and Sediments 2004” are listed below:

**Regulation B-5** *Sediment Management for Ships*

1. All ships shall remove and dispose of sediments from spaces designated to carry Ballast Water in accordance with the provisions of the ship‘s Ballast Water Management plan.
2. Ships described in regulation B-3.3 to B-3.5 should, without compromising safety or operational efficiency, be designed and constructed with a view to minimize the uptake and undesirable entrapment of Sediments, facilitate removal of Sediments, and provide safe access to allow for Sediment removal and sampling, taking into account guidelines developed by the Organization. Ships described in regulation B-3.1 should, to the extent practicable, comply with this paragraph.

**Regulation D-2** *Ballast Water Performance Standard*

1. Ships conducting Ballast Water Management in accordance with this regulation shall discharge less than 10 viable organisms per cubic meter greater than or equal to 50 micrometers in minimum dimension, and less than 10 viable organisms per milliliters less than 50 micrometers in minimum dimension and greater than or equal to 10 micrometers in minimum dimension; and discharge of the indicator microbes shall not exceed the specified concentrations described in paragraph 2.
2. Indicator microbes, as a human health standard, shall include:
   1) Toxicogenic *Vibrio cholerae* (O1 and O139) with less than 1 colony forming aunit (cfu) per 100 milliliters or less than 1 cfu per 1 gram (wet weight) zooplankton samples ;
   2) *Escherichia coli* less than 250 cfu per 100 milliliters;
   3) Intestinal *Enterococci* less than 100 cfu per 100 milliliters.

## 2.4 Restricted Microorganisms on Ballast Water

There arefour restricted microorganisms that are stated in the Ballast Water Management Convention of IMO. Among those four are plankton, toxicogenic *Vibrio cholerae* (O1 and O139), *Escherichia coli*, and intestinal *Enterococci*. Table 1consists the list of the number of microorganisms allowed referring to the convention.

Table 1thenumber of microorganisms of discharged ballast water that are allowed referring to BMW Convention IMO.
*Source: Lloyd's Register*

| Organism category | Regulation |
|---|---|
| Plankton, > 10-50 µm in minimum dimention | <10 cells/m³ |
| Plankton, 10-50 µm | <10 cells/m³ |
| Toxicogenic *Vibrio cholera* (O1 and O139) | <1 cfu/100 ml or less than 1 cfu/gr |
| *Eschericia coli* | < 250 cfu/ 100 ml |
| Intestinal *Enterococci* | < 100 cfu/ 100 ml |

a. Toxicogenic *Vibrio cholera*

*Cholera* is an acute diarrheal illness caused by toxigenic strains of the bacterium *Vibrio choleraesero*groups O1 and O139 (Cohen et al., 2012).*V. cholerae*is found commonly in marine and estuarine environments, living freely or on surfaces, such as plants and animal shells, and in intestinal contents of marine animals (Cabral, 2010). *V. cholerae* infection is typically acquired by ingestion of contaminated water or food (Seas et al., 2009). *Vibrio cholera*is short, curved, comma shaped gram-negative bacilli which can be readily stained by aniline dyes. They measure about 1.5 µ 0.2-0.4 µ in size, have rounded or slightly pointed ends. Figure 4shows how *V. cholera*looks under the microscope.

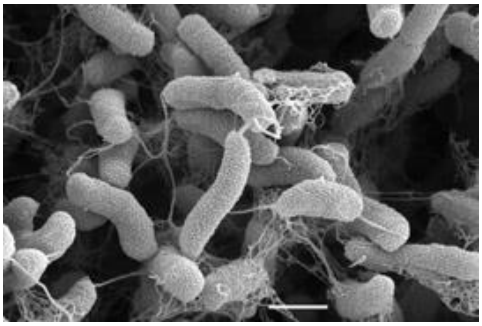

Figure 4*Vibrio cholera*
*Source: https://diritalab.natsci.msu.edu/research/*

b. *Escherichia coli*

*Escherichia coli* is a gram-negative, facultatively anaerobic, rod-shaped, coliform bacterium of the genus Escherichia that is commonly found in the lower intestine of warm-blooded organisms (endotherms) (Tenaillon et al., 2010). Most *E. coli* strains are harmless, but some serotypes can cause serious food poisoning in their hosts, and are occasionally responsible for product recalls due to food contamination (Vogt et al., 2005). Cells are typically rod-shaped and are about 2.0 µm long and 0.25–1.0 µm in diameter, with a cell volume of 0.6–0.7 $\mu m^3$. Figure 5is *Escherichia coli* seen under the microscope.

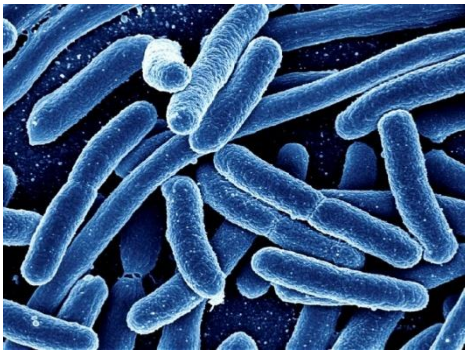

Figure 5*Escherichia coli*
*Source: https://www.bbc.com/news/health-13639241*

c. Intestinal *Enterococci*

These pathogens could sicken swimmers and others who use rivers and streams for recreation or eat raw shellfish or fish. Other potential health effects could include diseases of the skin, eyes, ears and respiratory tract. Figure 6is the scanning electron micrograph of *Enterococci*. Though they are not capable of forming spores, *Enterococci* are tolerant of a wide range of environmental conditions: extreme temperature (10–45 °C), pH (4.5–10.0), and high sodium chloride concentrations.

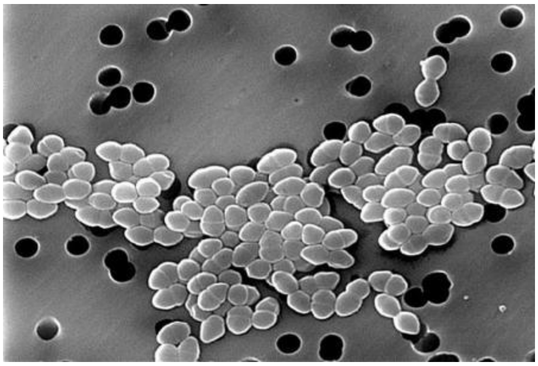

Figure 6 Intestinal *Enterococci*
*Source:Lisac Mark, U.S. Fish,and Wildlife Service*

## 2.5 Ballast Water Treatment Methods

There are two general types of process technology used in ballast water treatment; solid-liquid separation, anddisinfection.

Solid-liquid separation is simply the separation of solid material, including the larger micro-organisms, from the ballast water, either by sedimentation (allowing the solids to settle out by virtue of their own weight) or by surface filtration (removal by straining; i.e. by virtue of the pores in the filtering material being smaller than the size of the particle or organism). All solid-liquid separation processes produce a waste stream containing the remaining solids. This waste stream consists of the backwash water from filtering operations. On deballasting, the solid-liquid separation operation is generally bypassed.

Disinfection removes and/or inactivates micro-organisms using one or more of the following methods:

- chemical inactivation of the micro-organisms through either:
  - oxidising biocides – general disinfectants which act by destroying organic structures, such as cell membranesor nucleic acids; or
  - non-oxidising biocides – these interfere with reproductive, neural, or metabolic functions of the organisms.
- physicochemical inactivation of the micro-organisms through processes such as UV light, heat or cavitation
- asphyxiation of the micro-organisms through deoxygenation.

All of these disinfection methods have been applied to ballast water treatment, with different products employing different unit processes (see Figure 7). Most commercial systems comprise two or more stages of treatment with a solid-liquid separation stage being followed by disinfection.

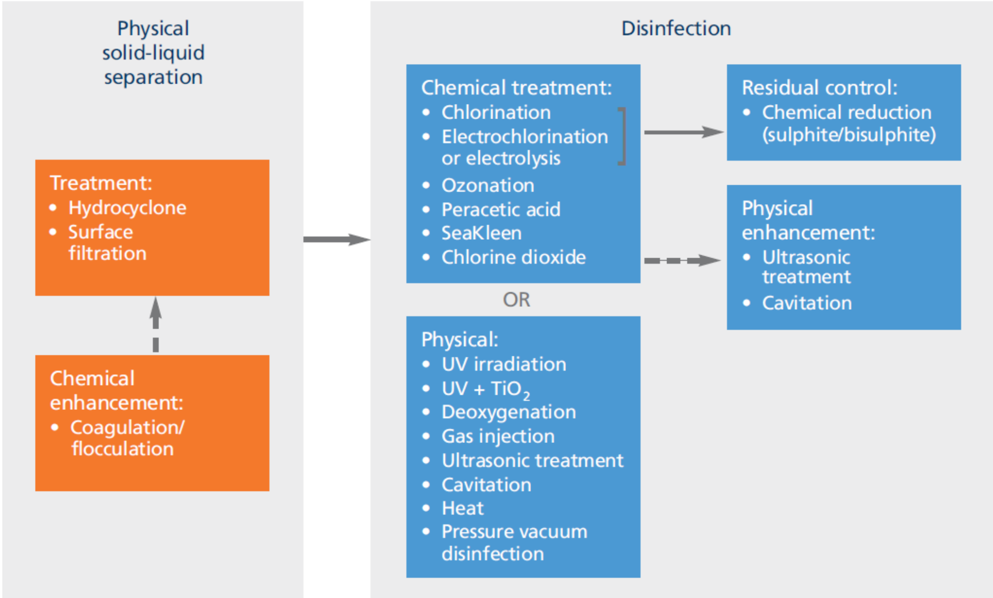


Figure 7 Generic ballast water treatment technology process options.
*Source: Lloyd's Register*

## 2.6 UV Radiation Method

One of the physical disinfection systems is using UV light radiation. UV radiation could leave cells in different conditions (live, dead or damaged), whereof the viability of damaged cells at discharge is uncertain (Olsen et al., 2015). UV light denatures the microorganism's DNA and prevents it from reproducing.

On this thesis, UV dosage of 120Watt will be used referring to the optimum result fromthe previous experiment done by Puspitasari H. in 2017. The benefits of using UV lights are first it is well established.Second it is used extensively in municipal and industrial water treatment applications, and third, it is effective against a wide range of micro-organisms and also compared to chemical disinfection UV light is considered more eco-friendly. The only thing that should be considered when using UV light is the turbidity of the water and the UV dosage. UV light works more effectively when the water is clear, therefore it is recommended to be combined by pre filtering for ballast water treatment. Figure 8shows an example of a UV tube on ballast water treatment system.

