DEGRADATION BEHAVIOUR OF O-RING ELASTOMER SUBJECTED TO PALM BIODIESEL IMMERSION

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This report is submitted
In fulfillment of the requirement for the degree of
Bachelor of Mechanical Engineering (Hons)

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2020

DECLARATION

I announce that this project titled "Degradation Behaviour of O-Ring Elastomer Subjected to Palm Biodiesel Immersion" is the original work, except where stated in citations.

Signature :...................................

Name :...................................

Date :………………………...

APPROVAL

I hereby recognize that I have read this project report and that this report is, in my view, appropriate in terms of reach and consistency for the award of a Bachelor of Mechanical Engineering degree. I have checked this report and the report can now be submitted to JK-PSM to be delivered back to the supervisor and the second examiner.

Signature :...................................
Name of Supervisor :...................................
Date :.................................

DEDICATION

To my beloved mother, Teo Siew Hoon, and father, Chin Kang Foh

ABSTRACT

It is common to find the use of elastomer in fuel lines of diesel automobile engines as well as a sealant for the engine parts. However, a polymer is well-known to be detrimental to elevated temperatures. In this study, two types of biodiesel sources of fuel were considered to evaluate the degradation behavior of the O-ring component based on nitrile rubber (NBR) in terms of the physical properties. The physical property is investigated in terms of the change in mass, in accordance with the ASTM D471. The weight of the samples was recorded before and after immersion. At the soaking stage, the O-ring samples were immersed up to 28 days in B10 and B30 biodiesel at the room temperature and 40℃ condition. The mass loss test results suggest that there is a decrease in mass loss with increasing biodiesel concentration for the NBR O-ring, from B10 to B30 biodiesel usage. Moreover, deterioration of elastomer is due to the increased polarity of biodiesel; these are related to carboxylic (ester) functional group in the biodiesel formation. Besides that, SEM micrographs at the cross-section show evidence of deterioration in the sample. Once immersed for up to 28 days (4 weeks) at 40℃, the O-ring sample in biodiesel B30 exhibits more holes and cracks than those in the B10 medium. It is possibly due to the absorption of biodiesel into elastomer, through which biodiesel may interfere with the cross-linking agent. These results suggest that NBR O-ring is acceptable for uses in the specified environment and biodiesel.

ABSTRAK

Elastomer merupakan satu bahan yang biasa digunakan dalam talian sistem bahan api malahan juga digunakan sebagai penyudah dalam bahagian enjin kereta. Walaupun, elastomer dikenali sebagai bahan yang mudah rosak pada sifat suhu. Dalam kajian ini, terdapat dua jenis biodiesel yang digunakan untuk mengkaji proses degradasi gelang O komponen berasaskan getah nitril (NBR) dari segi sifat fizikal. Ciri-ciri fizikal dikaji melalui perubahan jisim merujuk kepada ASTM D471. Jisim sampel sebelum dan selepas rendaman juga direkodkan. Di dalam eksperimen ini, sampel gelang O telah direndam di dalam biodiesel B10 dan B30 pada suhu bilik dan suhu 40 ℃ hingga 28 hari. Keputusan hasil kajian menunjukkan bahawa jisim berkurangan dengan peningkatan kepekatan biodiesel, dari B10 ke B30 yang digunakan. Tambahan pula, kemerosotan elastomer adalah disebabkan oleh peningkatan ketubuan biodiesel; ini berkaitkan dengan kumpulan berfungsi karboksilik (ester) dalam pembentukan biodiesel. Malahan, kemerosotan sampel gelang O telah dirakamkan melalui pengimejan menggunakan mesin mikroskop imbasan elektron (SEM). Apabila masa rendaman mencecah 28 hari (4 minggu), pada suhu 40 ℃, gelang O yang direndam di dalam biodiesel B30 menunjukkan banyak lubang dan retakan berbanding dengan sampel yang direndam di dalam biodiesel B10. Hal ini kerana penyerapan biodiesel ke dalam elastomer menyebabkan biodiesel mengganggu agen perangkaian silang. Hasil kajian ini menunjukkan bahawa gelang O yang diperbuat dari elastomer NBR ini sesuai untuk digunakan di dalam medium biodiesel dan persekitaran tertentu.

ACKNOWLEDGMENT

First and foremost, I would like to express my deepest appreciation to my supervisor, Dr. Siti Hajar Binti Sheikh Md. Fadzullah for providing me this opportunity to complete a final year project with her. She never felt obliged to offer me help and feedback whenever I was faced with problems. I would also like to express my appreciation to Dr. Muhd Ridzuan bin Mansor, Dr. Mohd Nur Azmi bin Nordin, Dr. Nadlene Binti Razali, and Dr. Mizah Binti Ramli for spending their time to guide me. They have indeed shared useful material and knowledge from the automobile industry with me and assist me in conducting the experiment.

My appreciation also goes to two MSc students, Zainalfirdaus Adnan and Solehah Jasmee, for taking their time in advising me to operate the equipment in the Amchal laboratory. I would also like to acknowledge my coursemates, namely Muhammad Al-Faaruuq bin Mohd Jamaluddin, Adib Aizat bin Mohd Dzahari, Syalman bin Hassan, and Muhammad Saiful Muslim bin Abdul Rahim for providing me with their help, wisdom, and motivation. The temperature-controlled bath would not have been completed without their assistance in the relevant period. Specific thanks to all my friends, my parents, and to all my siblings who have given me all of the moral encouragement throughout the entire project up to this stage.

Special thanks to Fakulti Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka (UTeM) for the technical assistce provided, and the Malaysian Palm Oil Board under MPOB/2019/FKM-CARE/G00066 grant for the financial support in completing this project.

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LIST OF ABBREVIATIONS

FAME	-	Fatty acid methyl ester
MPOC	-	Malaysian Palm Oil Council
MPOB	-	Malaysian Palm Oil Board
FKM	-	Fluoroelastomer
SR	-	Silicone Rubber
NBR	-	Acrylonitrile Butadiene Rubber / Nitrile Rubber
HNBR	-	Hydrogenated NBR
CR	-	Poly Chloroprene Rubber / Neoprene
ECO	-	Epichlorohydrin
EPDM	-	Ethylene-propylene-diene Rubber
SBR	-	Styrene-Butadiene Rubber
IR	-	Polyisoprene
NR	-	Natural Rubber
ACM	-	Acrylic Rubber
ULSD	-	Ultra-Low Sulphur Diesel
NOx	-	Nitrogen Oxides
VOCs	-	Volatile Organic Compounds
SOx	-	Sulphur Oxides

N_2O - Nitrous Oxide

CO_2 - Carbon Dioxide

CH_4 - Methane

PM - Particulate Emissions

B0 - Pure Diesel

B10 - 10 vol.% of the biodiesel blended with 90vol% of the diesel

B30 - 30 vol% of the biodiesel blended with 70vol% of the diesel

FFA - Free Fatty Acids

ASTM - American Society for Testing and Materials

MITC - Melaka International Trade Centre

DOE Design of Experimentation

SEM Scanning Electron Microscope

LIST OF SYMBOLS

A - Ampere

C - Calibration constant

M_1 - Mass of sample in air before soaking

M_2 - Mass of sample in the air after soaking

t - Time

ºC - Degree in Celsius

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Biodiesel is one type of biofuels that is regarded as a substitute to diesel partially or entirely for the past few decades. It is clean and renewable fuel energy that works better with a little reconstruction in the existing energy portfolio. Nowadays, biodiesel is widely utilized in the transportation sector, especially diesel engine vehicles. Significant concerns with diesel, such as the depletion of natural resources, effects of environmental pollution, and lack of supplication fossil fuel, have caused biodiesel to become a useful alternative fuel source in the global market. Hence, biodiesel can be regarded as a first choice to replace diesel in this application because biodiesel has similar properties with pure diesel fuel.

According to Akhlaghi et al. (2015), biofuels are typically classified based on the technology generation or the feedstock of biological sources. The variety of biofuels are produced from lipids, proteins, and carbohydrates in the feedstock (Huo *et al.*, 2011). More commonly, biodiesel is produced from lipid-based biofuel. There are two types of generation technology based on lipid-based biofuels to produce biodiesel that has hitherto been recorded. Saturated and unsaturated dietetic plant oil from oil seeds like corn, canola soybean, and sunflower while fruits like palm, coconut, and olive are the feedstock of the first generations. Besides, the second generation based on lipid-based biofuel produced from insects, oleaginous microorganisms, animal fats, and waste vegetable oils. Chandran et al. (2016) stated that pure diesel (B100) also named as a fatty acid methyl ester (FAME). The variety of biodiesel is usually manufactured from animal or vegetable through the transesterification process. The main objective of the transesterification process is used to decrease viscosity of the vegetable oil from $40mm^2 s^{-1}$ to the lower viscosity, which is approximately $5mm^2s^{-1}$ (Chandran et al., 2016). This value of viscosity is most suitable for the operation of diesel engines.

This work generates biodiesel from palm oil because Malaysia is well-known as one of the world's leading manufacturers and exporters of palm oil. Malaysia accounts for 11% of world production of oils and 27% of global oils and fats trade. Based on information on the Malaysian Palm Oil Council (MPOC) website, Malaysia's oil palm production uses approximately 4.49 million hectares of land. This industry can generate 2.13 million tons of palm kernel oil and 17.73million tons of palm kernel oil. More than half a million employees can be employed, and an additional one million people live in the sector (*The Oil Palm Tree – MPOC*, no date).

Biodiesel has similar mechanical properties to pure diesel fuel. Moreover, biodiesel can offer some technical benefits over traditional diesel, which include higher flashpoints, a higher number of cetane, better lubricity and decreased exhaust emission, etc. (Ferreira *et al.*, 2008; Chen *et al.*, 2010). Nonetheless, biodiesel also has several drawbacks. One of the significant disadvantages of biodiesel is that it can cause deterioration and swelling of the elastomer and rust of the metal part. Such behavior will cause some problems, including fuel pump breakdown, motor shaking, plugging of filters, deposits on engine walls, coking of injectors on pistons of engines, and excessive engine wear.

There is a huge range of interchangeable components in an automobile framework like an engine, fuel pump, exhaust system, and fuel injector. The place of several metallic and elastomer parts traditional fuel system for vehicles is as shown in **Figure 1.1** (Akhlaghi *et al.*, 2015). Among the variety of rubber parts used in automotive fuel delivery system are Fluoroelastomer (FKM), Silicone Rubber (SR), Acrylonitrile Butadiene Rubber (NBR), Hydrogenated NBR (HNBR), Poly Chloroprene Rubber (CR), Epichlorohydrin (ECO), Ethylene-propylene-diene Rubber (EPDM), Styrene-Butadiene Rubber (SBR), Acrylic Rubber (ACM) and Polyurethane. Besides, as for the metallic parts, some of the typical applications in the fuel delivery system include camshaft, lifter, head surface, timing gear, and chain, etc. Chandran et al. (2016) argued that the storage and automobile fuel supply system in an engine usually contain some components like fuel tank, fuel lines, fuel pump, fuel rail, and fuel injectors. The automobile fuel supply network for a diesel engine is, as illustrated in **Figure 1.2** (Chandran et al., 2016). **Table 1.1** shows the components used to manufacture parts for fuel storage and transmission (Chandran et al., 2016).

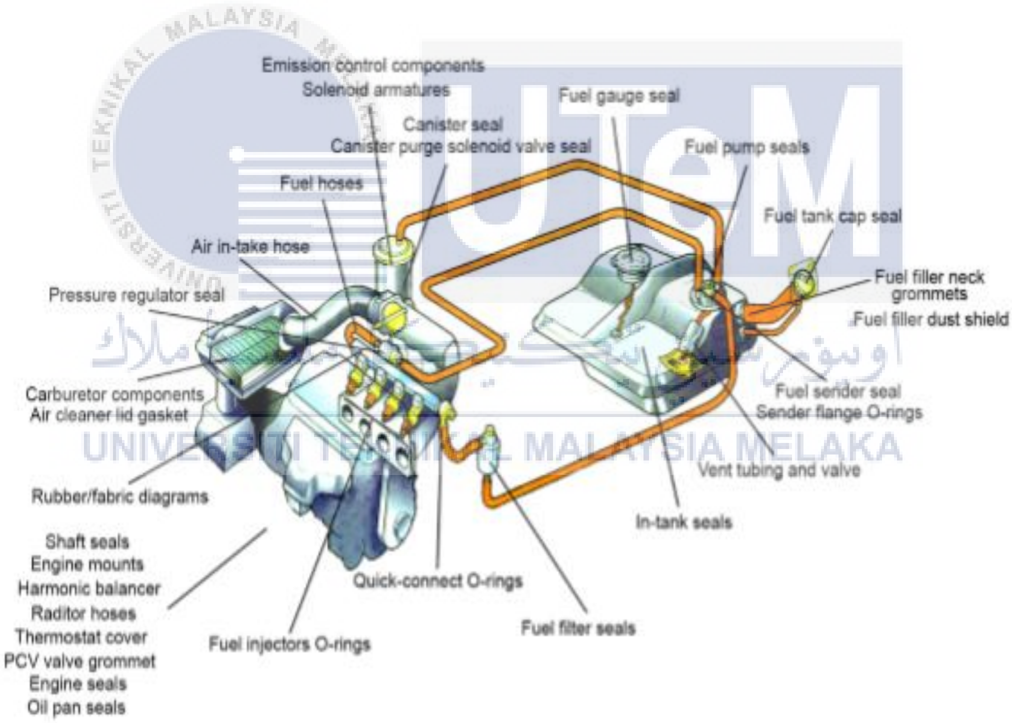

FIGURE 1.1: THE PLACE OF SEVERAL METALLIC AND ELASTOMER PARTS TRADITIONAL FUEL SYSTEM FOR VEHICLES

(Akhlaghi et al. 2015)

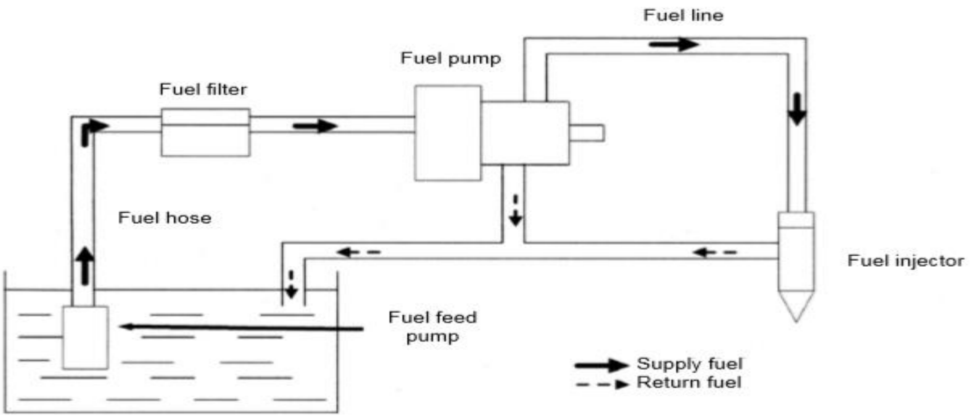

FIGURE.1.2: THE AUTOMOBILE FUEL SUPPLY NETWORK FOR THE DIESEL ENGINE

(Chandran et al., 2016)

TABLE 1.1: COMPONENTS USED TO MANUFACTURE PARTS FOR THE FUEL TANK AND TRANSMISSION

(Chandran et al. 2016)

Components	Compositions
Fuel storage	Polyethylene, steel
Pump for fuel supply	Alloy based on iron, alloy based on copper, and aluminum metal
Hoses	Polyethylene, steel, polymer
Filter of fuel	Polyethylene, aluminum, journal, resin, and document with impregnated
Pump for fuel	Alloy based on iron, alloy based on copper, and aluminum metal
Fuel injection	Inox steel
Beak	Steel
Pipe flange gasket	Polymer, journal, stopcock, and copper

From the literature, the injection system is facing various problems like swelling and deterioration in the elastomer parts of the fuel delivery system when biodiesel was utilized as a fuel in diesel engines. Since deterioration of the elastomer seal, hoses, gaskets, and O-rings have become the main problem concerning automobile material biofuel incompatibility, several works have investigated the shorter and longer-term quality of biodiesel and deterioration actions of various rubber parts used in the fuel supply system. Based on the Haseeb et al. (2011) research, swelling results of the biodiesel and its blends in the different elastomer parts compared with the swelling results of the pure diesel. It was reported that there is a significant deterioration, based on the reduction in volume, increase in the mass, decreases the tensile strength, and lowers the hardness strength with the concentration is increased (Haseeb, Jun, *et al.*, 2011). Besides that, Akhlaghi et al. (2015) also argued that when increasing concentration leads to reduce stress, meanwhile, with the change in weight, tensile strength, elongation strength, toughness strength, and stress softening are lowered.

