EFFECT OF BIODIESEL CONCENTRATIONS ON SWELLING PROPERTIES OF POLYMER BASED O-RING

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A report submitted
in fulfillment of the requirements for the degree of
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2020

DECLARATION

I declare that this project report entitled “Effect of Biodiesel Concentration on Swelling Properties of Polymer Based O-ring” is the result of my own work except as cited in the references

Signature : ....

Name : ....

Date : ....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of the Bachelor of Mechanical Engineering.

Signature : ....

Supervisor's Name : ....

Date : ....

DEDICATION

To my beloved mother and father

ABSTRACT

Nowadays, most of the industry rely on diesel to fuel heavy machineries and vehicles due to its high efficiency. However, the usage of diesel could cause harm to the environment because it releases harmful gases that can pollute air, water, soil, reduce visibility and global climate change. To reduce the usage of diesel in heavy machineries and vehicles due to its harmful properties that polluting the environment, many researches has been focusing on developing biodiesel as a substitute of conventional diesel. Biodiesel is made of reusable natural elements and emits less harmful chemical to the environment. Although biodiesel could replace diesel as fuel source, there are a few cons in using biodiesel compared to diesel. Biodiesel prone to have corrosive properties when it is mixed with Ultra Low Sulphur Diesel (ULSD). There, biodiesel could affect the elastomer part that exist in fuel delivery system. The elastomer parts present in fuel delivery system such as fuel lines, fuel tank, gasket, and O-ring. In this project, biodiesel B10 and B30 will be used to study its effect on elastomeric O-ring. Therefore, there a few tests will be done to study the effect of biodiesel concentration on swelling properties of elastomeric O-ring. Immersion test and mass test is done to study the mechanical properties of the O-ring after being soaked in biodiesel with certain duration and temperature according to ASTM D471-06. Hardness test is done to study the mechanical properties of the O-ring according to ASTM D2240-15.

ABSTRAK

Pada masa kini, sebahagian besar industri bergantung pada penggunaan diesel untuk menggerakkan mesin berat dan pengangkutan kerana kecekapannya yang tinggi. Namun, penggunaan diesel boleh membahayakan alam sekitar kerana ia melepaskan gas berbahaya yang mencemarkan udara, air, tanah, mengurangkan jarak penglihatan dan perubahan iklim global. Bagi mengurangkan penggunaan diesel dalam industri permesinan dan pengangkutan, banyak penyelidikan telah dilakukan berfokus kepada pengembangan biodiesel sebagai pengganti diesel konvensional. Biodiesel diperbuat daripada unsur semula jadi yang boleh diperbaharui dan ia mengeluarkan bahan kimia yang kurang berbahaya kepada alam sekitar. Walaupun biodiesel dapat menggantikan diesel sebagai sumber bahan bakar, terdapat beberapa kekurangan dalam menggunakan biodiesel. Biodiesel cenderung untuk mempunya sifat menghakis ketika dicampur dengan Ultra Low Sulphur Diesel (ULSD). Oleh itu, biodiesel akan mempengaruhi bahan-bahan elastomer di dalam sistem penghantaran bahan bakar di dalam kenderaan. Bahagian elastomer dalam sistem penghantaran bahan bakar adalah termasuk saluran bahan bakar, tangki bahan bakar, gasket and cincin O. Dalam projek ini, biodiesel B10 dan B30 akan digunakan untuk mengkaji tindak balasnya terhadap cicin O elastomer. Oleh itu, terdapat beberapa ujian akan dilakukan untuk mengkaji kesan kepekatan biodiesel terhadap sifat pembengkakan cincin O elastomer. Ujian rendaman dan ujian jisim akan dilakukan untuk mengkaji sifat mekanikal cincin O setelah direndam di dalam biodiesel dengan jangka masa dan suhu tertentu mengikut ASTM D471-06. Ujian kekerasan dilakukan untuk mengkaji sifat mekanikal cincin O mengikut ASTM D2240-15.