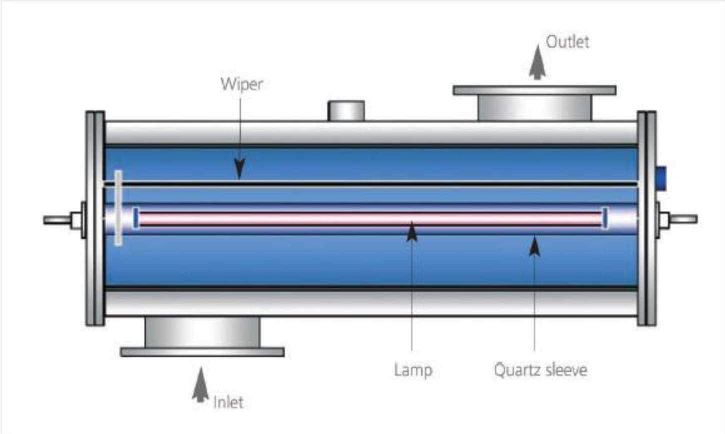


Figure 8 Example of a UV tube on the BWT system.
*Source: Lloyd's Register*

## 2.7 Crumb Rubber

Crumb rubber is the name given to any material derived by reducing scrap tires or other rubber into uniform granules. There are several processes for manufacturing crumb rubber. Two of the most common are ambient grinding and cryogenic processing.

Crumb rubber performed well in these biological wastewater treatment processes. Because of its elasticity, crumb rubber is an excellent filter medium for water and wastewater treatment. Using crumb rubber for wastewater filtration reduces scrap tire problems, and more importantly, it provides a new filtration technology which is far more effective than the current dual-media sand-anthracite filters. Figure 9 shows crumb rubber in different sizes, (from left to right) 6mm, 10 mesh,and 20mesh.

The crumb rubber used in this experiment is from the waste of a tire-retreading company. Before old tires are retreaded, the initial process was to first grind old tread off existing tires and then the retreading process takes place. This leaves waste of grinded tires from the initial process, and that is the crumb rubber used in this experiment. Though, the grinded tires-or some may call the tire chips-is not invaluable, the use of it has not lived up to its potential. It is used to create sandals and flip-flops. It is also known to be used for turf fields, although the safety of it to human health is still debatable. Another quite interesting use of the tire-retreading waste is on the city roads. Nowadays, asphalt is mixed with tire scraps that have been processed to form powder to create a better pressure-withstanding road. The idea of making tire waste into water filters is not yet popular. Few studies had been conducted especially on the use of crumb rubber for ballast water treatment, but it has never reached the point where crumb rubber is finally introduced to be an approved filter media for the ballast water treatment system.


Figure 9 Crumb rubber of different sizes.
*Source:* *http://syco.com.mx/asfaltos.php*

To increase the effectiveness of bacteria removal, the crumb rubber used in this experiment is smaller in size compared to a latest experiment done by Puspitasari on 2017. This hypothesis is driven by literature study from previous experiments (Tang et al., 2006) that show the better result with smaller size crumb rubber.

The size of the crumb rubber is approximately 4 mesh. Mesh size is not a precisemeasurement of particle size. Mesh is defined by how many openings there are in one inch of screen. The size 4 mesh is equaled to 4.75 mm. So, the size of the crumb rubber particles is 4.75 mm and below. This experiment uses a basket to sieve the crumb rubber. The size of the holes are 4.75 mm, therefore the crumb rubber particles can be defined by 4 mesh in size. Figure 10 shows the sample of crumb rubber used in the previous experiment (left) and the crumb rubber used in this experiment. (right). The size of the crumb rubber used on the previous experiment was approximately 5 mm x 5 mm. From the photos below, we could see the different of the shape and also the size of the filter media. The crumb rubber shown on the left were derived from cutting inner tire one by one. Meanwhile, the crumb rubber on the right side of the photo was taken from a tire-retreading company sieved with a basket having 4.75 mm size of holes.

Figure 10 Crumb rubber from the previous experiment (left), crumb rubber used in this experiment (right)

Despite its ability to perform well on wastewater and ballast water treatment, studies done on crumb rubber shows that crumb rubberconsists of several toxins that could leach through the water. This becomes the new consideration of this thesis compared to previously done by Fauzi et al. and Puspitasari et al. in 2017.

## 2.8 Total Plate Count Method

The method used to determine the total amount of microorganism content on treated ballast water in this research is the Total Plate Count (TPC) method. The Total Plate Count (TPC) is used as an indicator of bacterial populations on a sample. It is also called the aerobic colony count, standard plate count, mesophilic count or Aerobic Plate Count.

The test is based on an assumption that each cell will form a visible colony when mixed with agar containing the appropriate nutrients. It is not a measure of the entire bacterial population; it is a generic test for organisms that grow aerobically at certain temperatures (25 to 40°C).

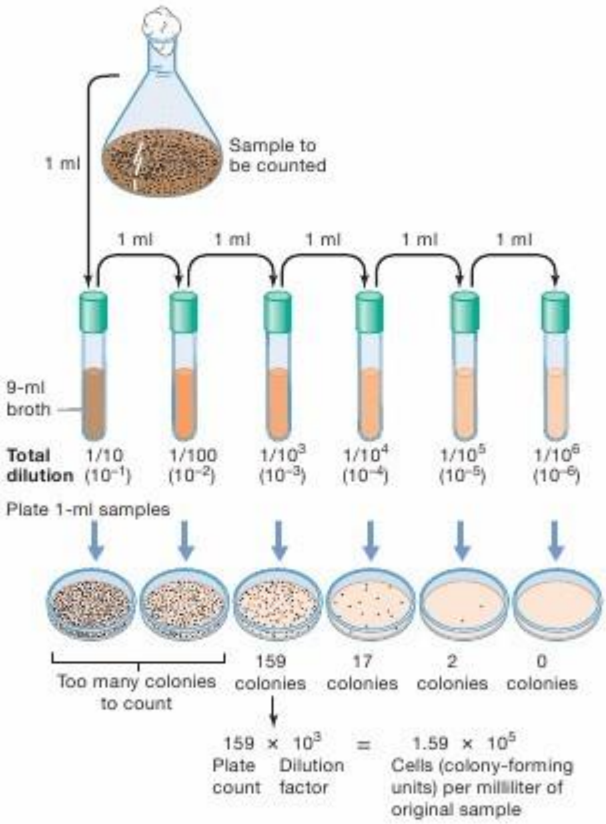


Figure 11 Mechanism of TPC method.
*Source:http://duniachemistry.blogspot.com/2015/11/total-plate-count-tpc.html*

Figure 11shows how the process of TPC. The process begins by mixing 9ml of diluents with 1ml of the sample. The second step is to take 1ml of the first mixture and add another 9ml of diluents. On this step, we obtain a $10^{-2}$ dilution. The same process is done until a number of desired dilutions.

## 2.9 Technology Readiness Level

"Technology Readiness Level" is a parameter that indicates at what point a particular technology is developing. This is to measure the maturity of a certain technology. There is more than 1 standard for TRL, for example, TRL established by NASA, U.S. Department of Energy, and Australia's Department of Defense. The standard of TRL used in this thesis will refer to TRL established by Australia's Department of Defense. Table 12 shows the TRL standard of Australia's Department of Defense. Like most TRL, Australia's Department of Defense divided the TRL into 9 levels. Level 1 for the least-developed technology and level 9 indicates the most mature technology. It is shown in Table 2 the description of each level. Referring to the TRL, the prototype in this thesis can be classified into TRL 4 since the prototype has been made but was still not capable to be applied to the real condition. Other than that, laboratory testing will also occur to validate the result of the ballast water treatment prototype.

This prototype will need more improvements to reach TRL 8, let alone TRL 9. But first, this thesis is proposed to verify the strength and weakness of the crumb rubber since the filter is the most important equipment on the system. Once the research of the filter is done the next step is to improve on the materials of the prototype itself. After that, the study can be continued by adjusting the size of the prototype to the real application and also to check if changes apply in the position of the sub system could affect the competence of the whole system. From this, the prototype shall be verified through a number of tests and then be commercially demonstrated. If this step is through, then this project has reached its finish line, TRL 9, where the ballast water treatment system will finally be able to enter mass production.

Table 2 Technology Readiness Level established by Australia's Department of Defense
*Source: https://www.dst.defence.gov.au/sites/default/files/basic_pages/documents/*

| | Technology Readiness Level Definition |
|---|---|
| **TRL 1** | **Basic Research:** Initial scientific research has been conducted. Principles are qualitatively postulated and observed. Focus is on new discovery rather than applications. |
| **TRL 2** | **Applied Research:** Initial practical applications are identified. Potential of material or process to solve a problem, satisfy a need, or find application is confirmed. |
| **TRL 3** | **Critical Function or Proof of Concept Established:** Applied research advances and early stage development begins. Studies and laboratory measurements validate analytical predictions of separate elements of the technology. |
| **TRL 4** | **Lab Testing/Validation of Alpha Prototype Component/Process:** Design, development and lab testing of components/processes. Results provide evidence that performance targets may be attainable based on projected or modeled systems. |
| **TRL 5** | **Laboratory Testing of Integrated/Semi-Integrated System:** System Component and/or process validation is achieved in a relevant environment. |
| **TRL 6** | **Prototype System Verified:** System/process prototype demonstration in an operational environment (beta prototype system level). |
| **TRL 7** | **Integrated Pilot System Demonstrated:** System/process prototype demonstration in an operational environment (integrated pilot system level). |
| **TRL 8** | **System Incorporated in Commercial Design:** Actual system/process completed and qualified through test and demonstration (pre-commercial demonstration). |
| **TRL 9** | **System Proven and Ready for Full Commercial Deployment:** Actual system proven through successful operations in operating environment, and ready for full commercial deployment. |

TRL 4 is the initial step to put together components into a whole system which is expected to work efficiently. The difference between TRL 4 and 5 is that on TRL 5 the results should be verified by laboratory testing the whole system, meanwhile, currently the ballast water prototype has not reached that stage yet and the filter is currently still the priority of the study.