1.2 PROBLEM STATEMENT

Biodiesel is one variety of biofuels with increasing popularity in the internal combustion engine applications because it can reduce the depletion of fossil fuels, improve greenhouse gas reduction, low-temperature operability, and stability. Nonetheless, despite the advantages mentioned earlier in this chapter, some of the issues with the use of biodiesel are that it has a corrosive property when combined with Ultra Low Sulphur Diesel (ULSD). Suchlike behavior will cause the parts used in fuel delivery systems such as Silicone Rubber (SR), Nitrile Rubber (NBR), Viton and Acrylic Rubber (ACM), etc. to swell when immersed in the biodiesel like B10, B20, B30, and B100. The results from the literature have also shown that the elastomer parts swelling in the fuel delivery process increases with rising biodiesel concentration. Hence, this results in a reduction in the tensile and hardness strength of the elastomer part in the fuel delivery system.

Consequently, the swelling rate of the elastomer and seals will be increased. Besides that, some effects on the elastomer will be apparent, which is contributing to the increase in biodiesel concentration. For instance, the elasticity of the elastomer parts used in the fuel delivery system will be affected due to the increase in the biodiesel concentration. Swelling of the elastomer parts demanded that these parts require replacement to avoid any blockage or leakage in the fuel delivery and storage system. Hence, as a result, the lifespan of the fuel delivery system will be reduced, particularly with increasing soaking time.

Biodiesel used as a transport fuel should have a higher resistance to oxidation along with the extent of storage and reduced the risk deterioration of the elastomer parts used in the fuel delivery and storage tank system as well as a construction element for mixing and transfer fuel. Therefore, biodiesel used as a transport energy source that has a peak amount of biodiesel for use in an engine, which is 20vol% of biodiesel blended to 80vol% of diesel is available to be applied (Chandran *et al.*, 2018).

According to this, further investigations are required to investigate the influence of biodiesel concentration on the performance of the type of elastomers used in the fuel supply and storage tank system. Nowadays, Malaysia is using B10 as a transport fuel, and B30 will be used as a transport fuel soon. Hence, it is essentially important to understand the existing elastomer performance and degradation behavior for uses in the fuel delivery system using both types of biodiesel, these being the B10 and B30.

1.3 OBJECTIVE

The purposes of this study are:

1. To examine the change in the physical property of the O-ring NBR elastomer samples as a function of immersion time, type of biodiesel as well as temperature exposed.
2. To determine the failure behaviour of the O-ring NBR elastomer samples as a function of immersion time, type of biodiesel as well as temperature exposed.

1.4 SCOPE OF PROJECT

The range of the program would be:

1. To prepare experimental test procedures and develop testing capability.
2. To perform the physical (mass test and SEM) properties characterization.
3. To perform failure analysis of the samples following different test conditioning (the type of biodiesel, temperature, and time).
4. To generate a test report and failure analysis report.

1.5 PLANNING AND EXECUTION

The research activities for PSM I and II are shown in **Tables 1.2 and 1.3,** respectively. The research activities include the literature review, lab visit, experimental design, formulation and preparation materials, and characterization testing. The characterization testing in this project considers both physical (mass test). The completion of all experimentation work will be followed by data analysis, report writing, report submission, and the presentation during the seminar for each semester.

TABLE 1.2: GANTT CHART FOR PSM 1

Weeks Activities	PSM 1															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Research Title Selection	■	■	■													
Background Study			■	■	■											
Literature Review				■	■	■	■	■	■	■	■	■	■	■	■	
Lab Visit			■													
Select Guide for Fuel Injection				■	■											
Drafting Chapter 1						■	■									
Submission Progress Report							■									
Preparation of Samples							■	■	■							
Jig Preparation							■	■	■	■						
Charaterization Testing:								■	■	■	■	■	■			
1) Physical								■	■	■	■	■	■			
2) Mechanical								■	■	■	■	■	■			
Data Collection & Analysis													■	■		
PSM 1 Report Writing													■	■	■	
Submission Report PSM 1															■	
PSM 1 Seminar																■

TABLE 1.3: GANTT CHART FOR PSM 2

Weeks Activities	PSM 1															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Literature Review	■	■	■	■	■	■	■	■	■	■	■	■	■			
Methodology			■	■	■	■	■	■	■	■	■	■	■			
Conduct Experiment: Soaking Test				■	■	■	■									
Conduct Experiment: Mass Test					■	■	■	■								
Conduct Experiment: SEM Test					■	■	■	■								
Progress Report Submission									■							
Data Analysis								■	■	■						
Results and Discusion								■	■	■						
PSM Report Writing										■	■	■	■			
Draft Submission														■		
PSM 2 Seminar															■	
Final Report Submission																■

CHAPTER 2

LITERATURE REVIEW

2.1 BACKGROUND

In recent years, mineral resources supply like gasoline and carbon are diminishing, and it is quite vital to ensure that energy preservation is feasible. On the other hand, the use of conventional fossil energy including pure diesel (B0), due to soot production, emission of toxic gasses, can lead to a lot of emissions and it is hazardous if used for an extended period (*Breathing dangerous diesel fumes - Truck News*, no date). Such observation is because mere diesel-powered gasses could induce the greenhouse effect that can lead to severe illness. In this aspect, depleting supplies and increasing crude oil prices pose a significant threat to the global economy as petroleum costs are the foundation for global industrialization. Such findings, combined with the increasing concern about global warming and widespread environmental degradation such as climate change, acid rain, and smog has accentuated community and science consciousness and resulted in significant efforts to create alternative energy sources. The level of pollution of atmospheric pollutants has gradually increased, creating some environmental issues due to some changes like the development of new technologies, particularly for motor vehicles, population growth, and urbanization.

Human activities also increased the number of chemicals that have been released into the environment. Emissions play a vital role in air pollution rates in cities as they release pollutants such as nitrogen oxides (NOx), carbon monoxide (CO), volatile organic compounds (VOCs), sulphur oxides (SOx), ammonia gases, and others (Ferreira *et al.*, 2008). Over an extended period, people who are exposed to high concentrations of pollutants are facing the risk of health issues, i.e., the likelihood of cancer or any other serious health issues. Pollutants cause severe neurological, respiratory, immune, and reproductive with reduced fertility damage (Ferreira *et al.*, 2008).

The transportation and agriculture industries are among the most common sectors with great supply for natural gas-based oil. This sector is among the significant consumers of gasoline, diesel, and carbon fuel, but is also among the main contributors to environmental contamination in the region. Therefore, a considerable sector is produced by the transport and automotive industries like off-road engines and trucks and automobiles. To diversify petroleum products, the use of alternative fuel sources is a quite effective, deep-term option (Giakoumis *et al.*, 2012).

Moreover, the thinning of the ozone layer is another result of greenhouse gasses, and this is also among the factors of global climate change. Thinning of the ozone layer may lead to health hazards, including eye cataracts, skin cancer, eye cancer, and many others. Global warming is also quite dangerous due to the melting of the ice in the South Pole and the North Pole. The ice melting in these regions would force the sea level to increase, as well as the death of animals residing there, like polar bears and penguins, who are already on the brink of extinction. Hence, it is clear that the use of alternative fuel is crucial to preserve the environment since we can conserve natural resources and allow only minimal carbon footprints with the use of biodiesel.

The environmental concerns and petroleum costs are now growing, raising the need to discover suitable and affordable renewable energy sources as a consequence of the incremental decline of energy reserves. The dedication to sustainable development, including the introduction of safer, low-impact renewable energy technologies, has fostered the international production and use of biofuels. Biodiesel is one type of biofuel generated from renewable energy sources, namely biomass — the worldwide promise of using biodiesel as a renewable fuel.

This research focuses on running some elastomer tests immersed in biodiesel to verify the physical characteristics of the polymer immersed in B10 and B30 biodiesel. The experiments are the experiments of the soaking, mass, and SEM. This chapter describes how to implement and describe the tools and equipment used in this task.

2.2 BIOFUELS

A lot of large and heavy automobiles, including lorries, vans, buses, and trucks are on the street. Usually, heavy automobiles use diesel for their fuel. Since sheer diesel has many hazardous impacts that can damage both the people and the environment, option fuels have already been implemented to protect the environment. Due to various similar characteristics, diesel replacement by biofuels provides an option in many diesel systems, from boilers to internal combustion engines. Biofuels are being used as a fuel source may help reduce greenhouse gas dependence and reduce fossil fuel reliance (Kass *et al.*, 2018).

The security of energy is a critical component in every country's economic stability, particularly for those with inadequate fossil and nuclear assets. Incremental depletion of energy resources, rising oil prices, and environmental issues have speeded up the need for appropriate and environmentally friendly renewable fuels to be discovered. Biofuels have taken on a prominent role as they have the vital benefit of being renewable, thus showing and benefit in decreasing carbon dioxide (CO_2) emitted (Hansen, Kyritsis, and Lee, 2010). Biofuels is an environmentally friendly, non-toxic, and sustainable source of fuel with a lot of potentials to be used as a petroleum diesel alternative.

In addition to the global benefits of biofuels, including energy security and foreign currency savings, the growth of biofuels could also support local industrial development in rural communities (Escobar *et al.*, 2009). The development and the function of biofuels are expected to have the ability to balance the growing need for fossil fuels among the feasible proposals. Biofuels could be easily produced from plentiful, affordable, and sustainable biomass assets like organic waste and plants. Because of low sulfur, carbon, and nitrogen content in biofuels, harmful greenhouse gas emissions, including nitrous oxide (N_2O) methane (CH_4), could be minimized by combining fossil fuels with biofuels (Axelsson *et al.*, 2012; Lane *et al.*, 2014). Therefore, when the carbon dioxide (CO_2) produced during the burning of biofuels is equivalent to the CO_2 absorbed in the photosynthesis of plants, the use of biofuels remains consistent in the environment (Budzianowski, 2012).

2.2.1 General classification of biofuels

Biofuels are generally categorized either by their feedstock's biological origin either by their engineering of production. Biofuels were initially made in feedstock from proteins, carbohydrates, and lipids (Huo *et al.*, 2011). According to Huo et al. (2011), only a small proportion of biofuel manufacturing capacity is presently compensated by protein-based biofuels. Such observation is mainly due to the complexities in denominating hydrolysates of proteins (Hazelwood *et al.*, 2008). There are also some biofuels, such as biohydrogen, derived from various sorts of natural sources (Azwar, Hussain, and Abdul-Wahab, 2014).

Biomass-based on carbohydrates is accessible on a massive scale from landfill through-products and residues from agriculture, food industries, and forestry as the inedible ratio of plants. The cellulose and hemicellulose derived from this origin are the primary feedstock for the manufacture of biofuels (Somerville *et al.*, 2010). Bioalcohol fuel, among the most widely used biofuels, is produced mainly from biomass based on carbohydrates (Weber *et al.*, 2010).

Two generations of biofuels dependent on lipids have been identified (Sawangkeaw and Ngamprasertsith, 2013). First-generation raw material involves unsaturated and saturated edible fruit like olive, coconut, and palm, while vegetable oil is extracted from oilseeds, including sunflower, canola, corn, and soybean. The second generation of biofuels dependent on lipids is developed from oleaginous microorganisms, waste vegetable oils, insects, and animal fats. Biodiesel is the best-known example of biofuels of the whole category.

2.3 BIODIESEL

Biodiesel is described as a combination of long-chain fatty acid monoalkyl esters extracted from sustainable biolipids like animal fats and vegetable oils (Coronado *et al.*, 2014). These can eliminate fuel and particulate matter pollution from contaminants relative to conventional diesel. These are also environmentally friendly and non-toxic. Significant progress in the generation capacity of the biodiesel industry is observed in recent years to meet market requirements. That use of the fuel, as well as its rise in the energy matrix, involves constant research and technological development to ensure its use in safety. Biodiesel use is limited in 7% biodiesel combined with diesel in the Brazilian fuel matrix. That year, however, the percentage of biodiesel would rise to 10% (Höpe, Hünerhoff, and Hauer, n.d.). Due to its biological process of deterioration, oxidation, or rigging, and consequentially of their mixes with diesel, fuel quality assurance is a more significant concern associated with increasing competition for biodiesel.

The use of biodiesel results in high potential and environmentally friendly alternative to minimize over-reliance on power imports (Giakoumis *et al.*, 2012). The reaction of transesterification could gain this biodiesel (Giakoumis et al., 2012; Alves, Mello and Medeiros, 2013; Coronado et al., 2014; Sorate, Bhale, and Dhaolakiya, 2015; Zhu, Cheung, and Huang, 2016). Because biodiesel would have similar physical characteristics as diesel, biodiesel and its mixture may be applied directly in the engine while blended with pure diesel (Vijay Kumar, Veeresh Babu, and Ravi Kumar, 2018).

Recently, several studies have shown that the use of biodiesel yield in lower particulate emissions (PM), unburned hydrocarbons and carbon monoxide relative to pure diesel, thus engine efficiency is unchanged or enhanced (Giakoumis et al., 2012; Alves, Mello, and Medeiros, 2013; Zhu, Cheung, and Huang, 2016).

2.3.1 Biodiesel composition

Biodiesel will be mostly fatty acid methyl esters generated through the transesterification of triglycerides (oils) from various feedstocks. There could be two forms of ester particles in biodiesel that is saturated esters and unsaturated esters. Methyl palmitate, methyl myristate, and methyl stearate seem to be the most popular saturated esters (Fazal, Rubaiee, and Al-Zahrani, 2019). Besides, methyl palmitoleate, methyl linolenate, and methyl linoleate are the typical unsaturated esters. Glycerin, aldehyde, free fatty acids, and ketone are the other metabolites. The structural and compositional study of biodiesel from various feedstock is summarised in **Table 2.1** (Fazal, Rubaiee, and Al-Zahrani, 2019). It is known whether unsaturated esters, fatty acids with metal surfaces are relatively quite active (Fazal, Haseeb, and Masjuki, 2011). Biodiesels with higher unsaturated esters such as rapeseed/~90%, soybean/~80%, jatropha/~77% are therefore more destructive than lower unsaturated esters like palm/~38% (Fazal, Rubaiee and Al-Zahrani, 2019).

TABLE 2.1: FUNCTIONAL AND TEXTURAL ANALYSIS OF BIODIESEL FROM THE DIFFERENT FUEL SOURCES

(FAZAL, RUBAIEE AND AL-ZAHRANI, 2019)

Types of biodiesel / Textural & molecular structure	Palm	Soya Bean	Edible	Jatropha	Waste cooking
Methyl myristate (C14:0) $CH_3(CH_2)_{12}COOCH_3$	6	0	0.1	0	0.90%
Methyl palmitate (C16:0) $CH_3(CH_2)_{14}COOCH_3$	40.4	14.1	6	14	23.74%
Methyl stearate (C18:0) $CH_3(CH_2)_{16}COOCH_3$	11.5	5.2	2.1	7	6.39%
Methyl palmitoleate (C16:1)	1.2	0.7	0	0	1.20%

$CH_3(CH_2)_5CH=CH(CH_2)_7COOCH_3$					
∑ Saturation of the ester	~57%	~19%	~8%	~21%	~31%
Methyl Olete (C18:1) $CH_3(CH_2)_7CH=CH(CH_2)_7COOCH_3$	36.1	25.2	60.34	43	31.1
Methyl Linoleate (C18:2) $CH_3(CH_2)_4CH=CHCH_2CH=CH(CH_2)_7COOCH_3$	0.1	48.7	20.87	34	24.2
Methyl Linolenate (C18:3) $CH_3(CH_2)_4CH=CHCH_2CH=CH(CH_2)_4COOCH_3$	0	6	8.15	0	1.6
∑ Unsaturated esters	~38%	~80%	~90%	~77%	~59%
Others	~5%	~1%	~2%	~2%	~10%

-

2.3.2 Transesterification

The process of transesterification is a reversible transformation that transforms an ester into another ester. This process involves combining ester groups and alcohol, while the source is available throughout the response (*Transesterification - Definition, Glossary, Details - Oilgae*, no date).