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LIST OF ABBREVIATIONS

FAME	-	Fatty Acid Methyl Ester
CPO	-	Crude Palm Oil
NBR	-	Nitrile Rubber
PTFE	-	Polytetrafluoroethylene
ULSD	-	Ultra Low Sulphur Diesel
FDS	-	Fuel Delivery System
ASTM	-	American Society for Testing and Materials
NO	-	Nitrogen Oxide
e.g	-	Example
FKM	-	Fluorocarbon
FTIR	-	Fourier Infrared Spectroscopy
ATR	-	Attenuated Total Reflection
UATR	-	Universal Attenuated Total Reflection
FEA	-	Finite Element Analysis
MPOB	-	Malaysia Palm Oil Board
PTC	-	Positive Temperature Coefficient

CHAPTER 1

INTRODUCTION

1.1 Background

Diesel is a type of fuel made of crude oil from fossil fuel. Fossil fuel were produced over a long time from the remains of plants and animals that lived millions year ago. Fossil fuel are known as non-renewable fuel sources. In 1892, Rudolf Diesel created a new fuel product that bear his name which is diesel. Diesel fuel is a reliable fuel source as it provides better fuel economy, greater torque and high energy density as compared to gasoline. Gasoline is a refined petroleum used as fuel for internal combustion engines.

However, despite providing a great fuel performance, diesel also causing more harm to the environment and health. In health issue, diesel emission contributes to the development of cancer, cardiovascular and respiratory health effect. To the environment, diesel causing harm by polluting the air, water, and soil. It also reduces the visibility and causing global climate change. Realising these implication, other alternative method should be invented to provide a greener fuel usage with minimum effect to the environment and health.

Biodiesel is a type of fuel that is combined of natural elements such as plants, vegetable, and other natural reusable materials. Biodiesel is a substitute of conventional diesel which emits less harmful chemicals to the environment from its combustion. Started by an inventor named Martin Mittelbach. He furthered the development of the biodiesel fuel industry in 1990s. First biodiesel production was from recycled used cooking oil due to rising price of crude oil and concerns over global warming. Since it is produced from renewable resources, biodiesel has many advantages such as it can be directly used in existing diesel engines, i.e. no modification of diesel engine is needed, less greenhouse gas emission, biodegradable and nontoxic. Many research were conducted to develop vegetable oil derivatives until the same level of properties and performance of hydrocarbons-based petroleum diesel. Substituting triglycerides for diesel fuel is linked with high viscosity, low votality and polyunstaturated characters. Palm oil biodiesel was succesfully produced by various processes that can be altered in at least four ways which are *pyrolysis*, *microemulsion*, *dilution* and *transesterification* [1].

Pyrolisis

Pyrolisis is a method of transformation of one substance into another by mean of heat with the aid of catalyst in the absence of air or oxygen. In early finding, hydrogen is used to remove oxygen in the form of water while now, the removal of oxygen in the form of water and carbon oxides is accomplished by using the shape-selective catalysts like zeolites [2]. This process is effective, simple, wasteless and pollution free, however, it requires high temperature, expensive equipment and produce low quality of biodiesel (contain heterogeneous molecules ncluding ash and carbon residue) [3].

Microemulsion

The vegetable or animal oil were solubized in a solvent (alcohol) and surfactant until the required viscosity is obtained. It is a simple process and pollution free, however, the product has high viscosity, low stability and could led to sticking, incomplete combustion and carbon deposition [3].

Dilution

Dilution is preheated vegetable or animal oils were blended with petroleum diesel within 10-40% ration. Then the resulted oil-diesel mixture is applied into the diesel engine. This process does not required any chemical process, absunce of technical modification and easy implementation, however, the blended biodiesel has high viscosity, unstable, low votality and increase in biodiesel concentration results in improper spraying pattern, poor atomisation, imcomplete combustion and difficulty in handling by standard engines [3].

Transesterification

This is the most common process for palm oil biodiesel. The Vegetable or animal oil and fats were reacted with alcohol and catalyst. Then the mixture of biodiesel (product) and glycerol (byproduct) will undergo separation and purification steps before further usage. This process provide high conversion of biodiesel with relatively low cost, mild reaction conditions, product properties are closer to the petroleum diesel and applicable for industrial scale production, however, this process requires low free fatty acids and content in the raw material, extensive separation and purification steps, possibilities of side reaction to occur [3].