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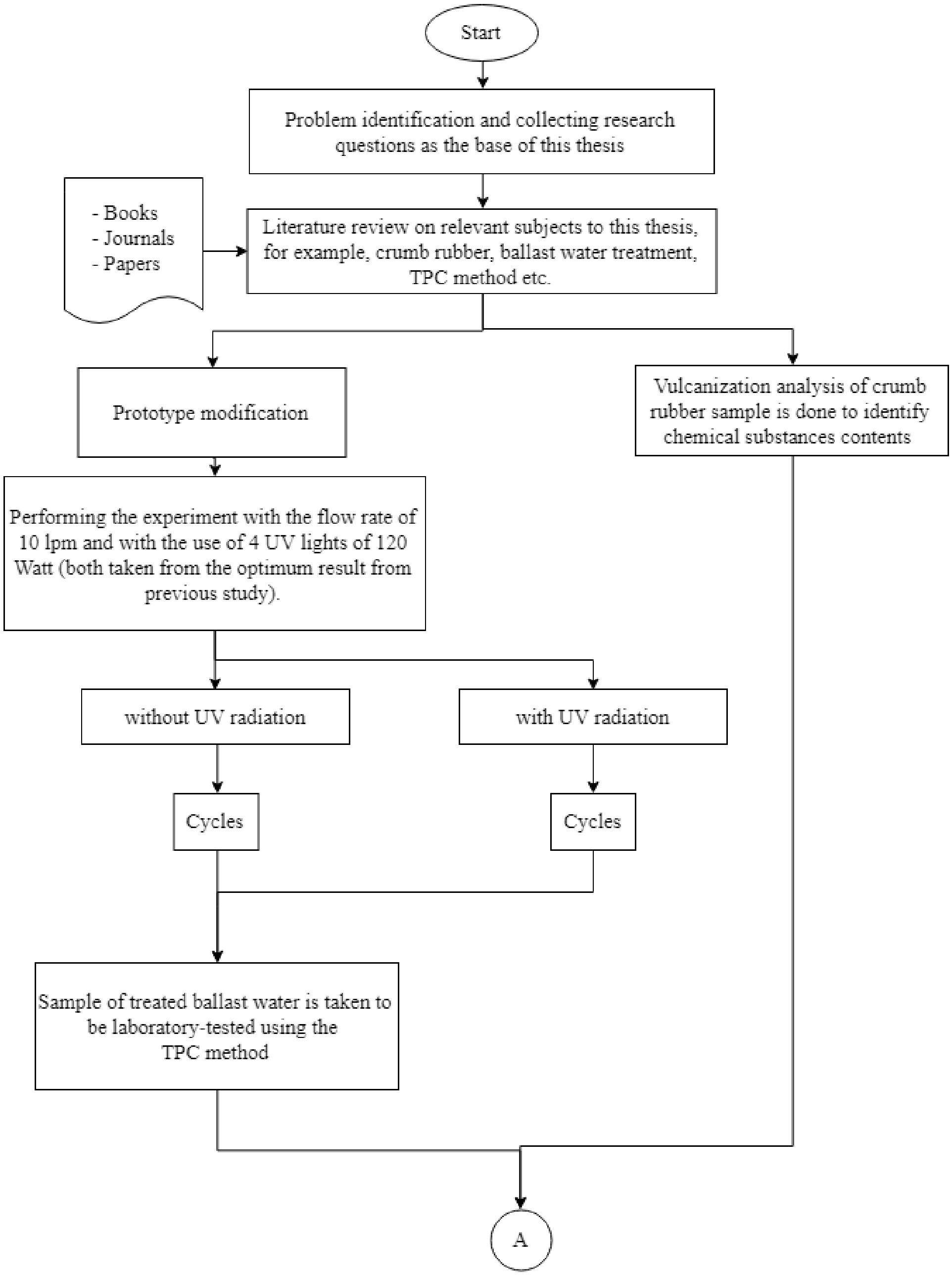
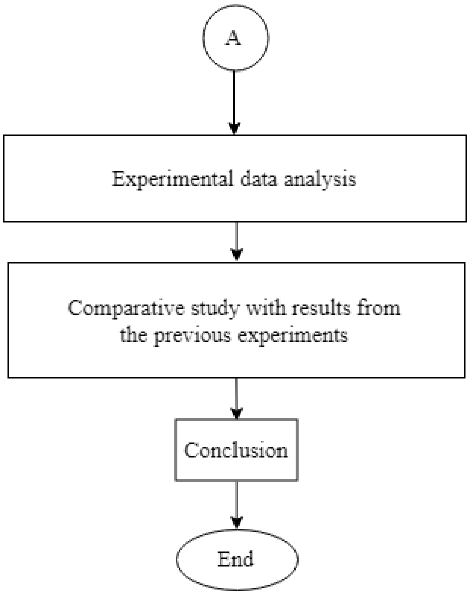
# CHAPTER 3
# RESEARCH METHOD

## 3.1 Overview

The research method is explained by a flowchart consisting steps of the process of doing this thesis.






## 3.2 Problem Identification

Problem identification is the first step of writing this thesis. The research questions for the thesis areobtained through problem identification. The main problem comes from the previous experiment where the results still did not meet the requirements of the regulation. The result from the experiment in the previous study shows that there are still about $x.10^4$ to $x.10^6$ amount of coli form bacteria which is far from the number of bacteria allowed according to the regulation. This is the core reason why this study is proposed by the writer, to achieve better results which are expected to meet the regulation.

## 3.3 Literature Review

After knowing the problems, a literature review is done to obtain more valid information as a standard and scientific base for this thesis. The literature review is done by reading journals, papers, and books. A literature review is also needed to seek original definition stated by scientists or experts. It is important to state the original definition and valid information in this thesis in order to make this thesis more convincing.

## 3.4 Vulcanization Analysis

From the previous study, the chemical contents of the crumb rubber are not considered. Not to mention one of the filters in Puspitasari's experiment were bought and not self made, so the ingredients of that filter are unknown, although generally it was a carbon filter, yet Puspitasari did not know the contents of it. For the crumb rubber filter, it was homogenous in terms of size

A sample of the crumb rubber that will be used for the experiment will be laboratory-tested to identify the chemical contents of the crumb rubber. The method to test the crumb rubber is called vulcanization analysis. This step helps determine which chemical substance(s) has the ability to inactivate or terminate microorganism on ballast water. There are several aspects that are necessary to be known from the crumb rubber contents regarding the relevancy of this thesis.

As recommended by the scientist on the Head Office of Indonesian Rubber Research Institute (Pusat Penelitian Karet), the tests needed for the crumb rubber sample related to the purpose of this thesis are shown on Table 3.

Table 3 List of the tests for the crumb rubber sample.
*Source: Head Office of Indonesian Rubber Research Institute (Pusat Penelitian Karet), Bogor.*

| No. | Analysis |
|---|---|
| 1. | Acetone Extract Level (%) |
| 2. | Ash content Level (%) |
| 3. | Type of polymer |
| 4. | Total sulfur content (%) |
| 5. | Content of vulcanization composition:<br>- Polymer content (%)<br>- Carbon content (%)<br>- Plasticizer content (%) |
| 6. | Type of vulcanization composition:<br>- Type of Plasticizer<br>- Type of Accelerator<br>- Type of Antioxidant |

The result will then be analyzed; which chemical substance(s) has the potential to penetrate into the microorganism and succeed to inactivate it by looking at the toxicity of the chemical substance itself. Even if the chemical substance is not considered as toxic, the chemical formula of each substance should be taken into account to find possibilities that the substance is harmfulto the microorganism contained in the ballast water. Other than that, there are also possibilities that these chemical substances will not inactivate butinstead, it binds with the microorganisms. Thus it makes the microorganism trapped in the filter. If that is the case, life span or the crumb rubber’s ability to bind shall be determined to prevent it from releasing the microorganisms or bacteria back to the water when it could not hold on to it anymore.

## 3.5 Prototype Modification

On this step, the prototype modification will be done as the beginning of the main activity of this thesis. New fittings are installed on the prototype such as valves and pipes to adjust the needs of the research.

## 3.6 Performing the Experiment

Doing the experiment is the main part of this thesis, which by conducting this step the writer could obtain the results. It is very important to pay attention to the details of this process for any small mistakes could later lead to false judgment on taking the conclusion. Since this study is the third research from the initial study done by Fauzi et. al on 2017, the execution of this experiment shall be improved in terms of detailing the data. Previously the properties of the filter have not been recorded. For example, the mass of the filter media was not measured, so each experiment might have a different mass of crumb rubber on the filters. Owing to the fact that the mass were not measured, there is a possibility that the crumb rubber receives different pressure from filling the cartridge to full condition. Things like this could have an impact on the result. As to make this experiment more detailed, the writer will try to record all matters related to the validation of the result. Therefore there are several preliminary steps before doing the actual experiment.

## 3.7 Experimental data analysis on treated ballast water and tested crumb rubber

When the experiment is done, data from the experiment will be obtained and from there we can determine the impact of the activities done in this thesis. The method to count the amount of microorganism content on treated water is TPC or Total Plate Count. Explanation of how this method is performed is stated in Section 2 – Literature Review.

## 3.8 A comparative study with results from previous experiments

The next step will be processing the experimental data. Data is compiled and formed to table or graphs. By then results of this experiment will be compared to pre-existing experiments.

## 3.9 Conclusion

This is the last step of this thesis. A comparative study will show which one has the best result. On this step, all research questions will be answered. Recommendations will be made for further research on relating topics.

The results of this thesis which are in a form of experimental data could be a reference for upcoming studies. The output expected is that through this prototype, ballast water is treated to meet the requirement of the BWM Convention.

# CHAPTER 4
# RESULTS AND DISCUSSION

## 4.1 Ballast Water Treatment Prototype 2.1

The ballast water treatment prototype 2.1 is the newest version of this prototype. The first prototype was made by Fauzi, to complete his bachelor thesis on 2017 (Ballast Water Treatment Prototype 1.0). Soon after, the study was preceded by Puspitasari to enhance the quality as well as the efficiency of this prototype. The secondprototype which is shown on Figure 14 with the blue paint (Ballast Water Treatment Prototype 2.0), had through significant modification from the first prototype to validate the accuracy of the results of the first study done by Fauzi. The second study attempted to larger the volume of UV reactor and double the amount of filter to increase the efficiencyof the prototype since the outcome of the first study still could not meet the requirements of the IMO-BMW regulation.Figure 12 shows the work flow of the prototype's system.

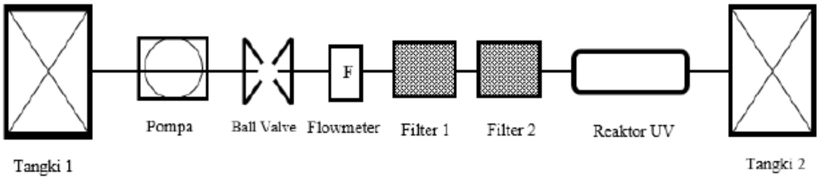



Figure 12 Work flow of the prototype's system

*Source: Puspitasari, H.(2017) Scalling Up Prototipe Sistem Pegolah Air Balas Menggunakan Filtrasi Karet Remah dan Radiasi Sinar UV. Surabaya.*

There are no significant modifications done on the latest version of the prototype. Changes apply on fittings and additional pipeline.The prototype modifications took place in Surabaya, and require three weeks to finish. Modifications of the prototype include:

1. Fitting replacements
2. Addition of pipeline from output to Tank I
3. Addition of drain valve on UV reactor
4. Addition of wheels
5. Flow meter replacement
6. Addition of valves on the output section
7. Addition of stainless steel plate in the inside part of both tanks
8. Rust removal and repaint

Figure 13, Figure 14, and Figure 15show several parts of the prototype that had been modified or changed.


Figure 13 New drain valve installed on UV reactor


Figure 14 New flow meter installed on the prototype.


Figure 15The new pipeline from output line, bypassed to the input tank.

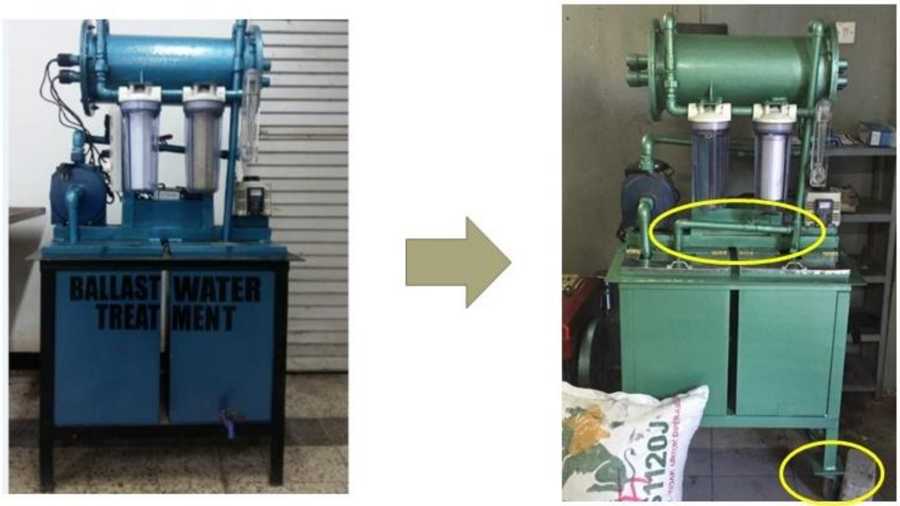



Figure 16 Before and after modification. Not all changes are shown in the picture.