Coronado et al. (2014) reported that biodiesel is produced by the esterification or transesterification processes involving the reaction of the fatty acid in the presence of catalysts with either short-chain alcohol, typically methanol. The traditional catalysts are homogenous alkaline and acidic, e.g., NaOH, H_2SO_4, KOH, and heterogeneous, produced by grafting bases, metal oxides, salts, and enzymes on different media like aluminum, titanium, resins, and silica (Vyas, Verma and Subrahmanyam, 2010). Due to economic considerations and strong transformation produces, transesterification through the use of alkaline catalysts would be the preferred approach for commercial production of biodiesel. Furthermore, the method is carried out at lower atmospheric pressure and temperature (Coronado *et al.*, 2014).

According to Chandran et al. (2016) research, biodiesel (B100) also identified as methyl ester fatty acid (FAME), is usually manufactured through the method of transesterification from animal fats or vegetable oil. Vegetable oil molecules consisting of triglycerides are transformed into three monoalkyl esters under transesterification, as shown in **Figure 2.1** (Chandran et al., 2016). In their study, the process aims to reduce the viscosity of oil from 40 $mm^2\ s^{-1}$ to approximately 5 mm^2s^{-1} lower viscosity, which is appropriate for use in diesel engines.

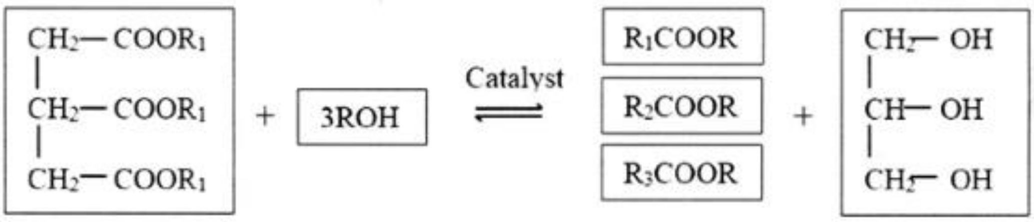

FIGURE 2.1: VEGETABLE OIL TRANSESTERIFICATION PROCESS TO PRODUCE BIODIESEL

(Chandran et al., 2016).

Methanol oil transesterification is typically done using simple homogeneous catalysts that are slower than acidic catalysts. Solubility sodium and potassium hydroxide are typical foundation catalysts.

2.3.3 Type of biodiesel

The manufacturing of biodiesel from various feedstocks has been well established. However, manufacturing processes involve continuous technical innovations and advancements to reduce costs and improve quality. Biodiesel is usually derived from multiple typical feedstocks such as vegetable oils (edible or non-edible), waste cooking oils, and animal fat, as shown in **Table 2.2** (Fazal, Rubaiee, and Al-Zahrani, 2019). There are several forms of development of biodiesel on the market.

TABLE 2.2: GENERAL PROPERTY OF BIODIESEL (SISBUDI HARSONO, 2011)

Properties	Palm Oil	Jatropha Curcas	Rapeseed	Soya Bean	Fossil Fuel	Standard of Biodiesel	
						Value	Method
Combustion of heat (MJ kg^{-1})		39.23	36.90		42	38.3	
Melting point (ºC)		20				>18	ASTM D 2500
Boiling point (ºC)	190	135	175	174	>68	>100	ASTM D 93
Density (kg m^{-3})		880	920		840	850-900	ASTM D 1298
Viscosity (mm^{2} s^{-1})		4.8	4.5		2.6	2.3-2.6	ASTM D 445
Cetane number	42		46	37.9		<51	ASTM D 613
The proportion of Ash (%)		0.20	0.01		0.17	<0.02	ASTM D 874
Ratio of Water (%)		0.073	0.075		<0.02	<0.05	ASTM D 2709
Quality of Acidic (mgKOH g^{-1})		0.40			<0.08	<0.08	AOCS Cal 2-55
The ratio of Contaminants in Coal (%)		0.20			0.17	<0.30	

Remark:

1. Calorific Quality / Combustion Energy - Heating bills or ignition energy could be the total of the ignition energy released by the cost of a fuel unit being burnt.
2. Pour (melt) Point - That point at which solid-shaped oil tends to melt or pour is the phase of pouring or melting. For conditions where temperatures fall underneath the melting point, it is necessary to cool the entire fuel chain, which includes both the fuel delivery system and fuel tank.
3. Flash Point (FP) / Boiling point - The flash point value of fuel might be the minimum temperature at which the fuel can burn when an origin of combustion has been used. The boiling point is different from the gas's variation. Limited burning phase temperatures are necessary for adequate protection and transportation of diesel.
4. Density - This is the volume per mass unit. Lightweight fluids supply most heat. For example, gasoline and diesel fuel have equal weight energy, but petrol is massive, and thus more energy per litre is generated.
5. Viscosity - Viscosity refers to the volume of oil. It is determined by measuring the amount of time needed for a nominal amount of oil to pass across a given size orifice. Viscosity allows the compressor to lubricate and fuel to atomize. Minimal viscosity fuel sources would not provide necessary lubrication for exactly matching fuel injection hoses, resulting in seepage or enhanced injury.
6. Cetane Number (CN) - This is a rough approximation of the duration between both the beginning of the injection and the motor-ignition of the fuel as the octane numbers assess the gasoline (petrol) quality and performance. The higher the rate of cetanes, the shorter the lag duration, and also the more influential the combustibility. Reduced Cetane petrol amount will result in a quick charge,

vibration, and exhaust vapor. Ultimately, fuel-efficient petrol engines with Cetane quantities above 50.

7. The ratio of Ash - Ash has often suggested the number of elements in the gasoline. High concentrations level of these substances will contribute towards the plugging of injector tips, deposits of combustion, and damage to the injection system. The ash content is essential for heating efficiency, as the heating performance decreases with reduced ash content.
8. The proportion of sulphur - The quantity by mass of sulphur throughout the Sulphur fuel content is regulated by law to a small portion of gasoline on the road.

Biodiesel also can be defined as a proportion of biodiesel in the fuel in some concentration. That is shown by the biodiesel volume ratio in the fuel. It can range from B0, B5, B7, B10, B20, B30, B50, and B100 in a few grades. With B0, because it has 0 vol% biodiesel, the fuel is classified as pure diesel. Its fuel has 100 vol.% diesel without any biodiesel mixture. It is the reason why biodiesel is regarded as pure diesel. On the other side, B5 has 5 vol% of biodiesel blended with 95 vol.% diesel. Apart from that, B7 has 7 vol.% of the biodiesel blended with 93 vol.% of the diesel B10 has 10 vol.% of the biodiesel blended with 90 vol.% of the diesel, B20 has 20 vol.% of the biodiesel blended with 80 vol.% of the diesel, B30 has 30 vol.% blended with 70 vol.% of the diesel and B50 has 50vol.% of the biodiesel blended with 50vol.% of the diesel.

Furthermore, some biodiesels are not suitable to be applied in the CI engine. The reason is due to the higher concentration of the biodiesel volume ratio can lead to failure of the fuel delivery system like those of obstruction and contamination with the fuel injectors, seal corrosion and pipe breakup (Chandran *et al.*, 2016). Thus, just gas with a total content of 80 vol% diesel mixed with 20% biodiesel (B20) is approved for CI engine use until currently (Chandran *et al.*, 2018). Nowadays, fuel with a concentration level of 30vol% of biodiesel with 70vol% of diesel is used for tried to test it is suitable for a CI engine.

2.3.4 Advantages of biodiesel

Particularly in comparison to pure diesel, biodiesel has a lot of benefits because, except for petroleum-based diesel derived from oil refineries, biodiesel is a renewable resource. The biodiesel is much less polluting than the others like diesel. The low concentration level of biodiesel blends with a high concentration level of diesel as B2 is discovered to considerably decrease the amount of toxic carbon-based emissions (*What are the advantages of Biodiesel over petroleum diesel? - BioCube*^{TM}, no date). The shortage of biodiesel sulphur contributes to an increased lifespan of the catalytic converter while using biodiesel. Besides that, it is also possible to blend biodiesel with several other current oil heat pumps and diesel engines such as CI engines without fully committing. Biodiesel can only be tailored to the established fuel supply system. It indicates this can be disseminated via established hoses for gasoline.

In addition to the benefits mentioned previously, there is an improved lubricity, decrease emission, increase cetane number, and flashpoint throughout the biodiesel (Alves, Mello, and Medeiros, 2013; Fazal, Rubaiee and Al-Zahrani, 2019). Moreover, biodiesel offers a higher lubricity, particularly in comparison to diesel fuel (Knothe, 2005; Knothe and Steidley, 2005). Such characteristic is because of the existence of oxygenated molecules, rate of unsaturation, long-chain particles would improve biodiesel lubricity effectively. Consequently, degradation of contact surfaces of metal can be minimized, either over another in slipping shape, thereby maximizing the lifespan of the engine. Burning of biodiesel fuel generally results in lower emissions of smoke, particle size matter, carbon monoxide, and hydrocarbon releases than diesel. Thus the efficiency of the engine is either unchanged or enhanced.

Furthermore, the functionality of biodiesel materials is considered as a growing concern (Fazal, Haseeb & Masjuki, 2011; Haseeb et al., 2011). It would be more oxidative and causes excessive oxidation and surface deterioration related to its structure and unsaturated compounds. Enhanced cetane number of biodiesel is related to saturated compounds longer carbon fatty acid chains (Puhan and Govindan, 2010). High cetane number of fuel with shorter combustion delay can provide full ignition, the cleaner function of the engine, more straightforward beginning of cold, decreased smoke during startup, fewer harmful emissions, reduced coal particles, higher fuel performance, etc. (Broatch *et al.*, 2014).

2.3.5 Disadvantages of biodiesel

Biodiesel already has its disadvantages despite its having plenty of benefits. The use of biodiesel or its mix triggers the early breakdown of fuel supply elements in the type of metal oxidation, breakup of hose, leakage of the fuel line, and corrosion of seal (Lee, Ray, and Little, 2010). Biodiesel has now become one and a half times more costs than pure diesel fuel from gasoline. The production of biodiesel often requires more energy as it needs to be fertilized, processed, gathered, and harvested. Biodiesel could remove dust from the engine. Such dust could be dumped into another fuel filter and oil filter to obtain overloaded and causing fuel system malfunction. Eventually, the elements of the fuel supply need to have some enhancement to ensure that perhaps the system operates efficiently without interruption.

Biodiesel has several limitations, such as limited storage times, higher viscosity, low oxidation stability, and increased corrosivity (Kovács *et al.*, 2015; Fazal *et al.*, 2016; Suthisripok and Semsamran, 2018). High viscosity, specifically across the piston rings, could create deposition on engine parts (Suthisripok and Semsamran, 2018). Weak oxidation stability causes serious technical problems like traveling components stopping, fuel filter clogging, crankcase sludging, combustion chamber debris, etc.

Microorganisms pollution and numerous biodiesel oxidized substances, like short-chain fatty acids, insoluble gums, ketone, and aldehydes, have been reported as aggravating to intensify the deterioration of engine materials for fuel delivery (Haseeb et al., 2010). Over an extended period, it would get worse. Throughout processing, biodiesel with a high concentration of mono-, di- and tri-glycerides consumes more water and transforms esters by the hydrolytic response to free fatty acids (FFA) and alcohol. During the processing time, the excessive water content of biodiesel may reduce its heat quality, function as a breeding ground for microbial, and enhance the aggression of the degradation attack.

2.3.6 Biodiesel standards

Biodiesel dependent on alkyl ester was gradually used in the 1990s as well as its mix as the substitute fuel being used in the automotive industry. Biodiesel specifications have already begun to develop to accommodate the specification. In 1999, ASTM International, also known as the American Society for Testing and Materials, introduced a preliminary standard PS 121 for biodiesel (*Biodiesel Standards & Properties*, no date). Throughout America, the first ASTM standard that is ASTM D6751 is introduced throughout 2002. On the other side, in October 2003, Europe is finalizing the EU standards that is EN 14214. This version was based on the traditional standard of DIN 51606 (*Biodiesel Standards & Properties*, no date).

Manufacturing companies of engines and biodiesel plants have their biodiesel standards. Although they have different criteria, in reality, they are entirely different from each other. Moreover, petrol or diesel engines already make it possible for the application of biodiesel. But there's a particular situation that must be encountered if the guarantee is to be efficient (Biodiesel standards/specification, 2019).

In this study, two types of biodiesel are used, that is the B10 and B30, which are supplied by the Malaysian Palm Oil Board (MPOB), with the focus on studying the physical and mechanical degradation behavior of an elastomer-based component in the fuel injection system of a continental car.

2.4 ELASTOMER

There is indeed a process in each engine to distribute the ignition fuels. This would be considered the network of fuel supply or fuel tanks. Typically the fuel system consists of a few polymer and metallic materials to supply the gas to the combustion chamber from either the tank or basin. The very same applies to the diesel engine. Rubber materials are available along the lines as well as metal components. They are sometimes recognized as rubber materials.

2.4.1 Meaning of elastomer

Elastomer is defined as any substance, including such natural or synthetic polymer that can restore its natural form following a significant force that deforms from the surface (*Elastomer definition and meaning | Collins English Dictionary*, no date). Elastomer is made up of long chains, including polymers or molecules, and, therefore, can retrieve its original form after already being extended to a considerable extent. The term is often taken from elastic-plastic. The phenomenon is called natural circumstances without the use of any applied force. The continuous chains of molecules are wrapped inconsistently throughout this state. It seems that there is zero force added to the polymer and a spontaneous arrangement of the molecules. When the force is passed to the components, the molecules are stretched out all the way. It would also allow the molecules to move during compression, depending on the direction of the force applied to the polymer. Instantaneously, the molecules bring it back to their ordinary compact and arbitrary arrangement once the force is released (*Elastomer | chemical compound | Britannica*, no date). This occurrence is the reason why elastomer could be extended and has elastic properties and returns to its original location. Nevertheless, unless the force imposed is too high and the molecules are unable to handle the tensile force added, they will break into two parts, causing failure.

2.4.2 Variety of elastomer

Elastomers are among the largest and vital types of components used throughout automotive fuel systems. Hence careful understanding of the material's behavior, especially degradation, has become a key concern because of the chemical reaction in the fuel source. The chemicals will make polymer fragile and weaken its physical characteristics as well as its durability. Butyl (IIR), Epichlorohydrin (ECO), Ethylene-propylene-diene Rubber (EPDM), Natural Rubber (NR), Poly Chloroprene Rubber (CR), Nitrile Butadiene Rubber (NBR), Hydrogenated NBR (HNBR), Polyisoprene (IR), Silicone Rubber (SR), Fluoroelastomer (FKM), Styrene-Butadiene Rubber (SBR), Acrylic Rubber (ACM), and Polyurethane are all available in the market. For fuel systems, these components are widely found (Mitra *et al.*, 2006; Akhlaghi *et al.*, 2015).

2.4.3 Properties of elastomer

In **Table 2.3**, a list of various types of elastomer with their corresponding general properties and general chemical resistance are summarised. The typical examples of elastomer presented here include butyl, ethylene propylene diene monomer rubber (EPDM), natural rubber, neoprene, and nitrile (Buna-N).