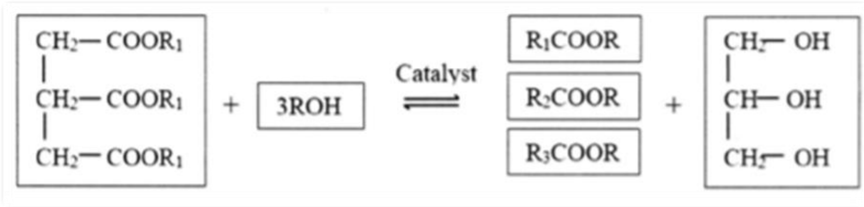

Figure 1. 1: Transesterification process of biodiesel

Biodiesel also known as fatty acid methyl ester (FAME) is produced from natural element through transesterification process as summarized in **Figure 1.1**. Vegetable oil which consist of triglycerides are converted into three mono-alkyl esters.

Table 1.1 shows the type of biodiesel according to its concentration percentage. A 100% pure biodiesel is known as B100 (*Biodiesel-100%*), where the digit indicates the percentage of biodiesel concentration in petroleum diesel. Here, B2 and B5 biodiesel are already widely used in most heavy vehicles, thanks to its lubricating properties. On recent development of biodiesel, many research works tend to produce a high-quality biodiesel to be used in diesel engine without reducing its performance and half-life of engine. Due to some challenges such as injector choking and sedimentation, only biodiesel with maximum concentration of 20% biodiesel B20 is permitted until today [4].

To increase the performance of biodiesel B40 on diesel engine, additive such as bio-polymer was proven to improve the characteristic of biodiesel such as kinematic viscosity, specific gravity, flash point and midpoint boiling temperature [5]. Biodiesel B40 incorporated with bio-polymer is strongly possible to be a substitute for petroleum diesel in diesel engine. Another study mix the palm biodiesel B20 with oxygen containing chemical such as methanol, ethanol, diethyl ether and distilled water to an extend of 2% to reduce the Nitrogen Oxides, NO_x emission [6]. The study shows that the emission like carbon monoxide and hydrocarbon was reduced by 28% and 30% compared to petroleum diesel, however, the emission of carbon dioxide was higher compared to petroleum diesel to due the combustion characteristic.

Table 1.1: Type of biodiesel and its usage [4]

Type of biodiesel	Percentage of biodiesel concentration	Usage
B2	2% Biodiesel, 98% Diesel	Usable in standard diesel engine.
B5	5% Biodiesel, 95% Diesel	
B10	10% Biodiesel, 90% Diesel	
B20	20% Biodiesel, 80% Diesel	
B30	30% Biodiesel, 70% Diesel	Under development
B100	100% Biodiesel, 0% Diesel	Unusable in standard diesel engine due to high corrosive properties.

1.1.1 Palm Oil Biodiesel

Currently, Malaysia is ranked number two in palm oil industry in the world right behind Indonesia. Therefore, Malaysia have focused on using palm oil as raw stock for biodiesel production. The palm oil that is harvested and produced from palm trees is defined as Crude Palm Oil (CPO). The crude palm oil is transferred to palm oil refinery for refinery process. Palm oil biodiesel is created by combining refined oil with petroleum diesel. Blending petroleum diesel with certain percentage of palm oil diesel is called as Envo diesel [7]. Recently, the Primary Industries Ministry of Malaysia stated that Malaysia will fully implement B20 palm oil biodiesel to 3400 petrol stations nationwide. It is expected to consume 534,000 tonnes of palm oil annually.

1.1.2 Elastomer O-ring

An O-ring is a torus, or doughnut shaped ring generally made from an elastomer. However, O-ring also commonly made from metal, elastomer, and thermoplastic materials such as Nitrile rubber (NBR) and Polytetrafluoroethylene (PTFE), respectively. The cross-section of the O-ring can be in a form of hollow or solid. O-ring's function is primarily for sealing to prevent the loss of fluid or gas. O-ring has wide scope of sealing such as static, reciprocating, oscillating, rotary, seat, pneumatic and vacuum. The material of O-ring depends on the application, for example, NBR O-ring has good mechanical properties and high wear resistance compared to other elastomer but it is not compatible with fuel of high aromatic content, aromatic hydrocarbons (benzene) and strong acid. O-ring can be applied to various application such as medical (syringe, pump, filtration), oil and gas industrial (valves, gas pump, storage tank), electronics (semiconductor) and food and beverage (beverage dispenser). O-ring has many advantages such as seal wide range of pressure, temperature, and tolerance. It requires a minimum maintenance, no critical torque on tightening and it is light in weight. However, O-ring could be weakened due to deterioration and corrosion. Deterioration is a term refers to chemical change of a material resulting in permanent loss of the properties of a material. While corrosion is the result of chemical action of a fluid and the elastomer compound upon the metal surface of a material.