## 4.2 Vulcanization Analysis

The contents from the crumb rubber were analyzed and the results of the vulcanization analysis are shown onTable 4.

Table 4 Results of vulcanization analysis from RPN-Bogor.

| No. | Analysis | Test Method | Result |
|---|---|---|---|
| 1. | Acetone Extract Level (%) | ASTM D297-93 (ra 2006) | 6.52 |
| 2. | Ash content Level (%) | ASTM D297-93 (ra 2006) | 5.92 |
| 3. | Type of polymer | ASTM D3677 - $10^{\epsilon 1}$ | Isoprene Rubber + Styrene Butadiene Rubber |
| 4. | Total sulfur content (%) | ASTM D297-93 (ra 2006) | 1.74 |
| 5. | Content of vulcanization composition: | LP-PPK* | |
| | - Polymer content (%) | | 59.46 |
| | - Carbon content (%) | | 28.10 |
| | - Plasticizer content (%) | | 4.25 |
| 6. | Type of vulcanization composition: | | |
| | - Type of Plasticizer | | Naphthenic Mineral Oils |
| | - Type of Accelerator | | Benzothiazole |
| | - Type of Antioxidant | | Not Detected |

From doing literature review, it is assumed that acetone and isoprene rubber are potential in inactivating the microorganism. Acetone, like alcohol serves as antibacterial, meanwhile isoprene has an unsaturated chemical formula in which it is potential to bind with the bacteria. There are 28.1 % content of carbon present on the crumb rubber. Carbon has high porosity and therefore it is also included as a potential filter for the bacteria. Further research should be done on this.

## 4.3 Preliminary Study

### 4.3.1 Preparing the Tools and Materials

In order to run the experiment properly and get the best result, all the tools and materials needed have to be well prepared.

1) Tools
   a. Two sets of Filters

   One set of filter consists of one filter housing and one filter cartridge inside. Figure 17shows the empty filter cartridge (a) and the filter housing (b).

(a) (b)

Figure 17 (a) Filter cartridge; (b) Filter housing

   b. One set of Pressing Tool

   The crumb rubber was not only filled on the cartridge but also pressed to make it condense. To press crumb rubber inside the filter cartridge, the compression tool is attached to a digital hanging scale. The compression tool and the digital hanging scale are shown inFigure 18. Figure 19shows the mechanism of the pressing process.

Figure 18 Compression tool.


Figure 19Digitalhanging scale

c. Two Buckets (medium to large size)

The buckets are used to transfer water from input tank to output tank, and for other purposes related to the experiment.

d. Sampling kit

The sampling kit consists of a bottle of 70% alcohol spray, sampling bottles, latex gloves, container box, and labels.

e. Stopwatch

f. Scissors, cutter, tape, etc.

g. Basket

The basket is used to sieve and separate big chunks of crumb rubber. The holes are approximately 5mm x 5mm, so particle larger than 5mm would not be able to pass through.

h. Digital Scale

The digital scale is used to weigh the crumb rubber before inserted to the filter cartridge.

i. Thermometer

Thermometer is used to measure the temperature of the sea water when taken for the experiment.

2) Materials

a. Crumb Rubber

The crumb rubber used in this experiment has the maximum size of 4 mesh. It is taken from tire-retreading Company. The crumb rubber is shown onFigure 20.

Figure 20 Crumb rubber used for the filter media.

b. Sea Water

The sea water which is takenaround 100 m from the shore is from Kenjeran Beach, Eastside of Surabaya. To be accurate, the exact location is shown on Figure 21 (a). The sea water for this experiment is taken on 5$^{th}$ of June 2018 at around 10:00 in the morning. The temperature of the water was 28°C as shown onFigure 21 (b). The sea water is brought to the experiment place from Kenjeran in 30 liter plastic jerrycans. In order to take the sea water the writer uses the service of local fisherman (Figure 22).

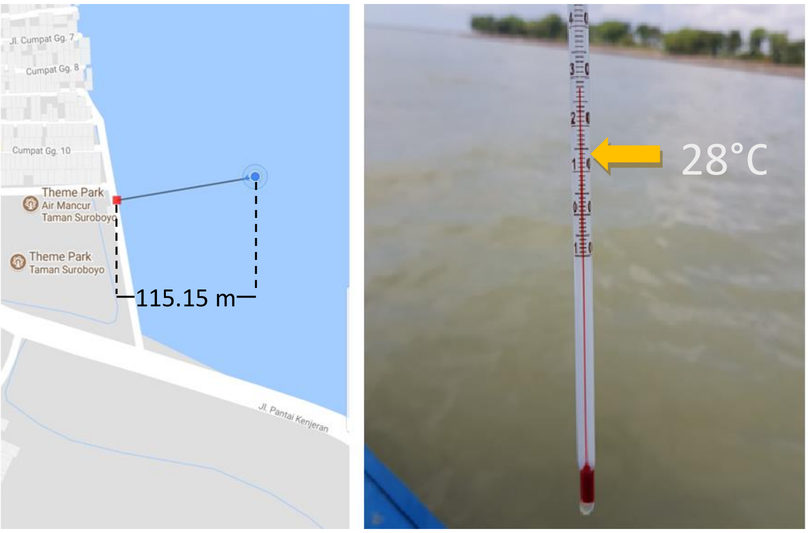


Figure 21 Exact location of sea water sample (left); temperature of the sea water (right).


Figure 22 Condition when taking sea water.

c. Sponge

Sponge is used inside the cartridge to prevent smaller particles of crumb rubber to leach. Sponge is placed on the bottom and top of the cartridge as shown on Figure 23.

Figure 23Sponge (orange color) on the top and bottom side of crumb rubber.

### 4.3.2 Pressing the Filters

To achieve better performance, the crumb rubber inside the filter cartridge is pressed. There are three alternatives of pressure; 5kg, 10kg, and 15kg. The tools used for pressing are shown in previous sub chapter. The mechanism of the pressing process is shown on Figure 24.

Figure 24 Mechanism of pressing process.

First, 1/3 of the cartridge is filled with certain amount of crumb rubber which has been weighed. Then the compression tool is placed on top of the filter media. The digital hanging scale is pushed downwards to reach the desired pressure. This step is repeated until the cartridge is full of crumb rubber.

The filter cartridge is then placed at the filter housing. Then put enough water in the input tank. The prototype is turned on for 20 seconds, and the system runs at 10lpm. After 20 seconds, the prototype is turned off and sea water on the output tank is measured. This procedure is repeated three times on each pressure to obtain a valid data. The average of the volume of water will be calculated on each pressure.

Table 5shows the recorded volume of water on each experiment. The result shows that the average amount of water is least on the experiment which filters pressed with 15kg of force. This concludes that the higher the pressure, the more resistance the filter gives to the water that went through. This condition is considered good because the water is expected to not only pass the filter but also to find ways through the smallest possible gaps. From this experiment, the pressure used for the ballast water treatment is 15kg.

Table 5Results of pressing the filter media-experiment.

| Experiment | Pressure (kg) | LPM | Mass (kg) | Time (s) | Water Volume (l) | Average Volume (l) |
|---|---|---|---|---|---|---|
| Repetition -1 | 5 | 10 | 0.26 | 20 | 2.3 | 2.291667 |
| Repetition -2 | 5 | 10 | 0.27 | 20 | 2.225 | |
| Repetition -3 | 5 | 10 | 0.26 | 20 | 2.35 | |
| Repetition -1 | 10 | 10 | 0.29 | 20 | 1.75 | 1.891667 |
| Repetition -2 | 10 | 10 | 0.29 | 20 | 1.825 | |
| Repetition -3 | 10 | 10 | 0.295 | 20 | 2.1 | |
| Repetition -1 | 15 | 10 | 0.3 | 20 | 1.85 | 1.86 |
| Repetition -2 | 15 | 10 | 0.35 | 20 | 1.83 | |
| Repetition -3 | 15 | 10 | 0.335 | 20 | 1.9 | |

### 4.3.3 Determining the Number of Cycles

Unlike the previous study done by Puspitasari et. al, this research propose repetition of cycles in the system. To determine how many cycles is effective for the filter, a few experiments need to be conducted. The hypothesis is that at a certain number of cycles, the filter will reach its saturation point. This will be seen on the volume of sea water on the output. The experiment is by measuring the volume of sea water after each cycle. To collect enough data, the writer had done three same experiments in a row, which then the result is taken by counting the average of the volume from each experiment. Figure 25shows how the water from each cycle is collected in buckets. From there the volume is measured. The time of each cycle is determined by the volume of the input tank. One cycle is defined as the time needed for the water from the input tank (on the left side of the prototype) to be delivered to the output tank in 10lpm debit/capacity (Q). This calculation is shown on the formula below.

Volume of the tank:

$$V = l \times w \times h$$
$$V = 33 \times 35.5 \times 37 \ (cm)$$
$$V = 43{,}345.5 \ cm^3$$
$$V = 43.3455 \ dm^3$$
$$V = 43.3455 \ litres$$

Total volume – volume of tank with *h* of strainer

$$V = l \times w \times (h - h_1)$$
$$V = 33 \times 35.5 \times (37 - 4) \ (cm)$$
$$V = 38{,}659.5 \ cm^3$$
$$V = 38.6595 \ dm^3$$
$$V = 38.6595 \ litres$$

Time per cycle:

$$Q = \frac{V}{t}$$

$$10 \ lpm = \frac{38.6595}{t}$$

$$t = 3.86595$$

$$t = 3.87 \ minutes$$

$$t = 3 \ minutes \ 52 \ seconds$$

Figure 25Sea water is collected in buckets to be measured.