TABLE 2.3: PROPERTY OF ELASTOMER

(PROPERTIES OF ELASTOMER - RUBBER COMPOUNDING, 2019)

General Name	Specific Name	Structure	Common Property	General Chemical Rebellion	
				Opposed to:	**Assaulted to:**
Butyl	IIR	Isobutylene-isoprene	- Quite strong resistance to conditions - Outstanding conductivity characteristics - Poor air permeability - Good grip characteristics - Poor petroleum-based fluid resistance	Animals & oils, vegetable fats, lubricates, oxidized cleaning agents, alkali, ozone, strong oxidizing chemicals, fluids and lubricates of silicone, ammonia, hydraulic fluids of phosphate ester	Lubricants and solvents based on petroleum oils, liquids and cleaning agents, coal, tar, and diester; organic compounds aliphatic and aromatic
Ethylene Propylene Diene Monomer Rubber (EPDM)	EPDM	Ethylene Propylene Diene Modified	- Great ozone, chemical substances, climate & Ultraviolet - Weak immunity to petroleum-based liquids	Fluids for livestock and brakes, seed oils, oxygen, powerful oxidizing agents, alkalis	Mineral chemicals and cleaning agents; oil, liquids, organic compounds aliphatic and aromatic
Natural Rubber	NR	Isoprene-natural	- Great physical characteristics include abrasion and tolerance to lower temperatures - Weak immunity to petroleum-based liquids	Many mild, aldehyde and ketone, warm or cold compounds, organic acids, and alcohols	Greenhouse gases, heavy acids, fatty acid, oils, liquids, sources of coal, lubricates, detergents, compressed gases, and certain hydrocarbons
Neoprene	CR	Chloroprene	- Excellent tolerance to weathering, durability, and discoloration - Fire inhibiting - Reasonable tolerance to petroleum-based liquids	Additives and acetic acid of moderate amounts, ozone, oils, protein, and fat. petrol fuel, nutritious and mammal fats, coolants, wind, carbon dioxide	Strong oxidizing acids, esters, ketones, chlorinated, aromatic, and nitro hydrocarbons
Nitrile (Buna-N)	NBR	Nitrile-butadiene	- Outstanding resilience to gas-based liquids - Excellent physical attributes including tear tolerance, discoloration, and thermal aging	Some fats, organic compounds, petrol, plastics, cleaning agents, additives, fuel grease, compressed gases	Greenhouse gases, glycogen, aldehydes, chemically treated and nitrocarbons (excluding PVC mixtures).

Polyisoprene	IR	Isoprene, synthetic	- Equivalent or identical features to those of natural rubber - The tensile strength of natural rubber is significantly higher than that of traction	Many mild, warm or cold compounds, soluble compounds, solvents, ketone, and aldehyde	Ozone, strong acids, fats, oils, fuels, solvents, petroleum derivatives, hydraulic fluids, greases, most hydrocarbons
SBR	SBR	Styrene-Butadiene	- Strong electrical separation and ethanol tolerance, oxidized cleaning agents and moderate acids - Similar characteristics of natural rubber, but with greater strength at low temperatures and liquid and temperature tolerance.	Most moderate chemicals, wet or dry, organic acids, alcohols, ketones, aldehydes	Greenhouse gases, heavy acids, proteins, oils, foods, sugars, much carbohydrate
Silicone	Q, Si	Polysiloxane	- Great properties at upper and lower temperatures - Effective vibration isolation and dielectric constant - Low tolerance to tensile, break, and discoloration - Odorless and anti-toxic in particular - Strong resilience to exhaustion, flexibility, and elasticity	Concentrated sodium hydroxide, moderate or oxidation substances, ammonia, hydrogen, Ultraviolet light, humidity, fungi	Most additives, fats, alkaline and volatile bases, liquids, potassium hydroxide dilution, organic compounds, water

2.4.4 Effect of biodiesel on elastomer

The use of biodiesel on rubber may have a few consequences. One of the changes in the weight and volume of elastomer for biodiesel use relative to diesel (Haseeb et al., 2011). The tensile strength, deformation, stiffness, and degradation of some typical polymers used in the fuel delivery system will be affected by the change in volume and weight. According to Haseeb et al. (2011), this research found that while Teflon displayed improvements in mechanical properties in nylon 6/6, nitrile rubber, and strong-density polypropylene. It was unaffected by Viton GFLT, and Viton 401-C Methylesters have already been proven to cause nitrile rubber and tributyl-dilene degradation. These results have been observed in the B10 palm biodiesel mix, including for lower biodiesel mixes like those of HNBR and acrylic rubber (Trakarnpruk and Porntangjitlikit, 2008). The latter investigator also indicated that within NBR and NBR / PVC, improvements in elongation are reduced concerning the immersion period. Based on the most recent research, NBR indicated a decline in soaked time duration. But Frame and McCromick documented a conflicting result for multiple varieties of biodiesel mixtures where NBR was estimated to have swelled by 14-18% of the B20 soy-biodiesel mixture (Frame and McCormick, 2005).

Moreover, only the degree of fuel absorption and the removal of soluble materials like plasticizers are different for different forms of rubbers under application conditions (Trakarnpruk and Porntangjitlikit, 2008). A complete explanation of these kinds of results is also rather difficult because it may include a range of different outcomes, including structural changes, volume change through the weight change, alter in tensile strength, elasticity, stiffness. Regardless of these impacts, the functionality of different polymers in biodiesel is generally attributed to a restricted but measurable position.

2.5 DIESEL FUEL SYSTEM

For all the burning fuel to happen, fuel and oxygen must be available. Currently, the automotive industry, primarily the automobile engines, requires the ignition to generate power. From the intake pipe, air could be pumped into the engine. Just from the other side, in preparation for either the ignition to occur, the fuel must be supplied to the engine. A fuel system, therefore, is an excellent thing to be able to ensure that perhaps the fuel could be delivered to the engine. This overall project fuel system would be the fuel supply system. The purpose of the fuel delivery network would be to pump the precise quantity of atomized and compressed fuel at the right moment into the engine chamber. Nevertheless, there is no flash involved in the engine throughout the burning process. When the compressed fuel is combined with pressurized air, the ignition happens (*E-ZOIL | Diesel Fuel System Basics*, no date).

The diesel fuel system requires several subsystems in the automotive sector. Fuel tanks have been the most vital component compared to other components in the automobile. The fuel tank should be able to store sufficient fuel for a reasonable time to run the engine. Also, the tank should be kept closed at all times to avoid contamination by metal objects. To enable oxygen to enter, it should also be expressed, substituting any gas requires by the engine. The fuel lines are another part to ensure that diesel could be delivered from the fuel tank to the engine. Three varieties of fuel lines are available; these include pressurized lines located between both the injection pipe and the injectors, medium weight lines for the low to medium gas stress located between both the injection pipe and the gas tank, while lightweight lines with little stress.

Besides that, fuel filters also are one type of fuel system in the automotive sector. In several systems, diesel fuel should be filtered not just once but numerous times. A standard system may have three phases of progressive filters — a tank or shift pump filter screen, a primary fuel filter, and a secondary fuel filter. All gas passes through one filtration system in series filters then through the other. A component of the gas passes across each filter in parallel filtration. Besides the fuel filter, the fuel transfer pump also is a variety of components in the automobile industry. Basic fuel systems utilize gravity or atmospheric pressure to obtain gas from the storage to an injection pump. A fuel transfer pump is commonly shown on proper high-speed engines. This engine-driven pump generates fuel to the diesel injection system immediately. The pump always has a hand priming lever from the machine for leaking fuel—another part of the diesel fuel system of the automobile, which is the fuel injection system. There are four sources of fuel injection systems exist which are specific injectors and pump for each piston, integrated compressor and injector, One pump with multi-cylinder injectors, and pumps in a widely known housing to each piston with The mass.

The direct injection network is growing accelerated prominence for on-road applications. On off-road vehicles and machine tools, the forms of in-line and distributors can be used. The most important feature of the fuel system is potentially diesel fuel injectors. The role of the injectors would be to supply each piston with an appropriate volume of atomized and pressurized gas. Highly atomized, high-pressure gas evenly spread across the tank leads to more considerable energy and fuel savings, lower engine noise, and better running. This system uses piezoelectricity to pump petrol or diesel gas, like those used in common rail fuel systems. Piezoelectric injectors are highly accurate and, therefore, can withstand the rather extreme temperatures indirect injection applications (*E-ZOIL | Diesel Fuel System Basics*, no date).

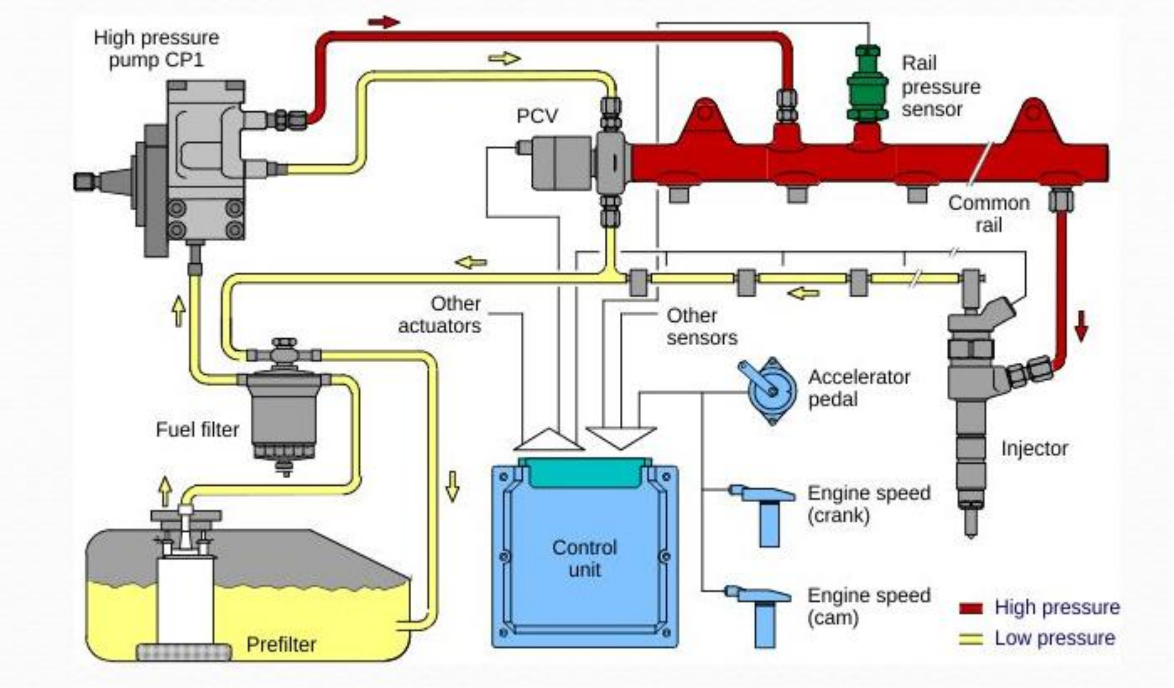

FIGURE 2.2: THE FUNDAMENTAL STRUCTURE OF THE FUEL SUPPLY NETWORK

(*E-ZOIL | Diesel Fuel System Basics*, no date)

Figure 2.2 displays a standard diesel engine's fuel supply system. Each part of the system has its position and is composed, as shown by their specific roles from various kinds of materials. That is because different model functions offer different components to ensure that the component is appropriate for the component feature. It also means that the parts could last further and lower the cost of maintenance. For instance, the fuel transfer device, fuel filtration device, and fuel storage device could be supplied the engine with safe running fuel (Caterpillar, 2013).

2.6 SOAKING TEST

The elastomers must first be immersed in the biodiesel before examining the elastomer's physical properties. The objective of dipping the elastomer sample in biodiesel would be to ensure that the polymer sample interacts with the biodiesel before carrying out further elastomer testing. This soaking experiment was carried out in compliance with the

American ASTM D 471 standard. Several rubber compounds could be used where they have to tolerate hostile fluids in extreme conditions in products, including hoses, gaskets, and O-ring. ASTM D 471 defines the methodology for determining the impact of uniform fuel oils, and other fluids on polymer products. The final consumer of the parts usually describes the actual fluids, temperatures, and processing times to satisfy the application's particular needs (*Effect of Liquids ASTM D471*, no date).

2.7 PHYSICAL TEST OF THE ELASTOMER

Several tests are required to characterize both the physical properties of the elastomer. In this task, the mass test will be carried out for physical testing. Once the mass test has been performed, the mass loss will also be calculated to analyze the mass properties of elastomer-based on the results of the mass test. The first experiment in this project, which is the mass experiment, would be completed for physical testing of the elastomer. In this project, which is an SEM experiment, a certain experiment will be carried out in addition to the mass experiment.

2.7.1 Mass experiment

The mass experiment is essential to confirm the elastomer's change of mass after already being immersed for the specified soaking period in the biodiesel to analyze the elastomer's impact of biodiesel. This experiment is critical for evaluating the elastomer's physical characteristics. Upon soaking, the polymer weight would be compared to the original mass value of elastomer. The experiment was carried out in compliance with the ASTM D 471 (*ASTM D471 | Testing by Standard | Smithers*, no date; ‘Part1STANDARDTESTINGOFELASTOMERRUBBER.pdf’, no date).

2.7.2 Scanning electron microscopy (SEM) test

Scanning Electron Microscopy (SEM) is a scientific technique that scans a sample to create a magnified view for examination with an electron beam. The method has always been identified as SEM microscopy, and SEM analysis is widely used in the study of strong inorganic compounds for microanalysis and failure. This is because SEM utilizes a concentrated high-energy electron beam to produce a range of signals on the surface of the strong sample. Signals resulting from electron-cell interactions indicate specimen details about the structure of crystalline, surface morphology (texture), chemical properties, and materials orientation (Goldstein *et al.*, 2017). Results are obtained over a specified region of the sample surface in most implementations, and a 2-dimensional illustration is created that demonstrates spatial differences in that property. Regions varying from nearly 1cm to 5 microns in size may be analyzed using standard SEM technologies (magnification varying from 20X to nearly 30,000X, 50 to 100 nm of spatial resolution). The purpose of this experiment is to observe the surface of both the elastomer pre and post immersed in B10 and B30 biodiesel.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This section addresses the methods used in this project to collect data on the physical characteristics of the elastomer. The methodology of this research is divided into five main stages. This study was initiated by the literature search regarding the role of biodiesel B10 and B30 as an alternative transport fuel and its effect on elastomer parts for fuel delivery and storage system, followed by a detailed project planning and design of experimentation (DOE). The research work continued with the preparation of the elastomer's physical property and degradation study. The physical testing done was conducted in accordance with the ASTM standard. The material preparation is briefly explained in the third phase of this project. The fourth phase is focused on procedures and analysis of the results obtained from the physical and morphological study, that is, the mass loss, and evidence associated with the O-ring sample degradation from SEM analysis. Finally, data obtained at different concentrations of biodiesel used in the experiment are then compared and correlated with the literature.

3.2 GENERAL METHODOLOGY

The motives needed to accomplish the achievements of this mission have always been mentioned below:

1. Analysis of the literature

Articles, journals, or any scheme material would be evaluated and studied.

2. Project planning

Project planning was carried out to ensure that the project could be carried out smoothly without delay.

3. Material preparation

Suppliers acquired raw materials, including polymer and biodiesel. For instance, MPOB supplies B10 and B30 for this project.

4. Soaking test

Before experimenting, the elastomer must be soaked in biodiesel first.

5. Mass and SEM tests

Upon soaking testing was done, some experiments are conducted based on the ASTM D 471 standard for the guideline of the mass experiments. After that, the SEM test will be conducted to determine the failure of O-ring.

6. Analysis and way to solve suggested

A review of information received from experiments and causes triggered by difficulties would be discussed. Solutions will be proposed based on the analysis.

7. Report writing

The research report was carefully written to satisfy the analysis criteria.

8. Presentation

A presentation on this project will be conducted at the end of the project.