1.2 Problem statement

Biodiesel have corrosive properties when it is blended with Ultra Low Sulphur Diesel (ULSD) [8]. In fuel delivery system (FDS) in diesel engine, O-Ring is one of the common parts in this system where it plays a crucial part in engine performance as its function is to prevent the loss of fluid and gas. Due to corrosive properties in biodiesel, the O-Ring will undergo degradation with the usage time [8]. In addition, O-ring properties is highly depends on the hardness of the material [9]. Swelling is the tendency of material to absorb moisture which occurred through the voids, pores, cracks present on and below the surface. Swelling can leads to severe degradation on the material with tendency towards surface protruding as well as cracks generation on its surface [10]. Thus, in this study, O-ring that is made of polytetrafluoroethylene (PTFE) is subjected to immersion test (ASTM D1414 - 94) of two different concentration of biodiesel, B10 and B30 in order to investigate the swelling properties of the O-Ring.

1.3 Objectives of project

This research is conducted to determine the solution for the issues stated in Section 1.2. Thus, the objectives of this research are as follows:

1. To determine the effect of different soaking time and biodiesel's temperature on swelling properties of O-ring.
2. To investigate the swelling properties of O-ring after being immersed in two different types of biodiesel, B10 and B30, respectively.

1.4 Scope of Project

The scopes of this project are:

1. Fabrication of test rig (*Temperature Controlled Bath*) for immersion test to control the temperature of the biodiesel at certain duration of time.
2. Conduct an immersion test of O-ring samples in B10 and B30 concentrated biodiesel at different temperature and duration.
3. Conduct a mass loss test of the immersed O-ring samples according to standards.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Over a long period, we have been depending on the fossil fuel as the main energy source to be used on electricity generation, industrial application, and transportation. Undeniably, fossil fuels are very important however, the usage of fossil fuel such as petroleum diesel causes numerous pollution due to the produced soot, harmful gasses and can be deadly if being utilized over a long period. In fact, based on the statistic from Intergovernmental Panel on Climate Change [11], carbon dioxide is the main product of combustion of fossil fuel. It contributes to 65% of global greenhouse gas emission in 2014.

Recently, there are numerous studies and research on fossil fuels to enhance the environment and maintain the sustainability of energy resources. The focus is attributed to biodiesel due to its sustainability and renewable characters that can lessen damage to the environment. They able to minimize emissions of contaminates gasses and particulate materials compared to diesel from fossil fuel. They also possesses biodegradable and non-toxic properties [12].

2.2 Biodiesel

As mentioned in previous chapter, a pure biodiesel B100 is a substitute of fossil fuel diesel made from natural elements. It is commonly used for transportation as fuel as it emits less greenhouse gas compared to diesel and produced by transesterification process. In the United States, the first specification standard for analysing pure biodiesel B100 has been determined which is ASTM Standard D6751-18. The standard shows specific tests that must be conducted to achieve stability in pure biodiesel B100 such as flash point, alcohol control, kinematic viscosity, and carbon residue. Meanwhile, biodiesel B5 follows the ASTM Standard D975 and biodiesel B6 up to B20 follows the ASTM Standard D7467-18a.

Pandit et. al [3] studied on the biodiesel production from *Scenedesmus armatus*, using egg shell waste as nano catalyst. They produce the biodiesel by transesterification process from the microalgal strain *Scenedesmus armatus* extracted from mangrove root and use chicken-eggshells as nano catalyst. The biodiesel produced was analysed by ^{1}H nuclear magnetic resonance spectroscopy using deuterated chloroform as solvent. They observed that the biodiesel is characterised by higher *cetane number*, CN58, due to higher saturation which improved clean up emission and higher combustion efficiency. Other properties of the *Scenedesmus armatus* derived biodiesel compared to petroleum diesel are stated in **Table 2.1**.