Table 6 Number of cycles-experiment.

| Experiment | Water volume (liters) | | | |
|---|---|---|---|---|
| | Repetition - 1 | Repetition - 2 | Repetition - 3 | Average |
| cycles -1 | 31.75 | 32.45 | 30.30 | 31.50 |
| cycles -2 | 33.25 | 33.10 | 31.75 | 32.70 |
| cycles -3 | 33.25 | 32.70 | 25.75 | 30.57 |
| cycles -4 | 33.10 | 32.30 | 29.95 | 31.78 |
| cycles -5 | 32.55 | 32.35 | 30.55 | 31.82 |
| cycles -6 | 28.35 | 32.45 | 30.75 | 30.52 |
| cycles -7 | 26.15 | 30.45 | 30.80 | 29.13 |
| cycles -8 | 23.50 | 29.85 | 31.00 | 28.12 |
| cycles -9 | 20.45 | 20.45 | 30.20 | 23.70 |

Table 6shows the result of the first experiment in finding the number of cycles. It is seen from the average volume of each cycle that the number starts to drop at cycle-6. If we look at cycle-9 on repetition 1 & 2, the volume is both 20.45l. The total amount of water loss in the first and second repetition is calculated as follows:

Water loss in first repetition:

$$V = Cycle1 - Cycle9(litres)$$
$$V = 31.75 - 20.45\ (litres)$$
$$V = 11.3\ (litres)$$

Water loss in second repetition:

$$V = Cycle1 - Cycle9(litres)$$
$$V = 32.45 - 20.45\ (litres)$$
$$V = 12\ (litres)$$

This happens due to the quality of the sea water. The sea water taken for this experiment is from the shore of Kenjeran Beach therefore it consist a lot of sand. At the end of cycle-6, the sand and other particle subject to the turbidity of the sea water eventually clogged the filter. This is followed by the declining of the debit shown on the flow meter. At some point it even reaches 0 lpm. This condition is shown on Figure 26.

Figure 26 Crumb rubber was pushed upwards resulting to flow drops.

To be sure of the result, another experiment had been done and a better and constant volume of sea waterwas obtained. This time the sea water was not taken from the shore of Kenjeran Beach but rather in the middle part,this is to avoid turbidity. The results of the second experiment are explained on Table 7.

Table 7 Represents the volume of water per cycle.

| Experiment | Water volume (Liters) | | | |
|---|---|---|---|---|
| | Repetition - 1 | Repetition - 2 | Repetition - 3 | Average |
| cycles -1 | 34.7 | 34.65 | 35.9 | 35.08 |
| cycles -2 | 35.5 | 35.6 | 35.6 | 35.57 |
| cycles -3 | 35.15 | 35 | 35.9 | 35.35 |
| cycles -4 | 35.3 | 35.05 | 35.4 | 35.25 |
| cycles -5 | 35.35 | 35 | 35.35 | 35.23 |
| cycles -6 | 35.5 | 34.9 | 35.05 | 35.15 |
| cycles -7 | 35.2 | 34.55 | 35.1 | 34.95 |
| cycles -8 | 35.05 | 34.35 | 33.8 | 34.40 |
| cycles -9 | 34.9 | 34.25 | 35 | 34.72 |

From Table 6it can be seen that the average volume of water from each cycle is slightly different. The average volume on the first cycle differs only 0.36 l of sea water, making it acceptable to include 9 cycles in the ballast water treatment experiment.

### 4.3.4 Choosing the Strainer (Sponge or Dacron)

As shown on the previous sub chapters of preparing the tools and materials, the cartridge needs something to hold the filter media from passing through the holes on the water way. The option for the strainer is to use sponge or dacron. Sponge is included when buying the empty filter cartridge. But the question is, does sponge works better than dacron which is commonly used in filtering aquarium waters. A test then is conducted to prove which is best. There are two factors to be considered; turbidity of the water and how much microorganisms can pass through. As for turbidity, sponge works better than dacron (Figure 27and Figure 28).

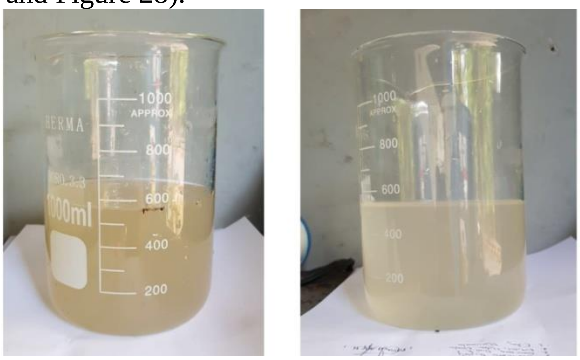



Figure 27 Sea water before and after filtered by sponge.

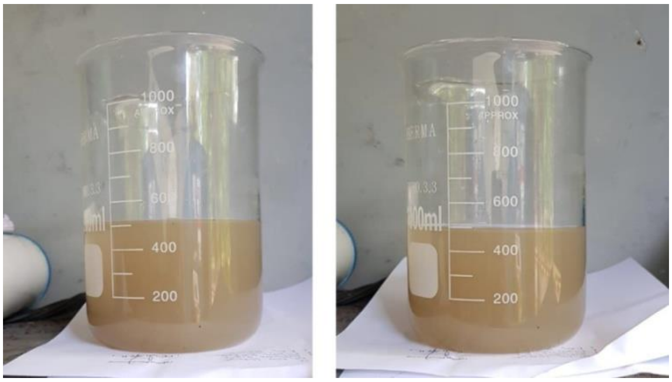



Figure 28Sea water before and after filtered by dacron.

The sea water strained by dacron and sponge is observed under binocular microscope with a magnification of 100x and the number microorganisms are respectively higher on sea water strained with sponge than dacron (Figure 29). The decision made is to use sponge instead of dacron, so the crumb rubber could be the only control of the number of microorganisms filtered.

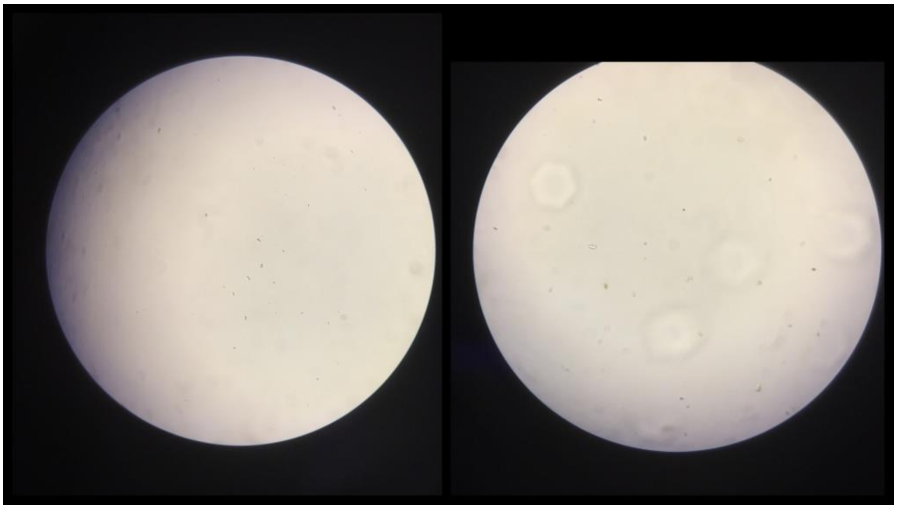


Figure 29 Sea water filtered by dacron (left) and by sponge (right) seen under binocular microscope (100x)

### 4.3.5 Performing the Experiment

The steps of the ballast water treatment experiment are as follows:

1) Fill in input tank with sea water.
2) Insert filter cartridge filled with crumb rubber to the filter housing attached to the prototype.
3) Set the debit to 10lpm on the flow meter.

4) Turn on the system and run the system for the amount of time needed for nine cycles.
5) Repeat this three times with the UV light on and three times without the UV light.
6) Take sample every time each cycle ends.
7) Turn off the system.
8) Samples are put in a sterilized container box and then delivered to be laboratory-tested.

The series of experiment is explained on Table 8 Total number of experiments.. There are 54 samples taken.

Table 8 Total number of experiments.

| | Cycle(s) | | | | | | | | | Repetition | Σ Experiments |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | |
| without UV | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 3x | 27 |
| with UV | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 3x | 27 |
| | | | | | | | | | | Total experiments | 54 |

There will be two variables that vary in this experiment. The first variable is the use of UV lamp. To determine the impact of the filter alone to this system, the writer decides to run the system with and without using UV radiation. The experiments which do not use the UV lamp, becomes the control. The flow rate and number of cycles will be the same for both treatments. This approach is to determine how much impact the filters contribute to inactivate or terminate the bacteria on the ballast water without the UV radiation process.

The second variable is the cycle of the treatment. It is assumed that repetition of the cycle would increase bacteria removal efficiency, though at certain stage the crumb rubber will begin to lose its ability to filtrate and bond with the microorganism. Repeating the cycle therefore is expected to help defines the impacts of repetition on the treatment and also defines when to stop repeating the cycle.

The experiment will be conducted in 10 lpm only, referring to the optimum flow rate from previous studies.

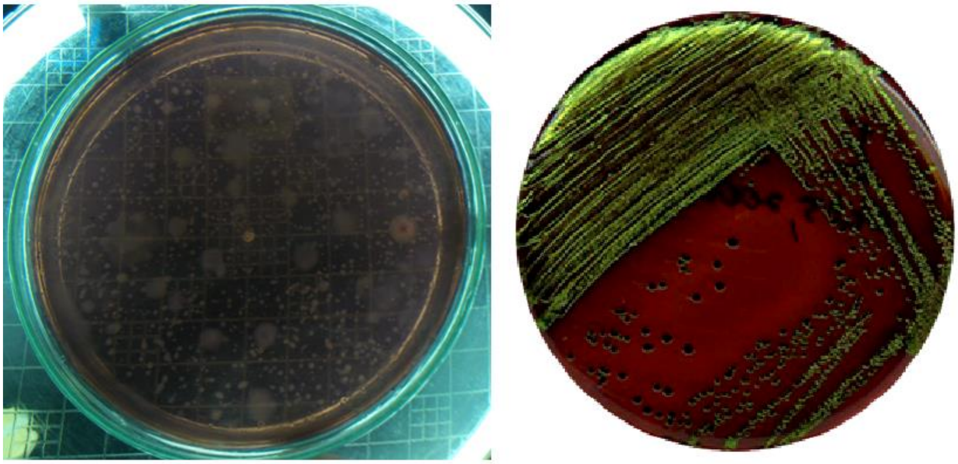
## 4.4 Bacteria Counting

The parameter of the performance of the prototype is the amount of bacteria found in the water after treated. Bacteria, specifically *Enterobacteriaceae*, are stated on the BWM Convention of IMO. There are several other microorganisms stated in the regulation, but this thesis focuses on the existence of*Enterobacteriaceae*in the treated water due to its potential harm to human beings. *Enterobacteriaceae* are a large family of gram-negative bacteria. *Enterobacteriaceae* includes familiar pathogenic agents such as *Escherichia coli, Salmonella, Yersinia pestis, and Shigella.* These bacteria pose serious health and ecological threat to the environment.

The number of bacterial content is obtained through doing the TPC (Total Plate Count) method. The reason why TPC is chosen as the bacteria detection method is because the process doesnot require a lot oftime so it is applicable when used in testing ballast water on site; for example at harbors. After the dilution process of the sample, 1ml is poured to EMB agar (Eosin Methylene Blue) as the selective stain to collect traces of *Enterobacteriaceae*.

Eosin Methylene Blue (or EMB) agar is a Selective & Differential Medium. Eosin methylene blue (EMB) agar is widely used for the detection of E. coli and related bacteria in water supplies and elsewhere. It contains the dyes eosin Y and methylene blue that partially suppress the growth of gram-positive bacteria. The dyes also help differentiate between gram-negative bacteria(Harley et. al, 2002). Using the *pour plate technique* the optimum result of the water samples are found in the $10^{-1}$, $10^{-2}$, and $10^{-3}$ dilution factor and observation will be focused on dilution factor of$10^{-2}$.