3.3 FLOWCHART

Proper management is quite essential to ensure that the project will work smoothly as well as to determine the period required to perform the task is adequate based on the specification. The flowchart in **Figure 3.1** indicates the plan starting in deciding the target until the results of the tests are evaluated based on the general methodology

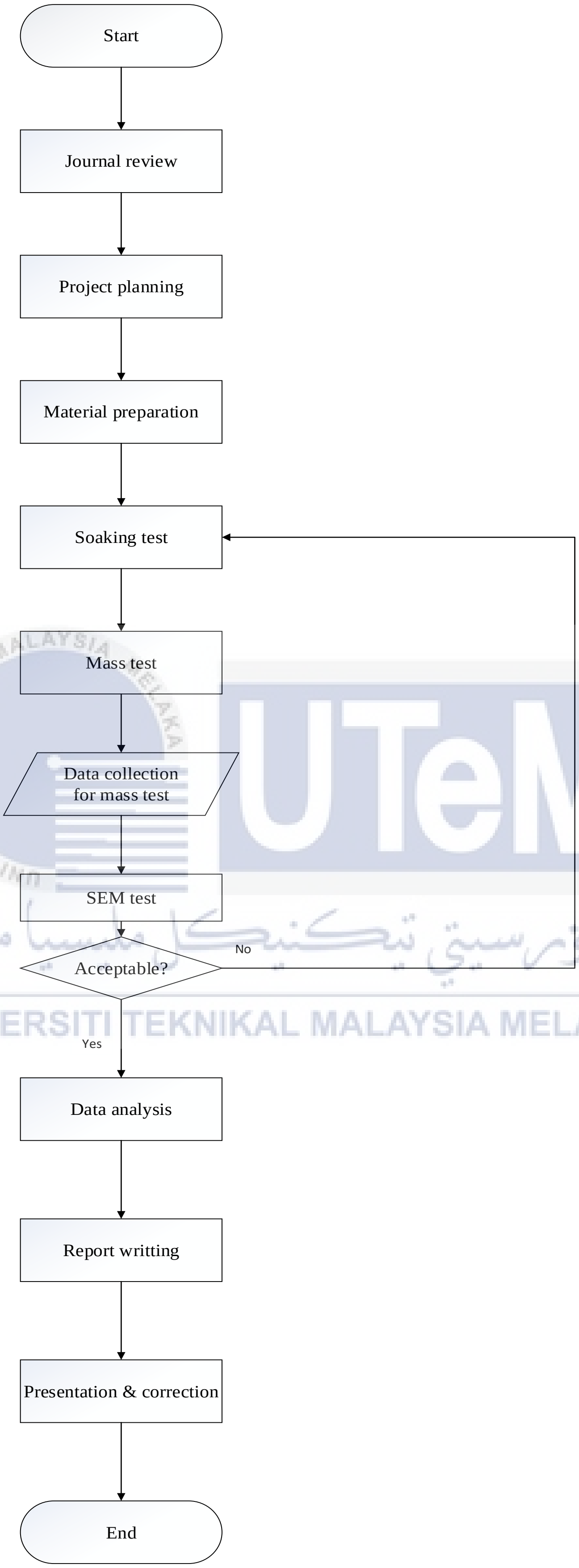

FIGURE 3.1: THE DEVELOPMENT FLOWCHART FOR THIS RESEARCH PROJECT

3.4 MATERIAL PREPARATION

3.4.1 Biodiesel preparation

The biodiesel considered in this project is supplied from the Malaysian Palm Oil Board (MPOB) at the Melaka International Trade Center (MITC) in Melaka, which was extracted from palm oil. The goal of this project is to classify biodiesel 30 as a replacement for biodiesel B10 used at the Malaysian petrol station. There have been some changes in the use of biodiesel in Malaysia. Initially, the B5 program was introduced, which is based on palm oil biodiesel back in 2011, before it was upgraded to the latest B7 mix in November 2014. Application of the B10 program is dedicated only to the transportation industry, beginning in December 2018, with the retail fuel sales started in Petronas, BHPetrol, Caltex, Petron, and Shell fuel station. In February 2019, compulsory application of the B10 biodiesel program will be imposed in Malaysia (PM launches B10 biodiesel program - to reduce CO_2 by 10%, boost demand for Malaysian palm oil, 2019). Moreover, it appeared recently in the news release that all petrol stations must change from selling the existing B7 diesel to B10 biodiesel (B10 biodiesel switch mandatory | The Star Online, 2019).

3.4.2 Temperature-controlled bath preparation

In this project, some experiments, such as soaking tests, weight tests, and SEM tests, will be carried out at different temperatures, such as room temperature and 40ºC. Hence, temperature plays a vital role as a manipulated variable in this project. Temperature-controlled bath can be used across a longer period of samples soaked in liquid at a constant temperature. Most temperature-controlled baths have an electronic or analog interface to enable users to create the desired temperature. Still, some temperature-controlled baths have currently flowing through some sensors to regulate their temperature. It is used to encourage chemical processes to happen at high temperatures. A temperature-controlled bath is a suitable heat source for warming the biodiesel to keep the constant temperature.

To function correctly, the temperature of biodiesel must be constant for the soaking testing in this project. The temperature-controlled bath was indeed used it to control the temperature of the biodiesel. The volume of biodiesel was poured into a 1000 ml in the temperature-controlled bath to maintain the temperature of biodiesel. The schematic design of the experimental set-up has been seen in **Figure 3.2**.

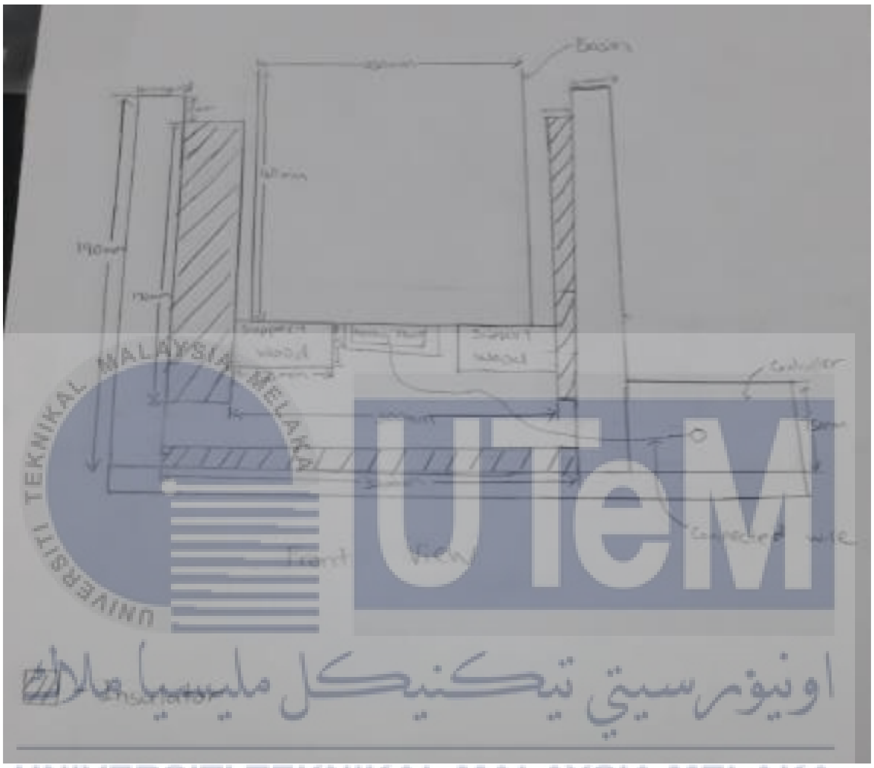

FIGURE 3.2: SCHEMATIC DESIGN OF THE TEMPERATURE-CONTROLLED BATH

For temperature-controlled bath design Solidwork was used to sketch the temperature-controlled bath. A basin size of 22x15x17 cm calculated the dimensions of this bath. The temperature-controlled bath design is as shown in **Figure 3.3,** while the product of the temperature-controlled bath illustrated in **Figure 3.4**. The exploded view of this design is attached in the **Appendix**.

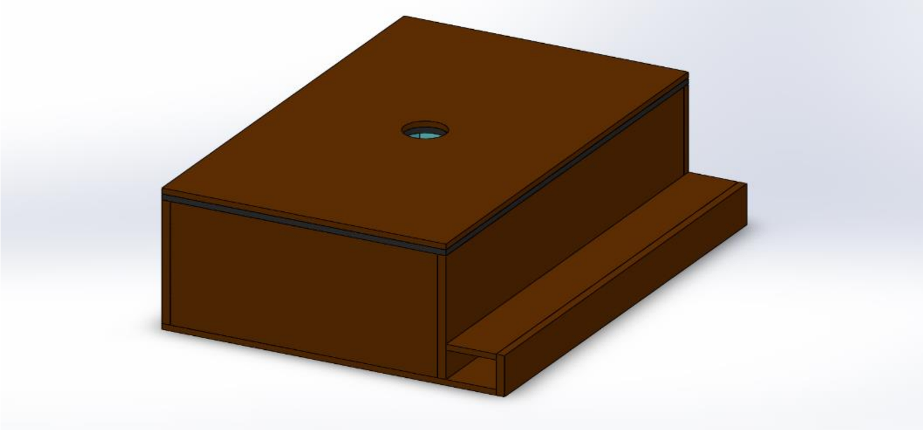

Figure 3.3: Design of the temperature-controlled bath

Figure 3.4: Product of temperature-controlled bath

3.4.3 Elastomer preparation

The supplies will have to be packed first before starting the experiments to ensure that everything has been planned. Furthermore, it is quite critical to schedule the equipment and supplies and ensures that the work is seamless without interruption. Some biodiesel like B10 and B30, while elastomer such as NBR is the components included in this project.

The fuel was acquired from the closest Petronas station for biodiesel B10 and managed to keep in a clean container to prevent contamination of the fuel. The fuel was mixed correctly for biodiesel B30 and kept in a secure tank to prevent contamination. The basis of the production of biodiesel B30 is primarily palm oil. The B10 and B30 biodiesel were collected from the MPOB based in MITC, Ayer Keroh, Melaka. The biodiesel requirement is shown in the **Appendix**. The elastomer was acquired from a store, on the other hand, and the rubber requirement was obtained from the authorized website manufacturing the elastomer product. NBR is the elastomer would use in this project, as shown in **Figure 3.5**. The elastomer specification used in this project will be as indicated in **Table 3.1**.

FIGURE 3.5: O-RING PART

TABLE 3.1: NBR O-RING REQUIREMENTS

BS Size Reference	Inside Diameter (mm)	Outside Diameter (mm)	Dross Section (mm)	RS Article no.	Inside Diameter (mm)	Outside Diameter (mm)
0265-30	26.4	32.5	3	128940	+/- 0.25	+/- 0.10

The O-ring component has been engineered to be immune to hydraulic mineral oils and greases. For continuous operation, it can resist temperatures from -40 ºC to + 110 ºC. It can withstand the short-term temperature of 135 ºC. In contrast, ' O ' rings and ' O ' ring seals are required for various applications in a variety of materials.

3.5 ElASTOMER SAMPLE PREPARATION

Upon receipt of the NBR O-ring, the ASTM D471 must first weigh to ensure for mass change record and analysis of the mass loss upon the soaking test. The sample was firstly weighed according to the required length. The sample was then prepared into the desired shape and length depending on the experiment done, as can be seen in **Figure 3.6**.

FIGURE 3.6: SAMPLE FOR THE MASS TEST

3.5.1 Mass test

The experiment sample consists of a complete O-ring if the external diameter is low enough to allow application in a test tube. The O-ring was cut into sections for sites that are too wide in diameter to be still incorporated as defined. The sample shall be a section size of 90 ± 2 mm (3.5 ± 0.08 in.). All tests Such assessments of change of mass, friction, pressure, elongation, and volume change shall be performed in triplicate. Triplicate testing shall be conducted for hardness, pressure, elongation, and volume change. All measures shall be done of triplicate for improvement in mass change, stiffness, stress, elongation, and density.

3.6 SOAKING TEST

The technique used for soaking tests is the static immersion test based on ASTM D 471. The biodiesel B10 and B30 are considered as the sample fluid for this experiment, which is contained in a sealed beaker, with the experimental build-up as given in **Figure 3.7**. The immersed test is performed to ensure that the ambient situation like temperature or atmosphere could be monitored. Throughout the soaking duration, the change in the sample in terms of the mass loss is monitored according to the test plan set for this project. Because two testing fluids, that is, the B10 and B30 biodiesels are studied, two groups of samples must be usable for a week. Besides, the static immersion test was performed for up to four weeks. Consequently, a total of 12 samples were prepared to be immersed in each B10 and B30 biodiesel.

a) Room temperature

b) 40ºC

FIGURE 3.7: SOAKING TEST FOR O-RING IN BIODIESEL B10 AND B30 AT A) ROOM-TEMPERATURE B)40ºC

At this stage, the soaking test for the O-ring samples was immersed in the B10 and B30 biodiesel for a maximum of 28 days or 672 hours. Following this, mass analysis and SEM testing were conducted on the O-ring samples to understand the degradation behavior of this material in terms of its physical properties.

3.7 MASS TEST

The samples must be completely immersed in the biodiesel B10 and B30, respectively, for mass testing, to mimic an actual environmental condition for the O-ring in the fuel injection system. The soaking method is quite critical, and few considerations must be taken into account to ensure no error happens during the experiment. For the mass test, the equipment used is a Mettler Toledo high-precision electronic balance, as seen in **Figure 3.8**. This test was performed following the ASTM D 471 standard.

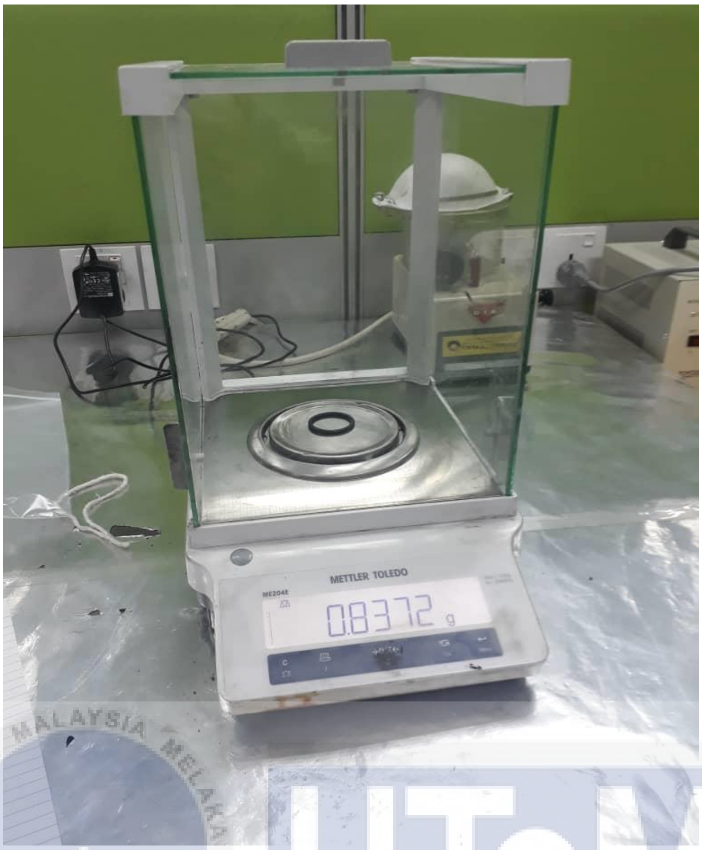

FIGURE 3.8: A METTLER TOLEDO BALANCE AVAILABLE IN AMCHAL LABORATORY

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3.7.1 Procedure of mass test

The original weight of the samples tested is calculated and documented to determine the mass change. The samples were then soaked in appropriate containers in the specified liquids-volatile liquids like fuels that need special attention. For the prescribed time intervals, the containers were then placed in the temperature-controlled bath system at the set temperatures. The samples can adjust to room temperature after the exposure time. The samples were cleaned, clean, calculating, and reporting the final mass.

The mass of the sample was measured before the samples were soaked in the biodiesel and named mass M_1. Afterward, the samples were fully soaked in the beaker containing 100 ml of the biodiesel. Because biodiesel has unstable properties, it is essential to close and securely protect the mouth of the beaker. The objective of protecting the beaker's mouth is to ensure that gas doesn't vaporize in the fuel and scatters in the surrounding environment.

Once total submersion time is completed, the samples were then carefully removed. Afterward, the samples were immersed in acetone at ambient temperature and partially wiped to lint-free resin and foreign matter. The samples are immediately put in a tared, stopped weighing bottle without spending any time. Upon completing the experiment, the weight of the samples was computed by measuring the samples, and the weight of each specimen after the soaking period, which is noted as M_2.