Table 2.1: Biodiesel fuel properties [3].

Biodiesel properties	ASTM -6751 biodiesel Standard	EN-14214 biodiesel standard	Commercial diesel	Fuel Properties
Cetane Number (CN)	47-65	51-120	40	58.07
Kinematic Viscosity (U) (mm^2/s)	1.3-4.1	1.9 – 6.0	1.9-4.1	3.9
Iodine Value (IV)	-	120	-	66.24
Density (ρ) (g/cm^3)	0.86	0.85-0.90	0.83	0.87
Cold Filter Plugging Point (CFPP)°C	-	-5 to 13	-	28.26
Cloud Point (CP)°C	-3 to 15	-	-	9.9
Pour point (PP)	-5 to 10	-	-	3.9

Palm oil biodiesel

Biodiesel can be produced from any natural element such as palm oil, cottonseed, peanut, soybean, sunflower seed, and rapeseed. Among of those potential resources of biodiesel, palm oil is a sustainable source for biodiesel due to its higher production rate per hectare of all edible oils as summarized in **Table 2.2**.

Figure 2.1: Palm tree

Figure 2.2: Peanut

Figure 2.3: Soybean

Figure 2.4: Sunflower seed

Table 2.2: Production rate and quantity of edible oil

Type of oil	Production quantity* [million tonnes]	Production rate/hectare/year
Sunflower	20	0.6
Soybean	70	0.4
Rapeseed	90	0.8
Palm	160	3.9

* *quantity of major edible oils production in 2016*

Vedaraman et. al [6] studied on the preparation of palm oil biodiesel and the effect of various additives on nitrogen oxide gases NO_x emission reduction in B20. They prepared the palm biodiesel using commercial edible grade palm oil with conventional alkali catalysed through a transesterification process. The properties of the palm biodiesel are shown in **Table 2.3**. They observe that the palm oil has high viscosity. However, it can be reduced to the desirable viscosity range after the transesterification process. The flash point of biodiesel is slightly higher, and the calorific value is slightly lower than petroleum diesel. These properties can affect the performance of palm biodiesel in diesel engine.

Table 2.3: Physical properties of pure biodiesel and various blends

Parameters	Palm oil bio-diesel	B20	B20 + 2 M	B20 + 2E	B20 + 2DW	B20 + 2DEE	Diesel
Kinematic Viscosity @40°C (cSt)	3.94	2.40	2.31	2.37	2.51	2.35	2.61
Density (Kg/m^3)	880	840	837	838	840	840	830
Flash Point (°C)	160	50	13	18	48	15	44
Fire Point (°C)	170	58	20	30	58	25	53
Gross calorific value (MJ/kg)	38.69	39.21	40.21	40.53	38.78	39.65	39.77

As stated in the previous chapter, biodiesel B20 is currently the maximun concentration of biodiesel in diesel fuel that is allowed to be used commercially. However, the biodiesel B20 will be degraded gradually after stored at ambient condition. Chen et. al [13] have investigated on profiling and catalytic upgrading of commercial palm oil-derived biodiesel fuel for high-blend fuels. They improved the performances of biodiesel B20 via hydrogenation process that supported by Palladium catalyst. The stability test of newly formulated biodiesel is conducted by heating the biodiesel for 16 hours under oxygen bubbling with flow rate of 100 mL min^{-1}. They observed that the biodiesel B20 formulated by blending petroleum diesel palm hydrogenated Fatty Acid Methyl Ester (FAME) showed excellent stability and almost no degradation or acidification after accelerated oxidation test.

Fangsuwannarak et. al [5] optimize the composition of palm oil biodiesel blend with the addition of bio-polymer additive according to the engine performance, the reduction of gas exhaust emissions and also compliance with the main regulation standards of ASTM and SEA. In this study, they discovered that by adding the bio-polymer additive has improved the lower heating values of modified biodiesel blend, range from B20 to B50. On top of that, modified B40 yields the most effective improvement with addition of 0.1g biopolymer additive.