The bacteria found on the plates were unfortunately not *Escherichia coli*, but it was a type of non-coliform gram negative bacteria and the color were off-white (Figure 30 (a)). Meanwhile, the existence of *Escherichia coli* in EMB should resulted in metallic green color (Figure 30 (b)). Based on the references, if the growth is colorless, off-white or a very light and dull pink, the pH has largely been unaffected: is probably a gram negative non-coliform bacteria. Any non-colored colonies that grow in/on the medium are not coliforms or *E. coli*,but may be members of the family *Enterobacteriaceae* such as *Salmonella, Shigella, Proteus,* etc.This indicates that the sea water where the sample is taken for the experiment is not safe for human beings. A person swimming in such waters has a greater chance of getting sick from swallowing disease-causing organisms, or from pathogens entering the body through cuts in the skin, the nose, mouth, or the ears.



(a) (b)

Figure 30 Non-coliform gram negative bacteria found on ballast water (a). How *E. coli* should look like on EMB medium (b).

There are two main aspects in this experiment; the cycles and the effect of the filter alone without UV light radiation. Therefore two series of experiment are conducted; three repetitions on the experiment without the use of UV light and other three repetitions for the experiment using the UV light. Each repetition is done in nine cycles. In total, there are 54 samples taken from these experiments. One sample is taken after each cycle; meaning that from every repetition nine samples are obtained. Meanwhile there are a total of six repetitions (3 with UV and 3 without UV)as a result the total number of samples are 54.

a. Non-coliform Gram Negative Bacteria Analysis based on Three Dilution Factors

Table 9shows the results from three repetitions of experiment without using UV light and Table 10shows the results from three repetitions of experiment with the use of UV light. Generally, the numbers shown on the non-UV experiment shows greater number of bacterial content. On the $10^{-1}$dilution factor the first cycle of the non-UV experiment shows 187 x $10^{1}$ cfu/ml of bacterial content which is considered a lot of amount of bacteria on a sample. Compared to that, the first cycle of the experiment using UV light shows lesser amount of bacteria, 55 x $10^{1}$ cfu/ml. On the $10^{-1}$dilution factor, we could see both experiments show a spike of bacterial content on the $6^{th}$ cycle, followed by the $7^{th}$ cycle on the non-UV experiment and the $8^{th}$ cycle of the UV experiment.

Table 9 Number of microbial content from samples of experiments without the use of UV light.

| | $10^{1}$ (cfu/ml) | | | | $10^{2}$(cfu/ml) | | | | $10^{3}$(cfu/ml) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cycles | I | II | III | $\bar{x}$ | I | II | III | $\bar{x}$ | I | II | III | $\bar{x}$ |
| 1 | 187 | 23 | 13 | 74.3 | 33 | 0 | 1 | 11.3 | 7 | 0 | 1 | 2.7 |
| 2 | 12 | 3 | 10 | 8.3 | 1 | 1 | 1 | 1.0 | 1 | 0 | 0 | 0.3 |
| 3 | 3 | 6 | 7 | 5.3 | 0 | 1 | 1 | 0.7 | 0 | 0 | 0 | 0.0 |
| 4 | 3 | 26 | 2 | 10.3 | 0 | 4 | 0 | 1.3 | 0 | 0 | 0 | 0.0 |
| 5 | 1 | 5 | 10 | 5.3 | 1 | 0 | 1 | 0.7 | 0 | 0 | 0 | 0.0 |
| 6 | 1 | 27 | TNTC | 9.3 | 0 | 0 | TNTC | 0.0 | 0 | 0 | 552 | 184.0 |
| 7 | 890 | 13 | 11 | 304.7 | 636 | 0 | 0 | 212 | TNTC | 0 | 0 | 0.0 |
| 8 | 1 | 57 | 30 | 29.3 | 0 | 0 | 0 | 0.0 | 0 | 0 | 0 | 0.0 |
| 9 | 83 | 26 | 12 | 40.3 | 0 | 0 | 0 | 0.0 | 0 | 0 | 0 | 0.0 |

Table 10 Number of microbial content from samples of experiments with the use of UV light.

| | $10^1$(cfu/ml) | | | | $10^2$(cfu/ml) | | | | $10^3$(cfu/ml) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cylces | I | II | III | $\bar{x}$ | I | II | III | $\bar{x}$ | I | II | III | $\bar{x}$ |
| 1 | 55 | 47 | 37 | 46.3 | 2 | 0 | 0 | 0.7 | 0 | 0 | 0 | 0 |
| 2 | 5 | 0 | 1 | 2.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 25 | 1 | 8.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 6 | 2.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 83 | 3 | 122 | 69.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 3 | 61 | 11 | 25.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 104 | 27 | 0 | 43.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 28 | 0 | 9.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Bacterial content on $10^{-1}$dilution factor of the non-UV experiment never reach 0 cfu/ml in all three repetitions, meanwhile zero existence of bacterial content was found on many cycles of the UV experiments in all 3 repetitions. Even the first 0 cfu/ml was shown on the 2nd cycle of Repetition-II. The best result from the $10^{-1}$dilution factor of the UV experiment is on the 4th cycle where all repetitions resulted on zero amounts of bacteria. On the other hand, the best average result of the non-UV experiment seen from the $10^{-1}$dilution factor is on the 3rd and 5th cycle where both resulted on 5.3 x $10^1$ cfu/ml.

Unlike the results on the non-UV experiment,the experiment using UV lights shows no existence of bacteria at all in all cycles and repetition, meanwhile bacterial content still exist on several cycles on the repetition. The spikes of bacterial content in the non-UV experiment are constant on the 6th cycle of the 3rd repetition, and on the 7th cycle of the 1st repetition in all dilution factors.

b. Non-coliform Gram Negative Bacteria Analysis based on the Chosen Dilution Factor $10^{-2}$

Results on the experiment without UV light obtained through TPC, shows that the number of bacterial contentgenerally decreases if we compare the 1st cycle to the 9th.

Bacterial content on the first sample were 33 x $10^2$ cfu/ml, meanwhile on the 9th sample there were no microbial contents at all, or as shown on Table 6 as 0cfu/ml. Sample taken from the 2nd cycle in fact shows significant declining from the 1st cycle. Only 1 x $10^2$ cfu/ml are present on the sample taken from the 2nd cycle. This indicates that the repetition of the cycle has an impact on the microbial content of ballast water. On the 3rd and 4th cycle of Repetition-I sample were free of microbial content. At this stage, the ballast water has passed the limitation of the D-2 Regulation from IMO. On the other hand the results from Repetition-II show different trends. From the 1$^{st}$ cycle to the 4$^{th}$, microbial content in fact increases from 0 cfu/ml to 4 x $10^2$ cfu/ml. And on Repetition-III the microbial content were constant from the 1$^{st}$ cycle to the 3$^{rd}$ having only 1 x $10^2$ cfu/ml but then decreases at the 4$^{th}$ cycle showing no microbes present at all. At the 5$^{th}$ cycle, Repetition-I and III shows 1 x $10^2$ cfu/ml of microbial content but on Repetition-II the number shows 0 cfu/ml. At an average, the number of microbial content from the 1$^{st}$ cycle until the 5$^{th}$ shows reduction, only there is a spike on the 4$^{th}$ cycle.

Moving on to the 6$^{th}$ cycle, the sea water sample of Repetition-I and II shows no microbial existence at all, it is on a great value of 0 cfu/ml. But then an anomaly appears on the sample of Repetition-III. It states on Table 6 "TNTC" or the short term of "Too Numerous To Count". Meaning that the number of microbes were uncountable or at least exceeding the TPC rule suggested by American Standard Testing and Methods 1998 (ASTM). For TPC using *pour plate* method, the countable ranges per plate is 30-300cfu/ml. This phenomenon is similar to the number of microbial content on the 7$^{th}$ cycle of Repetition-I. The table shows 636 x $10^2$ cfu/ml of microbial content on that stage. Only on Repetition-II shows good results from the 5$^{th}$ cycle until the end. Together, the present findings confirm that the filter was effective only after 5 cycles. On this series of experiment, only the samples that consist 0 cfu/ml is considered to pass the regulation of IMO.

Compared to results on the experiment without UV light, the experiment using UV light combined with the filter shows a very little amount of bacteria. Only the sample taken from the first cycle of Repetition-I shows the existence of non coliform gram negative bacteria. The number of bacterial content on that stage is 2 x $10^2$ cfu/ml, which is still unacceptable for ballast water to be discharged. The regulation states the limit of *Enterobacteriaceae* to be found on ballast water should be below 250 cfu/100ml. It means that only 2.5cfu/ml is allowed on the sample. The rest of the result demonstrated that the ballast water treatment system shows great performance, since no microbial content was found. This suggests that the combination of crumb rubber-filter and UV light radiation in the system performs better than the treatment without the use of UV light.

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# CHAPTER 5
# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

Series of experiments had been conducted to answer research questions of this thesis. There are several findings that lead to conclusions as follow:

1) The present findings confirm that the crumb rubber’ssize give positive effect to the system’s performance. From thebacterial content, this experiment shows higher improvements in the ability to remove bacteria than the pilot studies.

2) The chemical contents of the crumb rubbers are shown onTable 4. Through literature study, it is assumed that acetone and isoprene rubber are potential in inactivating the microorganism. Acetone, like alcohol serves as antibacterial, meanwhile isoprene has an unsaturated chemical formula in which it is potential to bind with the bacteria. There are 28.1 % content of carbon present on the crumb rubber. Carbon has high porosity and therefore it is also included as a potential filter for the bacteria. Further research should be done on this.

3) Based on the results on $10^{-2}$dilution factor the repetition of the cycles/loops resulted in better filtration, respectively. The optimum result is shown after 5 cycles in the experiment without UV radiation, and for the experiment using UV radiation, 2 cycles is enough to filter microbes to 100%.

4) The results show that combining crumb rubber filter and UV radiation increase bacteria removal compared to the results from the experiment of using only the filter.

5) By judging from the microbial content, this experiment proves better performance of the ballast water treatment system compared to the pilot study, where 0 cfu/ml of bacteria was found in $10^{-6}$dilution factor meanwhile the findings in this research shows 0cfu/ml of bacteria in $10^{-2}$dilution factor.

## 5.2 Recommendations

It is essential to continue this research to reach the next Technology Readiness Level. In order to achieve higher improvements on the system, there are several recommendations to be considered in the upcoming research.

1) The time for the UV radiation shall be considered and adjusted with the efficiency of the UV light in inactivating microbes; needs longer inactivation time than the present study.

2) Backwashing the filter shall be put in consideration to increase the life span of the filter media."MARPOL (Marine Pollution) Annex IV- Regulations for the Prevention of Pollution by Sewage from Ship" shall be put in consideration for discharging the waste from the backwashing.
3) To gather more properties of crumb rubber as the filter media, more detailed study of the life span shall be considered in the next study.
4) To be more applicable, this prototype's system shall be taken into account with the real condition of the vessel.

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# APPENDIX A

Prototype Modification Process

Figure 1. 1 Installing the UV glass protector


Figure 1. 3 Rust removal.