The expression in **Equation (3.2)** is used to calculate the mass change collected from the experiment, as follow:

$$\%Mass\ Change = \frac{M_2 - M_1}{M_1} \times 100\% \tag{3.2}$$

Where:

M_1 = Mass of the specimen before soaked in biodiesel

M_2 = Mass of the specimen after soaked in biodiesel

3.7.2 Precautions of mass test

As biodiesel will be more viscous than other fuel types, it could be challenging to eliminate samples with fast acetone dip and blotting or more intense cleaning after soaked in the biodiesel. It may result in inaccurate results of the tests. Apart from that, it is not necessary to recycle the sample fluid and add it to the experiment. When the sample is removed from the beaker, the biodiesel B10 and biodiesel B30 could not be used again in this project.

3.8 SCANNING ELECTRON MICROSCOPE TEST

A scanning electron microscope (SEM) is used to scan a directed electron beam to generate a picture over a surface. The electrons throughout the shaft communicate with the sample, generating specific signs which can be used to provide details about both the topography and structure of the surface (Egerton, 2016). Although the electrons 'wavelength is so much lower than the light's wavelength, the sensitivity of the light microscope is inferior to that of the SEM. For this project, the objective of this test is to analyze the surface of both the pre and post elastomers soaked in biodiesel B10 and B30. **Figure 3.9** is illustrated the SEM machine available in the SEM lab.

FIGURE 3.9: SEM MACHINE AVAILABLE IN THE SEM LAB

SEM depends on the detection of large-energy electrons released from a sample's surface after being subjected to an extremely focused electric field from an electron gun. To use the SEM focused lens, this electron beam is centered on a tiny area on the sample sheet.

It is necessary to adjust factors such as the accelerated voltage required, the diameter of the aperture used, and the gap between both the sample and the electron gun to obtain the highest quality images. Two electron detection techniques make for various forms of scanning and analysis, both of which provide valuable insights. Backscattered electrons could be identified through an image to provide a comparison based on different chemical formulations. Secondary electrons released near the sample surface provide details about the topography of the surface.

3.8.1 Procedure of SEM experiment

First and foremost, the main steps involved in the SEM experiment is the sample preparation, which includes cutting the sample to size and coating with Platinum for non-conductive material like polymer. Following this, the SEM chamber is vented, enabling the chamber to exceed negligible pressure. Then, the sample compartment for SEM is enabled, and the sample stage is removed. Place the sample stub into the stage that includes the material. Squeeze stub into position. If the program could not monitor the z-distance, ensure that the sample stage with the sample stub has the appropriate height to get a better image. The stage of the sample is then placed into a sample chamber. The sample section is then sealed. The pump is then switched on to enable the vacuum to enter the system. Once this is achieved, the system will inform the user by an indication sign. The program is then allowed for the SEM analysis to take place. An ideal voltage of service varied from 1–30 kV. Higher operating voltage provides a better comparison to the signal if charges collect in the sample will yield a lower resolution.

Then, the procedure will continue to capture the SEM image. In the SEM software, the 'Auto Focus' is launched by pressing on the main button. It will create a focused sample image that could be used as a point of reference. Verify that the magnification is adjusted to the minimum 50X magnification. Then, the 'Fast scan' option. The emphasis will be shifted to the coarse mode while reaching a rough target. The external knobs are manually adjusted to the phase until the area of concern is noticeable on the screen. The magnification can be adjusted until it is compliant with the requested functionality. At around this magnification, the coarse targeting knob can be set to concentrate on the image approximately. To enhance the concentration, the fine targeting knob is used to provide a centered image at the required magnification point. If the magnification amount has raised, this move should be replicated. Once the ideal magnification is achieved, the fine targeting knob is adjusted to increase the visibility. To improve image quality, we can zoom nearly to the full level and then use the fine concentrate knob to concentrate the shot. If it is difficult to acquire a clear image, the stigmatism in both x and y-direction can be adjusted. The concentration and stigmatization balanced must be held up before the best and most accurate image at the elevated magnification point is produced.

Users can go back to the appropriate zoom point after hitting a standard image of the sample. The image can be saved by clicking the photo toolbar either in ‘slow photo’ or in ‘fast photo’ settings. The ‘slow photo’ setting provides improved image quality and higher resolution. Next, the procedure is to create adjustments to use the SEM software. In the drop-down selection of 'Panels,' choose ‘Measurement Tools. The SEM software may explicitly calculate different measurements such as angle, length, and area. Tap on the appropriate button throughout the measurement tool screen to do one of those calculations. Scroll to the image from the SEM measurement page. Measures are achieved by pressing on the image icon to establish comparison points where the algorithm can evaluate. The calculated data points may be incorporated explicitly into the picture if the consumer so wishes. Images will also be saved to the computer.

CHAPTER 4

RESULT AND DISCUSSIONS

The experimental results of the physical test in terms of the mass change test and surface morphology using Scanning Electron Microscopy (SEM) on the O-ring samples in the as-received condition as well as the following immersion up to 4 weeks at room temperature and 40℃ with biodiesel B10 and B30 are presented in this chapter. Discussion relating to the influence of immersion on the physical properties of the O-ring elastomer samples are shown in understanding the degradation behavior of such materials.

4.1 MASS TEST

Table 4.1 shows the individual sample mass, termed M_1, in the as-received condition, before the soaking test, in which the O-ring samples are immersed in the B10 biodiesel from week 2 to week 4. In contrast, in **Table 4.2**, the mass change for each sample attained following up to 4 weeks of immersion in the B10 biodiesel at room temperature is shown.

TABLE 4.1: RESULT OF MASS TEST FOR A SAMPLE BEFORE IMMERSED IN B10 AT ROOM TEMPERATURE

Week	**M_1 (g)**			
	1	**2**	**3**	**Average**
2	0.8220	0.8217	0.8213	0.8217
3	0.8284	0.8284	0.8283	0.8284
4	0/8361	0.8358	0.8360	0.8360

TABLE 4.2: RESULT OF MASS CHANGE FOR SAMPLES FOLLOWING UP TO WEEK 4 IMMERSION IN BIODIESEL B10 AT THE ROOM TEMPERATURE

Week	**M_1 (g)**	**M_2 (g)**				**% of mass change**
		1	**2**	**3**	**Mean**	
2	0.8217	0.8082	0.8082	0.8080	0.8081	1.66± 0.88
3	0.8284	0.8047	0.8043	0.8044	0.8045	2.89± 0.88
4	0.8360	0.8075	0.8074	0.8088	0.8079	3.36± 0.88

Table 4.3 displays the as-received individual sample mass, labeled M_1, before the soaking experiment, in which the O-ring samples were soaked in the B10 biodiesel from week 2 until week 4 at 40℃. **Table 4.4** is illustrated the mass change for each sample attained following up to 4 weeks of immersion in the B10 biodiesel at 40℃.

TABLE 4.3: RESULT OF MASS TEST FOR A SAMPLE BEFORE IMMERSED IN B10 AT 40℃.

Week	**M_1 (g)**			
	1	**2**	**3**	**Average**
2	0.8320	0.8322	0.8320	0.8321
3	0.8338	0.8336	0.8339	0.8338
4	0.8335	0.8335	0.8339	0.8336

TABLE 4.4: RESULT OF MASS CHANGE FOR SAMPLES FOLLOWING UP TO WEEK 4 IMMERSION IN BIODIESEL B10 AT THE 40℃

Week	**M_1 (g)**	**M_2 (g)**				**% of mass change**
		1	**2**	**3**	**Mean**	
2	0.8321	0.8122	0.8119	0.8118	0.8120	2.42± 0.42
3	0.8338	0.8066	0.8068	0.8065	0.8066	3.26± 0.42
4	0.8336	0.8097	0.8095	0.8099	0.8097	2.87± 0.42

Table 4.5 displays the individual sample mass of O-ring in the as-received condition before the soaking test, in which the samples are immersed in the B30 biodiesel following up to 4 weeks. **Table 4.6** shows the mass change for each sample attained following up to 4 weeks of immersion in the B30 biodiesel at room temperature.

TABLE 4.5: RESULT OF MASS TEST FOR SAMPLES BEFORE IMMERSED IN B30 AT ROOM TEMPERATURE

Week	M_1 (g)			
	1	2	3	Average
2	0.8406	0.8404	0.8407	0.8406
3	0.8353	0.8353	0.8358	0.8355
4	0.8322	0.8323	0.8324	0.8323

TABLE 4.6: RESULT OF MASS CHANGE FOR SAMPLES FOLLOWING UP TO WEEK 4 IMMERSION IN BIODIESEL B30 AT THE ROOM TEMPERATURE

Week	M_1 (g)	M_2 (g)				% of mass change
		1	2	3	Mean	
2	0.8406	0.8197	0.8194	0.8191	0.8194	2.52± 0.02
3	0.8355	0.8158	0.8159	0.8114	0.8144	2.53± 0.02
4	0.8323	0.811	0.8108	0.8114	0.8111	2.55± 0.02

Table 4.7 indicates the independent sample mass, labeled M_1, in as-received form, before the soaking experiment, where the O-ring samples are soaked in the biodiesel B30 between week 2 to week 4. In contrast, **Table 4.8** indicates the mass difference for each sample obtained following up to week 4 of room temperature soaking in the biodiesel B30 at 40°C.

TABLE 4.7: RESULT OF MASS TEST FOR SAMPLES BEFORE IMMERSED IN B30 AT 40°C

Week	M_1 (g)			
	1	2	3	Average
2	0.8362	0.8362	0.8363	0.8362
3	0.8366	0.8366	0.8365	0.8366
4	0.8339	0.8340	0.8338	0.8339

TABLE 4.8: RESULT OF MASS CHANGE FOR SAMPLES FOLLOWING UP TO WEEK 4 IMMERSION IN BIODIESEL B30 AT THE 40°C

Week	M_1 (g)	M_2 (g)				% of mass change
		1	2	3	Mean	
2	0.8362	0.8066	0.8067	0.8066	0.8066	3.54± 0.31
3	0.8366	0.8117	0.8118	0.8114	0.8116	2.99± 0.31
4	0.8339	0.8092	0.8086	0.8089	0.8089	3.00± 0.31

Equation (3.2) was used to calculate the mass change, which is the mass loss collected from the experiment, with the results as tabulated in **Table 4.2** and **Table 4.6**. Based on **Table 4.2**, there are 1.66% with a small scatter of 0.88% of mass change when the O-ring sample is immersed for up to 14 days, 2.89% with a small scatter of 0.88% of mass change when soaked for up to 21 days and 3.36% mass change when the O-ring sample immersed for up to 28 days in the B10 biodiesel at room temperature with a small scatter of 0.88% will be illustrated. From **Table 4.6**, the results demonstrated that there is a 2.52% of mass change when immersed for up to 14 days, 2.53% of mass change when soaked for up to 21 days, and 2.55% of the mass difference, when immersed for up to 28 days in the biodiesel B30 with smaller scatter of 0.02% at the room temperature will be shown. It may be attributable to the viscosity of biodiesel based on the results of **Table 4.2** and **Table 4.6**.

Besides, **Equation (3.2)** was utilized to estimate the difference in mass, which is the mass loss obtained from the experiment, mostly with findings as tabled in **Table 4.4** and **Table 4.8**. According to **Table 4.4**, there is a 2.42% of mass change with a small scatter of 0.42% occurs when the O-ring sample was immersed for up to 14 days. A 3.26% of the mass change with a small scatter of 0.42% occurred when the samples were immersed for up to 21 days, and finally, up to 28 days of immersion in the B10 biodiesel at 40℃, there is a mass change of 2.87% with a small scatter of 0.42%. From the results presented in **Table 4.8**, it is apparent that there is a mass change of 3.54% with a small scatter of 0.31% when immersed for up to 14 days; 2.99% of mass change with a small scatter of 0.31% following immersion up to 21 days, and finally, upon immersion up to 28 days, there is a mass change of 3% with a small scatter of 0.31%.

From these findings, although the B10 and B30 have a lower viscosity, the elastomer is more immersed in biodiesel, which has higher viscosity compared to the sample before immersed in the biodiesel (Acharya *et al.*, 2019). It has a strong effect on the elastomer's durability and leads to problems with the fuel supply process. Higher viscosity will be caused by the deposition on the engine part of the vehicles. It is because the elastomer will be swelled and might blockage in the fuel system of the automobile system. Besides that, the result which tabulated in **Table 4.2** is similar to those found in the studies (Höpe, Hünerhoff, and Hauer, no date; Haseeb, Jun, *et al.*, 2011). Some errors might be occurred to cause the results cannot obtain accurately. This mistake may occur because the sample was not properly cleaned as well as the sample already contains biodiesel, and affect the reading of the sample's weight.

Figure 4.1 provides a comparison between the results of mass change (%) for the three consecutive weeks for the samples immersed in B10 and B30 biodiesel at room temperature. Based on the results, at the ambient temperature, the samples experienced a slight mass loss. The mass of sample soaked in biodiesel B10 is marginally higher than the mass of sample soaked in biodiesel B30. It suggests that the B10 biodiesel is being absorbed more into the specimen compared to the biodiesel B30. That may be attributed to the viscosity of biodiesel from the discrepancy. Since the B30 has a lower viscosity, the biodiesel was immersed more into the elastomer compared to B10, which has a higher viscosity (Acharya *et al.*, 2019). That would lead the elastomer to swell, which result in obstruction in the fuel delivery system if it swells wider. It would then impact the elastomer's stability and create issues mostly on the fuel delivery system.