Rubber seed oil biodiesel

Yoosuk et. al [14] had conducted a research on rubber seed oil as potential non-edible feedstock for biodiesel production using heterogeneous catalyst in Thailand. Rubber seed oil obtained from the natural resources of rubber seed, that can be easily collected from the rubber tree plantation. From their experimental investigation and observation on rubber seed oil as a potential feedstock for biodiesel, the chemical properties and other performances of rubber seel oil biodiesel is meet with those of biodiesel and diesel standards, e.g EN 14214 and it is comparable to palm oil biodiesel.

Liu et. al [15] done a research on performance characteristics of rubber seed oil biodiesel. They discovered that rubber seed oil biodiesel and its blend provided excellent lubricity, flammability and cold flow property. Rubber seed oil prone to oxidation although the oxidation stability of rubber seed oil could be enchanced by specific antioxidants such as B100. Rubber seed oil is not compatible with most elastomer except hydrogenated nitrile-butadiene.

Sonthalia et. al [16] studied on performance, combustion and emission of a single cylinder diesel engine fuelled with rubber seed oil and its biodiesel along with ethanol as injected fuel. They discovered that rubber seed oil and their ester in diesel engine results in improvement in combustion performance and increase in brake thermal efficiency.

Rapeseed Oil Biodiesel

Akhlaghi et. al [17] conduct a research on degradation of fluoroelastomers in rapeseed biodiesel at different oxygen concentrations. They discovered that the terpolymer FKM absorbed the largest amount of biodiesel due to the cavitation in the rubber. Terpolymer FKM showed the greatest decrease in strain-at-brak and Young's modulus due to extensive dehydrofluorination and the rupture of the bound rubber-carbon black network.

2.3 FDS of a Diesel Engine

FDS in vehicle is responsible to store and supply fuel to the engine. It consists of fuel tank, fuel lines, fuel filter, fuel pump, fuel rail and fuel injector. As illustrated in **Figure 2.5**, the fuel is stored in the *fuel tank* and the *fuel pump* draws fuel from the *fuel tank*. Then, the fuel will travel through the *fuel lines* and delivered through a *fuel filter* to the *fuel injector*. The components of FDS that are made of metals and elastomers are listed in **Table 2.4**.

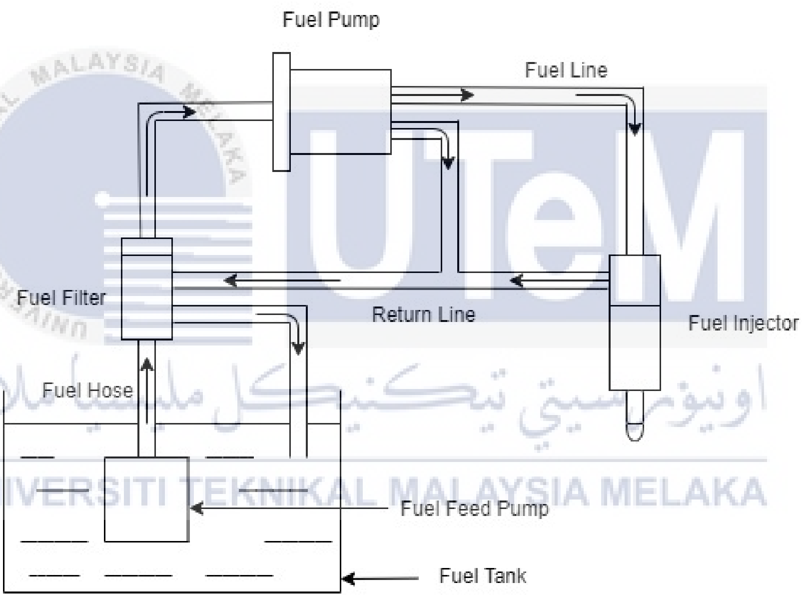

Figure 2.5: FDS in Diesel Engine [18]

Table 2.4: Materials Used for The Fabrication of Fuel Storage and Delivery Component [18]

Parts	Materials
Fuel Tank	Steel, Plastic
Fuel Lines	Steel, plastic, rubber
Fuel Filter	Aluminium, plastic, paper, resin impregnated paper
Gasket	Elastomer, paper, cork, copper