Figure 1. 2 Modification of BWT prototype 2.0 on progress.

Figure 1. 4 Rust removal from UV reactor.

# APPENDIX B

Microorganism Checking under Microscope
(Performance of Dacron and Sponge)

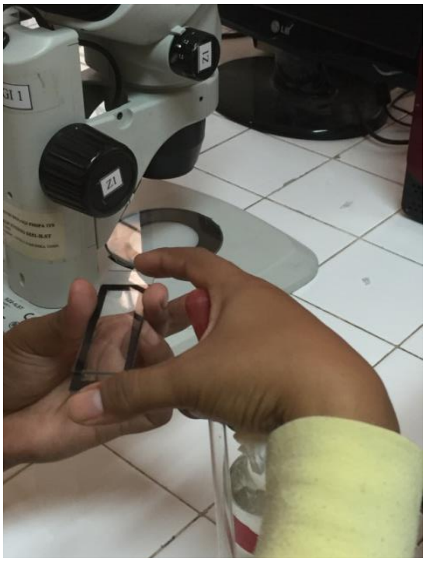

Figure 1. 5 Observation of microorganism from sea water filtered by dacron and sponge (1).

Figure 1. 6 Observation of microorganism from sea water filtered by dacron and sponge (2).

# APPENDIX C

TPC Process

Figure 1. 7 Taking 1 ml of sample.

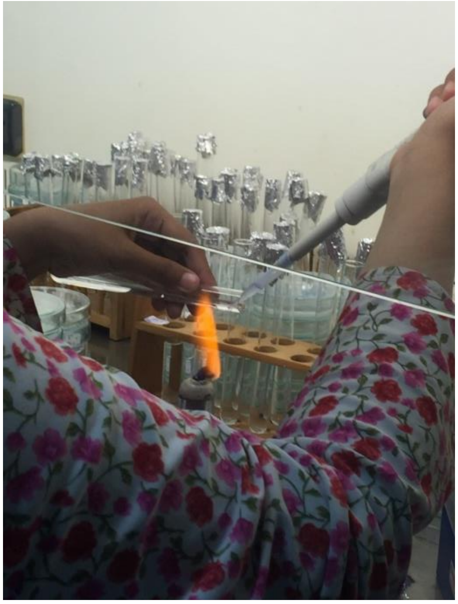

Figure 1. 8 Putting 1 ml of sample to the diluents mixture.

Figure 1. 9 Placing the test tube on top of the vortex.

Figure 1. 10 Pouring liquid form of EMB medium to the plate.

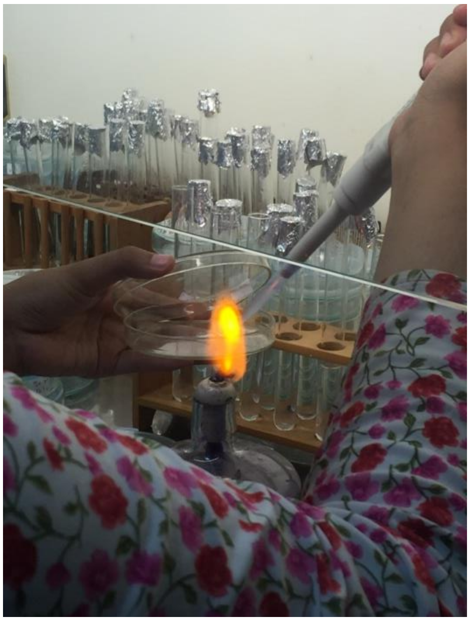

Figure 1. 11 Putting 1 ml of sample to EMB medium

Figure 1. 12 Where TPC process takes place.

Figure 1. 13 Counting the number of bacteria on the colony counter.

Figure 1. 14 the bottle used for keeping the sample

Figure 1. 15 Autoclave used to sterilized sample bottles.

# APPENDIX D

TPC Results (without UV Radiation on dilution factor of $10^{-2}$)