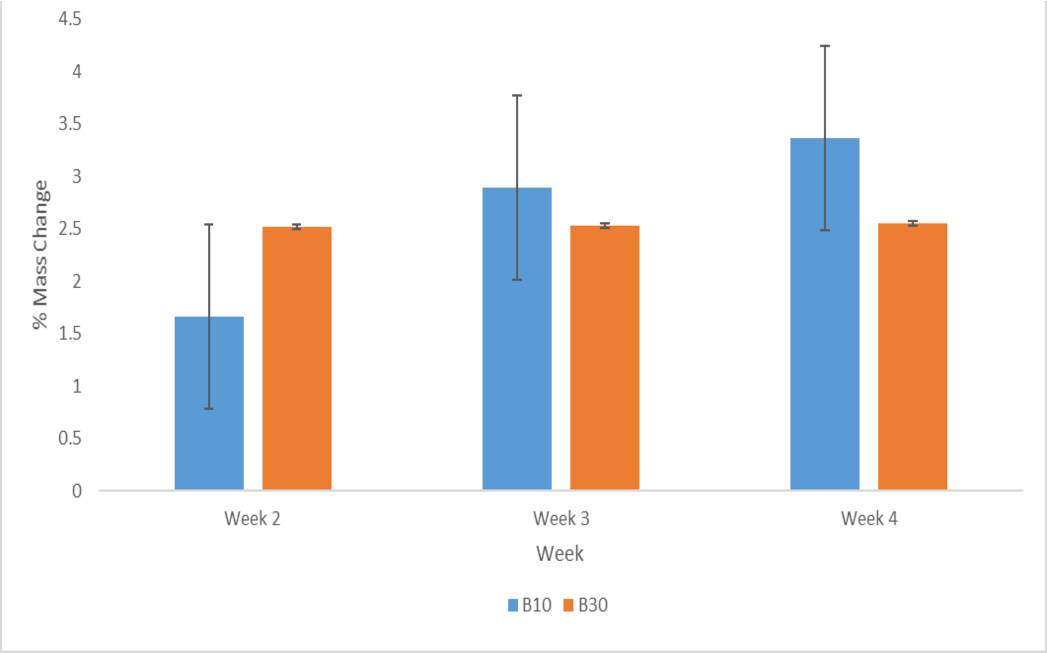

FIGURE 4.1: GRAPH OF % MASS CHANGE VERSUS TYPES OF BIODIESEL AT ROOM TEMPERATURE

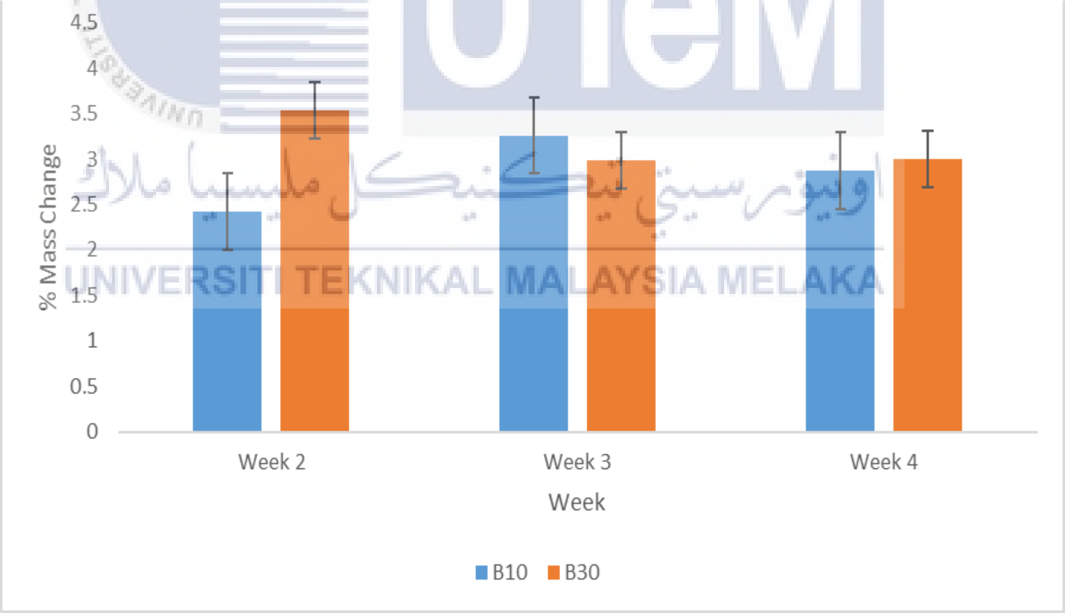

FIGURE 4.2: GRAPH OF % MASS CHANGE VERSUS TYPES OF BIODIESEL AT 40°C

Figure 4.2 presents the mass change (%) obtained for the samples immersed in both biodiesels at 40°C. Clearly, the trend is rising for both of the O-ring when immersed in the B10 and B30 at 40°C. For week 3, the result of the mass change when sample soaked in B10 biodiesel is higher than the result of the mass change for week 4. For B30 biodiesel, this indicates the mass change result of week 2 is higher than the mass change result of week 4. Such scatter in the data attained maybe because the specimen was not properly washed and rinsed during measurement of the mass, and the biodiesel remains on the sample, thus influenced the reading of the sample mass reading. Based on **Figure 4.2**, O-ring indicated a slight mass drop. With regards to the changes in mass at 40℃, the result for B10 is more inferior than B30. With the biodiesel tested, the mass change with NBR indicates a strong movement to higher biodiesel concentrations. In terms of mass changes, there is a relatively weaker effect on the elastomer physical property when immersed in B10 biodiesel than those in the B30 biodiesel medium. The mass loss for the samples will be increased due to higher concentrations of biodiesel at 40℃. It is because the concentration of biodiesel improved liquid absorption relative to soluble elastomer materials; the NBR O-ring samples demonstrated substantial mass differences in the interaction with the B30 biodiesel. The NBR O-ring showed significant mass changes in connection with biodiesel B30, due to concentration of B30 is higher than the concentration of B10. These results suggest that the mass change of the elastomer would be influenced by the concentration of biodiesel (A. S M A Haseeb *et al.*, 2010).

4.2 SURFACE MORPHOLOGY USING SCANNING ELECTRON MICROSCOPY (SEM)

To further understand the degradation behaviour of the NBR O-ring samples, SEM analysis was done on selected exposed surfaces up to the most severe conditions studied. The SEM micrographs attained from the NBR O-ring samples demonstrated a high level of worsening and erosion when soaked in the B10 biodiesel compared to the condition of the sample in the B30 biodiesel, at different temperatures. The findings again provide evidence to support the argument that there is a clear association between biodiesel and elastomers, which could have led the identified elastomers to degrade.

According to the literature, the elastomer degradation reported is in the form of swelling, fracture, and threatening to break off the elastomer material as a function of the solvent intervention of the biodiesel blends. The operation of deterioration begins with assault and penetration by liquid starting to construct ampoules and afterward, the creation and transmission of the crack propagation and reduction of the raw material across its surface. The SEM photos are verification that the concentration of the biodiesel blends raises (Coronado *et al.*, 2014).

Figure 4.3 displayed the SEM micrograph of the O-ring sample in the as-received condition. The O-ring sample in this condition does not have any traces of deterioration, such as pits and cracks, suggesting that there is no significant degradation and swelling. **Figure 4.3** is used as a reference image to compare the results of other SEM microscopy when the samples are submerged in the B10 and B30 biodiesel up to 4 weeks at different temperatures. Besides observing the level of deterioration of the O-ring samples, it can also be used to determine the relationship between biodiesel and elastomer. It is one of the efficient and simplest ways to help us determine the level of degradation for O-ring samples when soaked in the B10 and B30 biodiesel at different temperatures.

The SEM analysis of the O-ring sample immersed in B10 biodiesel up to 4 weeks is presented in **Figure 4.4.** From the micrograph, there are traces of small pits and cracks. The defects could be seen as irregular existence of holes for samples submerged in the B10 at the room temperature. Moreover, this evidence indicates little alteration for O-ring when immersed in biodiesel B10. These results also suggest that, up to 4 weeks, in the room temperature condition, there is only a marginal effect of the B10 biodiesel onto the O-ring that may not significantly affect the exposed O-ring to degrade.

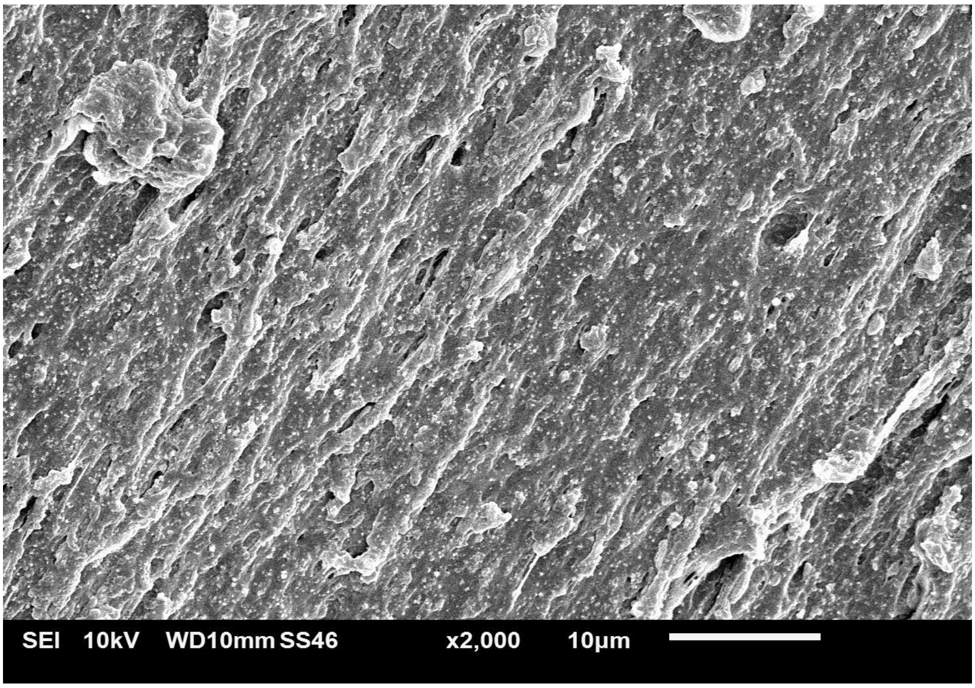

FIGURE 4.3: SEM MICROSCOPY OF O-RING SAMPLE AS-RECEIVED CONDITION

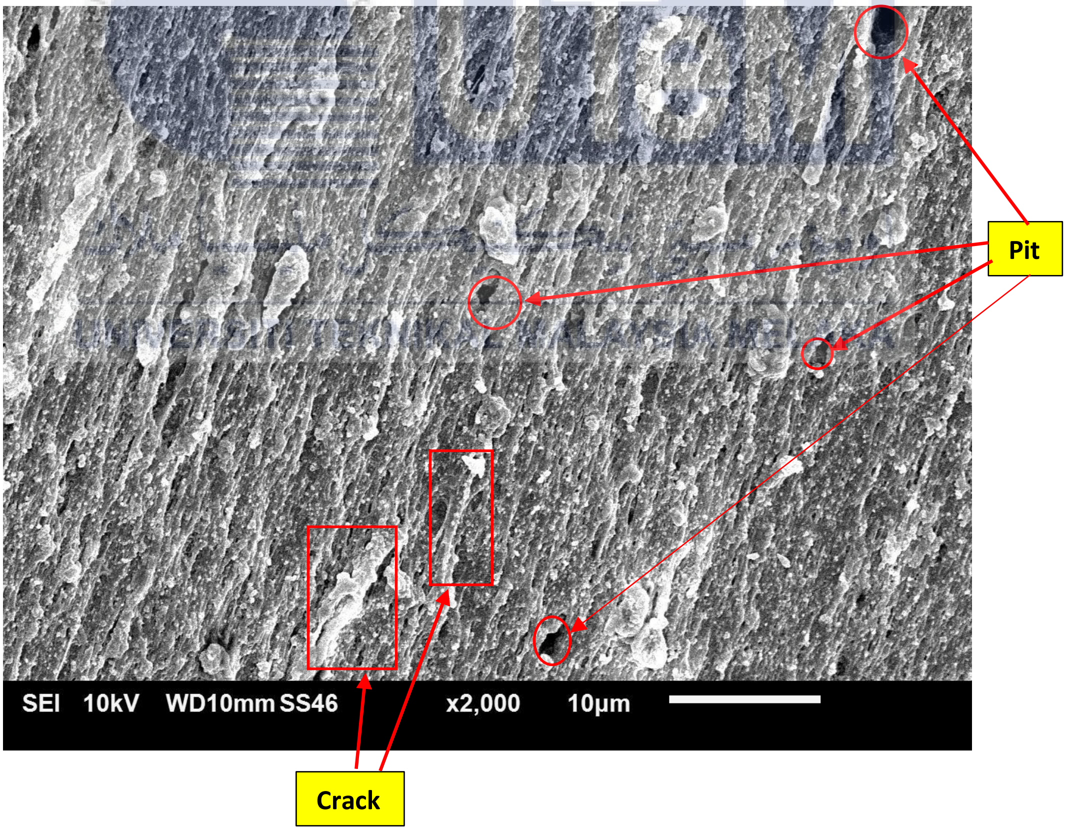

FIGURE 4.4: SEM MICROSCOPY OF THE O-RING SAMPLE IMMERSED IN THE B10 BIODIESEL UP TO 4 WEEKS AT ROOM TEMPERATURE

The SEM micrographs of the O-ring sample immersed in B30 biodiesel up to 4 weeks is displayed in **Figure 4.5**. As compared to the SEM micrograph of the reference sample (an as-received condition in **Figure 4.3**), there are clear traces of pits and cracks present at the sample cross-section, an indication that the sample surface is affected in the B30 medium even at the room temperature. The mass loss may be captured from the existence of a random hole, indicates a higher level of degradation and corrosion in the O-ring elastomer sample. More specifically, more severe surface harm is seen in **Figure 4.5** as proof of crack forming coupled with tiny holes. These findings suggest a strong effect of the B30 biodiesel on the degradation behaviour observed in the exposed O-ring sample surface. The SEM micrograph also indicates that the deterioration of the O-ring is exacerbated as the concentration of biodiesel rises in biodiesel mixture. This evidence confirms our earlier hypothesis that the cross-linked hydrolysis, which caused de-crosslinking, is the primary degradation mechanism. The polymer deterioration attributes alterations in surface chemical characteristics and impacting bulk properties, therefore related to severe physical surface harm as captured from the SEM analysis (Mitra et al., 2006). Besides, the SEM surface morphology analysis indicates the swelling, fracture, and corrosion of the polymer component arising from the liquid interaction of the biodiesel blended. The phase of deterioration begins mostly with the incorporation of the liquid, starting to produce ampoules, so the development and spread of fracturing across its surface (Coronado et al., 2014). The SEM images prove that the concentration of the biodiesel blends enhances. These findings contribute to the conclusion that biodiesel and polymer material has a close interaction that may impact the deterioration of the identified polymer material.

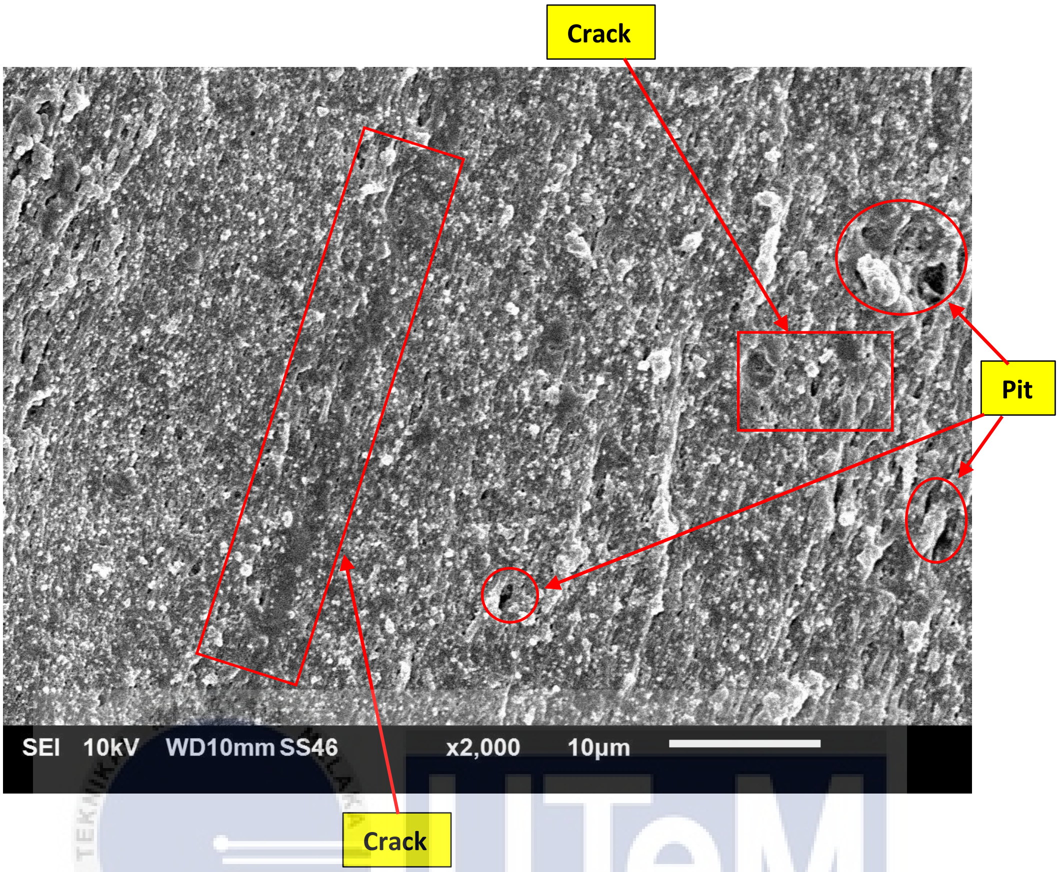

FIGURE 4.5: SEM MICROSCOPY OF THE O-RING SAMPLE IMMERSED IN THE B30 BIODIESEL UP TO 4 WEEKS AT ROOM TEMPERATURE

The SEM micrograph of the O-ring sample immersed in B10 biodiesel up to 4 weeks at 40°C is shown in **Figure 4.6**. Based on the SEM micrograph, there are traces of tiny pits and cracks. The formation of pits may be due to the cross-linking or scission of the macromolecule chain or the incorporation of polar oxygen functional groups into elastomers. These microstructural changes can lead to increased surface energy. Rising surface energy induces localized declines or density raised. It is seen as an efficient precursor for creating crack sites, vacuums, or pits. Commonly, cracking may result from the freezing of the huge amount of pressure energy in the rubber (Miller-Chou and Koenig, 2003). The polymer may be dissolved through solvent either by showing a dense swollen coating or even by substantial cracking, based on how easily the osmotic pressure that accumulates throughout the polymer matrices is eased (A. S M A Haseeb *et al.*, 2010). That is, lesser dissolving elastomer has minimal risk of swollen or cracked.