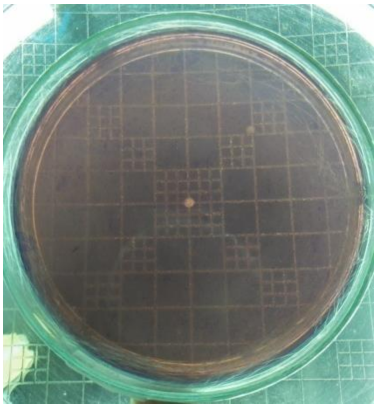

Figure 1. 16 Cycle-1, Repetition-I

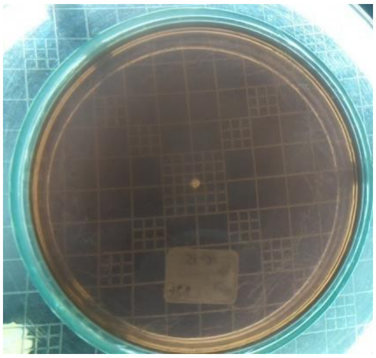

Figure 1. 17 Cycle-1, Repetition-II

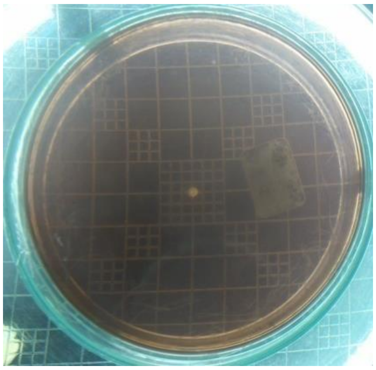

Figure 1. 18 Cycle-1, Repetition-III

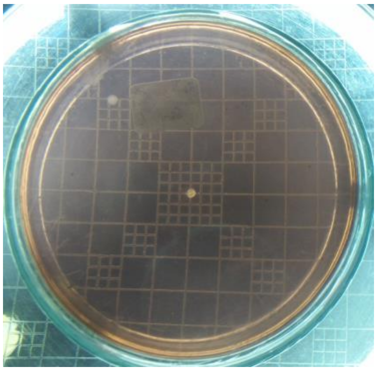

Figure 1. 19 Cycle-2, Repetition-I

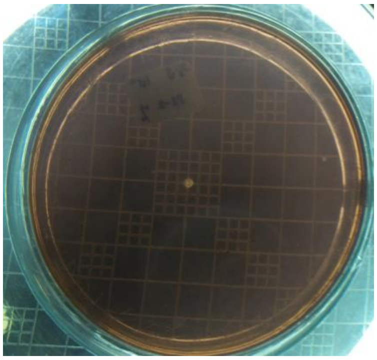

Figure 1. 20 Cycle-2, Repetition-II

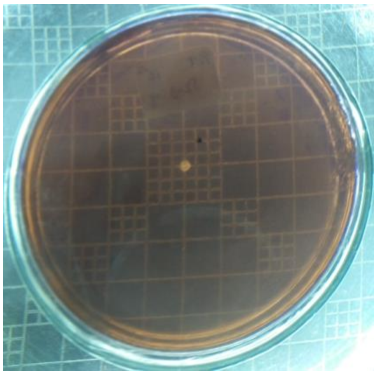

Figure 1. 21 Cycle-2, Repetition-III

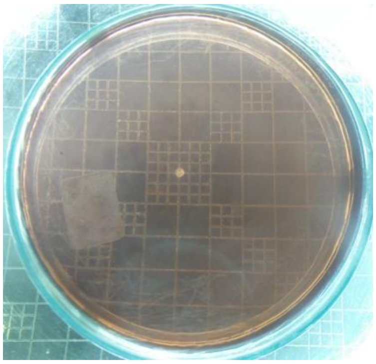

Figure 1. 22 Cycle-3, Repetition-I

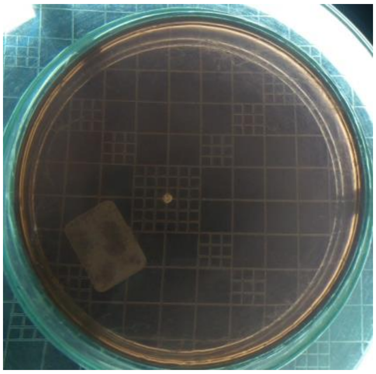

Figure 1. 23 Cycle-3, Repetition-II

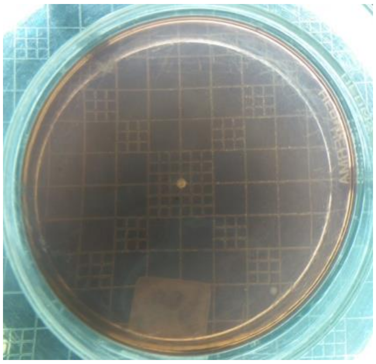

Figure 1. 24 Cycle-3, Repetition-III

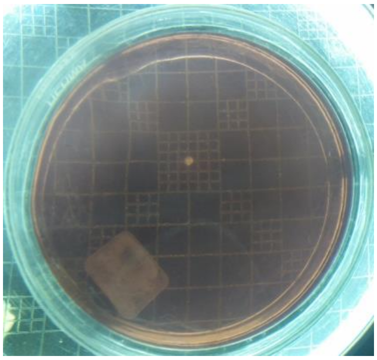
Figure 1. 25Cycle-4, Repetition-I

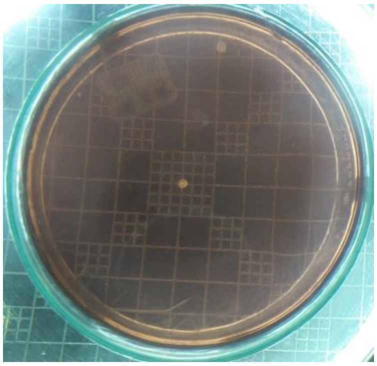
Figure 1. 26 Cycle-4, Repetition-II

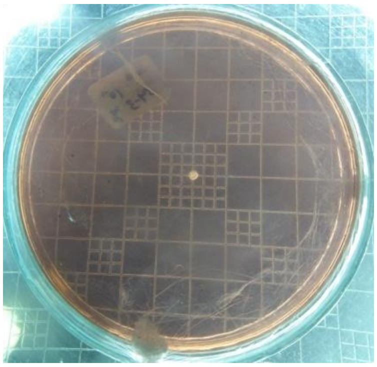
Figure 1. 27 Cycle-4, Repetition-III

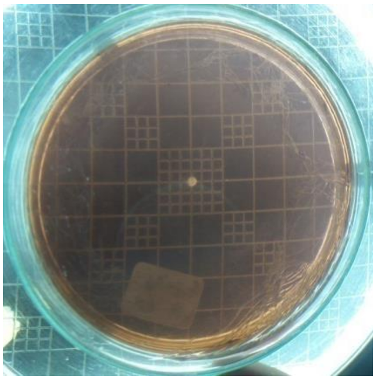

Figure 1. 28 Cycle-5, Repetition-I

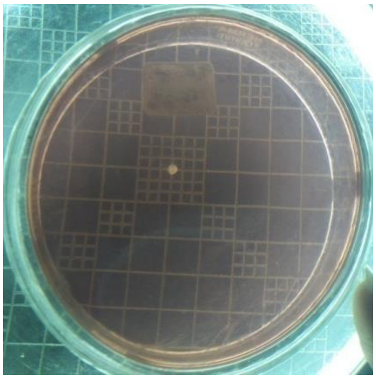

Figure 1. 29 Cycle-5, Repetition-II

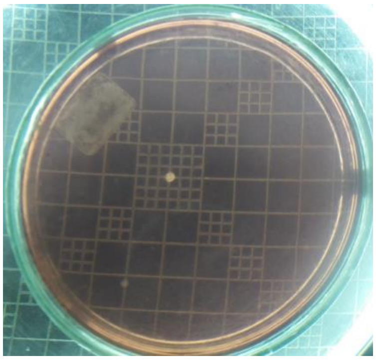

Figure 1. 30 Cycle-5, Repetition-III

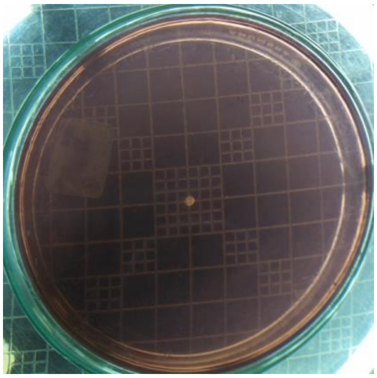
Figure 1. 31 Cycle-6, Repetition-I

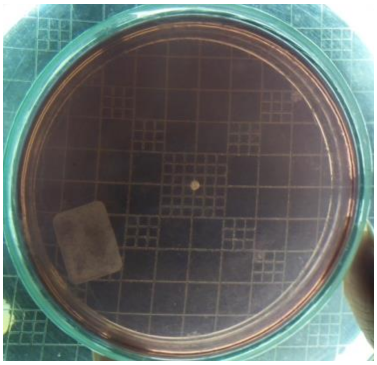
Figure 1. 32 Cycle-6, Repetition-II

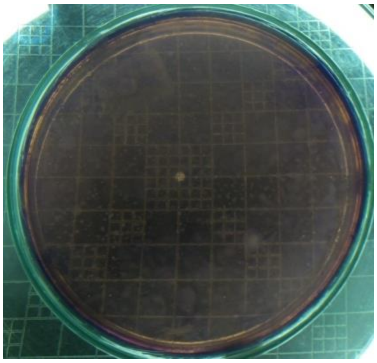
Figure 1. 33 Cycle-6, Repetition-III

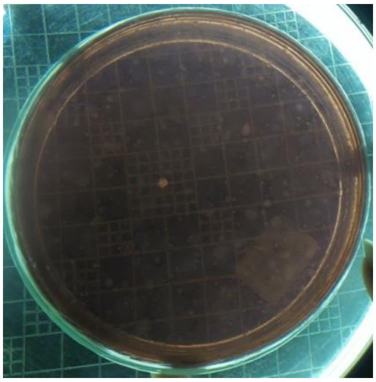

Figure 1. 34 Cycle-7, Repetition-I

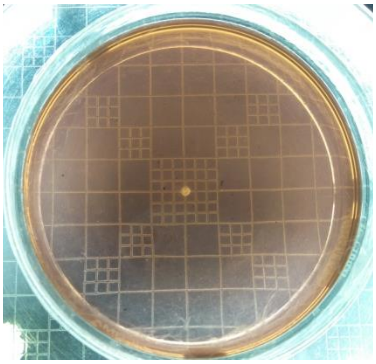

Figure 1. 35 Cycle-7, Repetition-II

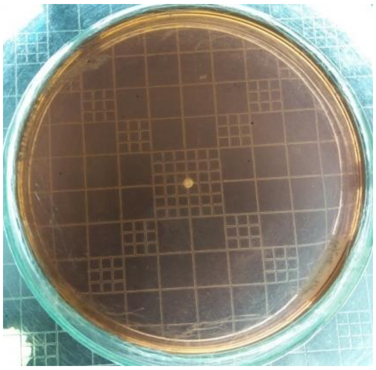

Figure 1. 36Cycle-7, Repetition-III

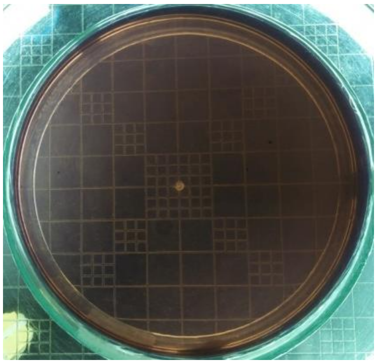

Figure 1. 37 Cycle-8, Repetition-I

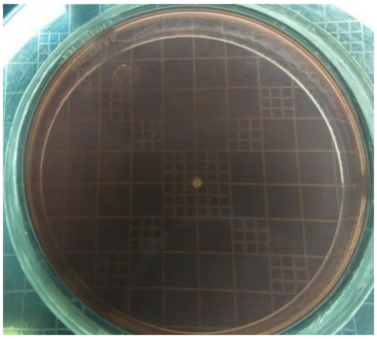

Figure 1. 38 Cycle-8, Repetition-II

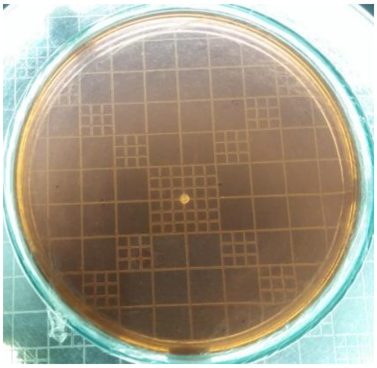

Figure 1. 39 Cycle-8, Repetition-III

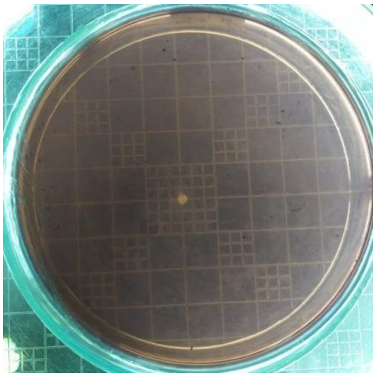

Figure 1. 40 Cycle-9, Repetition-I

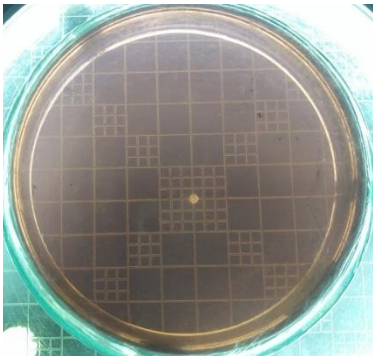

Figure 1. 41 Cycle-9, Repetition-II

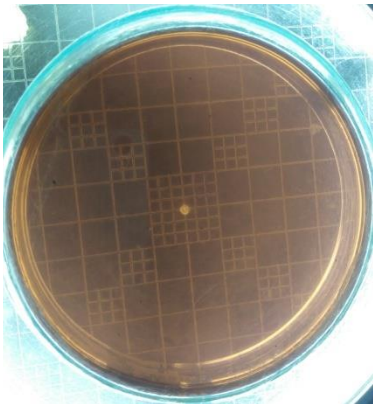

Figure 1. 42 Cycle-9, Repetition-III

# APPENDIX E

## Vulcanization Analysis Results

**PUSAT PENELITIAN KARET**
*Indonesian Rubber Research Institute*
**LABORATORIUM PENGUJI**
*Testing Laboratory*

KAN Komite Akreditasi Nasional
Laboratorium Penguji LP-029-IDN

Jl. Salak No. 1 Bogor 16151 Indonesia | Phone : (0251) 8319817 – 8352732 | Fax : (0251) 8324047
Email : ppkbogor@puslitkaret.co.id; ppkbogor@gmail.com | web : www.puslitkaret.co.id

**CERTIFICATE OF ANALYSIS**
Sample Number MT.LA.02.18.03.018

| | |
|---|---|
| Type of Sample | : " Vulkanisat " |
| Type of Sample Analyzed | : Vulcanizate |
| Request from | : Sdri. SEKAR ADHANINGGAR |
| Address | : Institut Teknologi Sepuluh Nopember |
| Reference number/ date | : - / 20 - 03 - 2018 |
| Received | : March 20, 2018 |
| Finished | : April 05, 2018 |

| Analysis | Test Method | Result |
|---|---|---|
| Acetone Extract, % | ASTM D297-93 (ra 2006) | 6.52 |
| Ash content, % | ASTM D297-93 (ra 2006) | 5.92 |
| Type of polymer | ASTM D 3677 - 10e1 | IR + SBR |
| Total Sulfur content, % | ASTM D297-93 (ra 2006) | 1.74 |
| Content of vulcanizate composition : | LP-PPK* | |
| • Polymer content, % | | 59.46 |
| • Carbon content, % | | 28.10 |
| • Plasticizer content, % | | 4.25 |
| Type of vulcanizate composition : | | |
| • Type of Plasticizer | | Naphthenic Mineral Olis |
| • Type of Accelerator | | Benzothiazole |
| • Type of Antioxidant | | Not detected |

Notes :
*) = Not accredited
IR = Isoprene Rubber
SBR = Styrene Butadiene Rubber

VALID FOR TESTED SAMPLE
NOT BE COPIED

Technical Manager

PUSAT PENELITIAN KARET RPN

Anwar Tavip

Certificate number : 037 K 2018

1/1

# BIOGRAPHY

Sekar Adhaninggar was born on 20th December 1995 in a city called Bogor, Indonesia. Her parents are Widi Hardjono and Terry Semestari. She spent 3,5 years of her childhood in Thailand when her father took his Doctoral degree in Asian Institute of Technology (AIT). On 2004, the whole family except for her father went back to Indonesia. She has an older sister named Ayu Aradhita which is 4 years apart in age. After returning from Thailand she continued her education in SDN Cibuluh I, SMPN 5 Bogor, and SMAN 1 Bogor. On 2012 she went for an exchange program, AFS Intercultural Programs, to the Netherlands which lasted a year. There, she lived with a host family in Hillegom, a small town located near Amsterdam and went to Herbert Vissers College to continue her high school education in Nieuw Vennep. It was really an eye-opening experience for her to be able to live abroad on her own. Not only meeting new friends and places, she also adopted the ability to speak Dutch which she believes could be a benefit for her one day. After 11 months, she return to her high school in Bogor to retake her last year of high school and on 2014 she got in Marine Engineering Department in Institut Teknologi Sepuluh Nopember at Surabaya. Apart from her academic activities, she was active on several organizations during her college days. She was one of the founders of ITS Muaythai Association, a new martial art sports club in ITS. She was part of the ITS Marine Solar Boat Team, a team which focuses on the development of solar-powered boats, and went to the Netherlands on 2016 for Dutch Solar Challenge with the team. She then explored her interest on oil and gas by joining an international competition in Bandung held by ITB with a team called Narayana. It was an Oil Rig Design Competition and they end up on the 5th rank. They join another Oil Rig Design Competition in Kuala Lumpur Malaysia held by UTM (Universiti Teknologi Malaysia), this time with a team called Ganapatih. They succeeded on taking 2nd place. She finished her study by writing this bachelor thesis, “Experimental Study on the Combination of UV Radiation and Crumb Rubber Filtration for Ballast Water Treatment”.

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