Such results also suggest that even at an elevated temperature, there is relatively weak interaction between biodiesel B10 and O-ring, and does not significantly induce a notable sign of corrosion of the identified O-ring. Thus, it can be suggested that the erosion of the O-ring would not and would start to deteriorate little when it soaks up at 40℃ in the biodiesel B10 for up to 4 weeks.

Figure 4.7 presents the SEM micrograph of the cross-section analysis of the O-ring sample immersed in B30 biodiesel up to 4 weeks at 40℃. There are more traces of pits and cracks, an indication of more severe surface damage experience in the sample when exposed to this condition. The failure could be seen as a random hole appearance. Moreover, it shows that the sample experience the highest rate of deterioration and rust. This evidence confirms the earlier argument that the close link formed in the B30 biodiesel and O-ring has a strong influence on the O-ring rate of degradation. Having the most biodiesel solubility, NBR O-ring shows more defects and cracks in B30 compared to B10 biodiesel, particularly in at elevated temperature of 40℃. Besides, adjustments in surface chemical properties due to deterioration and impacting bulk products also are related to extreme physical surface harm, as reported in the SEM research (Mitra *et al.*, 2006). Thus, it can be suggested that the O-ring sample rate of degradation is directly proportional to the concentration of the biodiesel concentration blend.

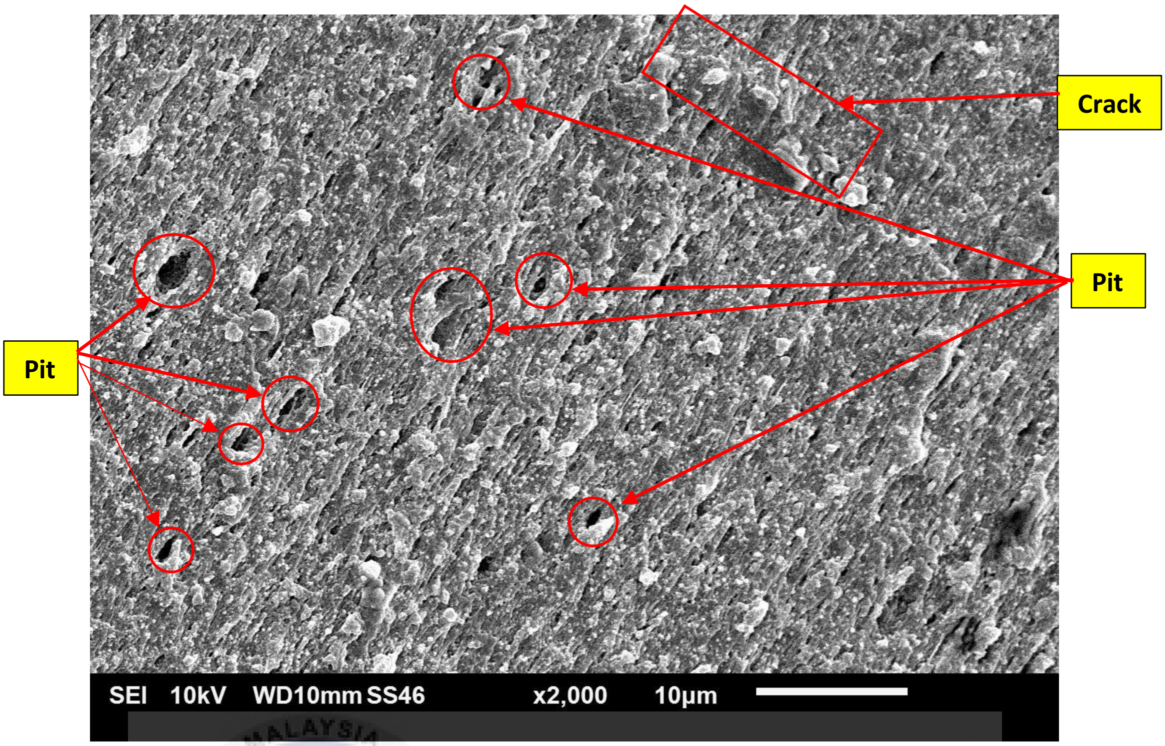

FIGURE 4.6: SEM MICROSCOPY OF THE O-RING SAMPLE IMMERSED IN THE B10 BIODIESEL UP TO 4 WEEKS AT 40°C

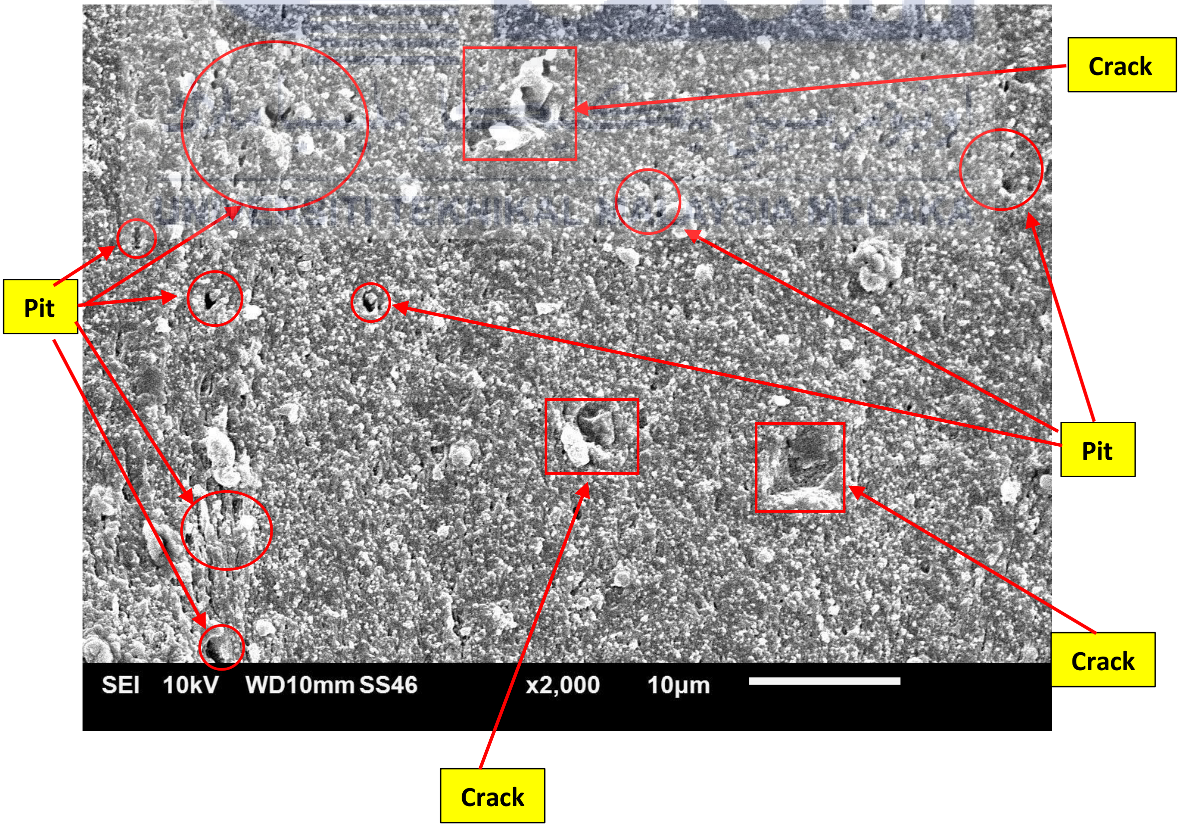

FIGURE 4.7: SEM MICROSCOPY OF THE O-RING SAMPLE IMMERSED IN THE B30 BIODIESEL UP TO 4 WEEKS AT 40°C

CHAPTER 5

CONCLUSIONS AND RECOMMENDATION

5.1 CONCLUSION

Based on the preliminary experimental results attained in this research work, which is correlated with the findings from the literature, several conclusions can be drawn: -

- Based on the results on the mass change of O-ring elastomer up to 28 days of immersion in B10 and B30 biodiesel at room temperature and 40℃, the physical degradation of the samples has been investigated.
- On average, at room temperature, up to 28 days of immersion in both B10 and B30 biodiesel, there is only a marginal mass loss in the NBR O-ring samples, with little difference in the mass loss when immersed in the two types of biodiesel.
- Up to 28 days, at an elevated temperature of 40℃, there is more severe mass loss exhibited by the NBR O-ring samples when exposed to the B30 biodiesel relative to those of the B10 biodiesel.
- These could be attributed to the deterioration of elastomer, which is due to the increased polarity of biodiesel associated with carboxylic (ester) functional group in the biodiesel formation.
- SEM analysis at the cross-section of selected samples exposed to the B10 biodiesel, up to 28 days, revealed that there are negligible traces of surface damage, which is irregular existence of holes on the NBR O-ring samples, regardless of the temperature studied.

- However, regardless of the temperature studied, there is a more significant effect on the NBR O-ring samples degradation behaviour observed when exposed to B30 biodiesel, which contains an increased concentration of the biodiesel in the blended fuels, with traces of more pits and cracks on the sample cross-section.
- Such observation could be attributed to the absorption of biodiesel into elastomer, in which biodiesel would interact with the cross-linking agent or filler of specific elastomer materials which will degrade the material property of elastomer.
- The concentration of biodiesel influenced elastomer characteristics and caused swelling, breaking, and fracture phenomena.

In conclusion, based on these findings, it can be suggested that the NBR O-ring elastomer is suitable for use in the fuel pump system with the B10 and B30 biodiesel as the fuel source.

5.2 RECOMMENDATION

From the preliminary experiment, based on the literature, further investigation focusing on the mechanical and thermal properties of the NBR O-ring elastomer such as hardness, tensile, and FTIR tests shall be carried out to evaluate the mechanical properties of the elastomer as a function of immersion time, type of biodiesel as well as temperature exposed. Some products with more substantial characteristics like Fluoro-Viton, Viton, and Teflon could be tested for additional research to have a more detailed input for the polymer degradation study. Also, the immersion period could be extended to investigate further the effect of biodiesel immersions on polymer degradation behaviour.

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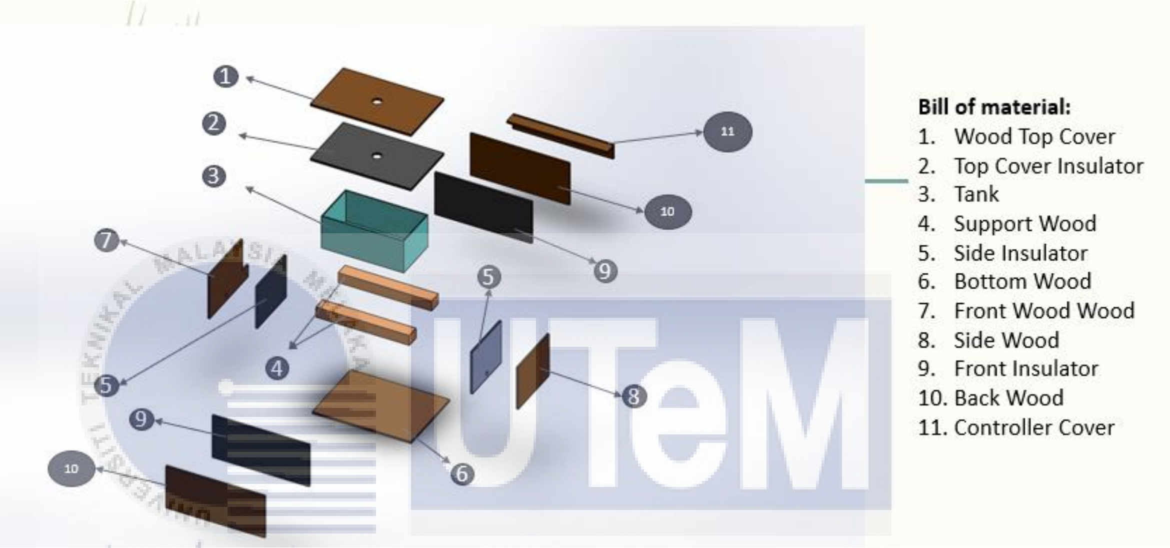
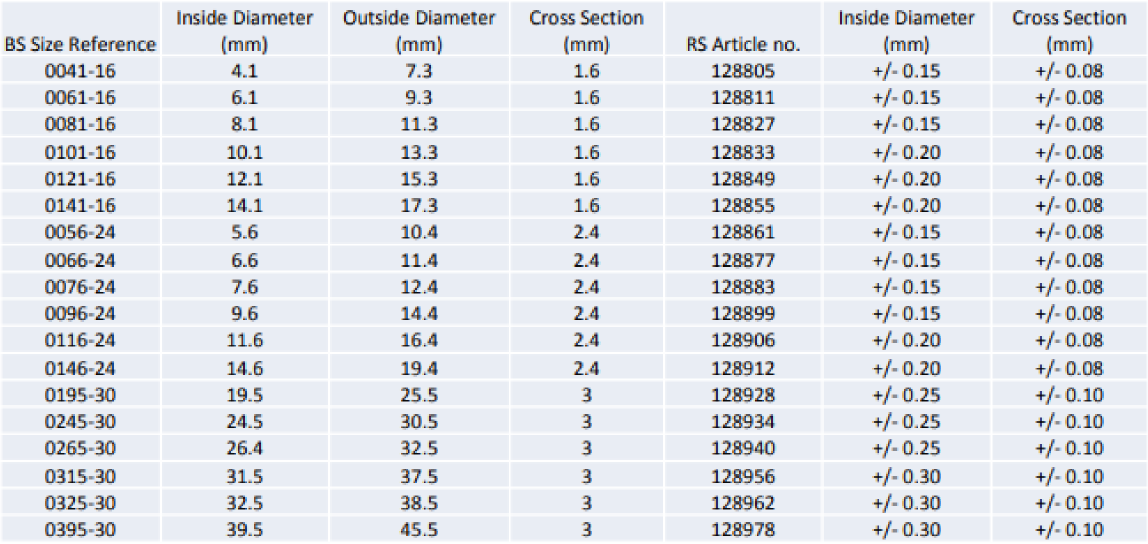
APPENDIX





BS Size Reference	Inside Diameter (mm)	Outside Diameter (mm)	Cross Section (mm)	RS Article no.	Inside Diameter (mm)	Cross Section (mm)
0041-16	4.1	7.3	1.6	128805	+/- 0.15	+/- 0.08
0061-16	6.1	9.3	1.6	128811	+/- 0.15	+/- 0.08
0081-16	8.1	11.3	1.6	128827	+/- 0.15	+/- 0.08
0101-16	10.1	13.3	1.6	128833	+/- 0.20	+/- 0.08
0121-16	12.1	15.3	1.6	128849	+/- 0.20	+/- 0.08
0141-16	14.1	17.3	1.6	128855	+/- 0.20	+/- 0.08
0056-24	5.6	10.4	2.4	128861	+/- 0.15	+/- 0.08
0066-24	6.6	11.4	2.4	128877	+/- 0.15	+/- 0.08
0076-24	7.6	12.4	2.4	128883	+/- 0.15	+/- 0.08
0096-24	9.6	14.4	2.4	128899	+/- 0.15	+/- 0.08
0116-24	11.6	16.4	2.4	128906	+/- 0.20	+/- 0.08
0146-24	14.6	19.4	2.4	128912	+/- 0.20	+/- 0.08
0195-30	19.5	25.5	3	128928	+/- 0.25	+/- 0.10
0245-30	24.5	30.5	3	128934	+/- 0.25	+/- 0.10
0265-30	26.4	32.5	3	128940	+/- 0.25	+/- 0.10
0315-30	31.5	37.5	3	128956	+/- 0.30	+/- 0.10
0325-30	32.5	38.5	3	128962	+/- 0.30	+/- 0.10
0395-30	39.5	45.5	3	128978	+/- 0.30	+/- 0.10