Biodiesel in FDS

Chandran et. al [18] studied on the compatibility of biodiesel fuel with metals and elastomers in FDS of a diesel engine. They reviewed the previous study on the effect of biodiesel on FDS. They discovered that the compatibility of biodiesel with FDS should be investigated under actual condition. The exact material present in the FDS should be systematically determined which includes elemental composition for both elastomer and metal. Metals are known for its excellent compatibility with diesel and its suitability to be implemented in FDS components. Meanwhile, elastomer is also compatible in the FDS however the usage of unsuited fuel speed up the degradation process.

Renewable energy in the form of biodiesel is getting popular in various countries due to the environment friendly characteristic and able to be used in diesel engine without having complex modifying to the engine itself. Tziourtzioumis et. al [19] studied about the diesel-injection equipment parts deterioration after prolonged use of biodiesel. They tested two different engines with high-percentage biodiesel blend B70. Their observed that biodiesel B70 can cause severe oxidation damaging the fuel injection system on diesel engine. They found that the main damage is to the pump piston due to presence of slurry deposit causing sticking of the pumping element as shown in **Figure 2.6**.

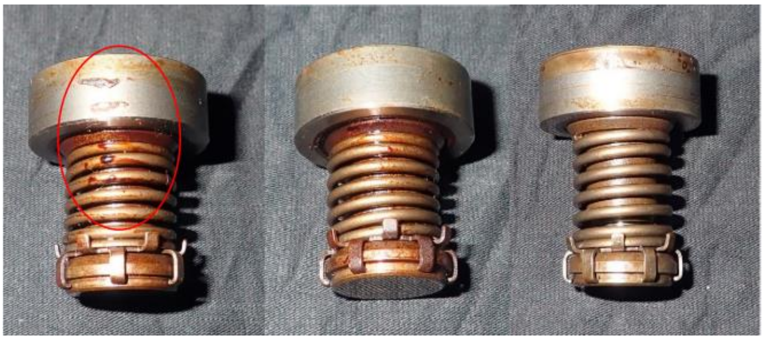

Figure 2.6: Thin brownish lacquer on pumping elements of the pump cylinders [4]

For more than a decade, many researches were conducted to adapt biodiesel fuel to power existing standard diesel engine. However, due to the incompatibility of fuel, many failures were identified especially in the FDS such as fuel line and hose leakage. To prevent the problem, Chandran et al [20] conducted a study on the critical relationship between biodiesel fuel properties and degradation of fuel delivery materials of a diesel engine. A novel immersion method was used which refers to the incorporation of fuel renewal interval in the typical immersion standard method such as ASTM G31 and ASTM D471. They obtained the corrosion rate for different type of metals and change of volume for different type of elastomer as illustrated in **Figure 2.7 and Figure 2.8,** respectively.

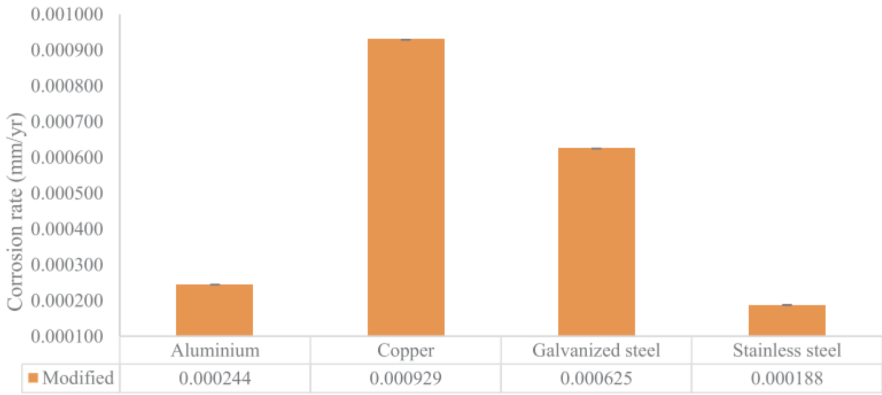

Figure 2.7: Change in corrosion rate corresponding to novel immersion investigation [20].

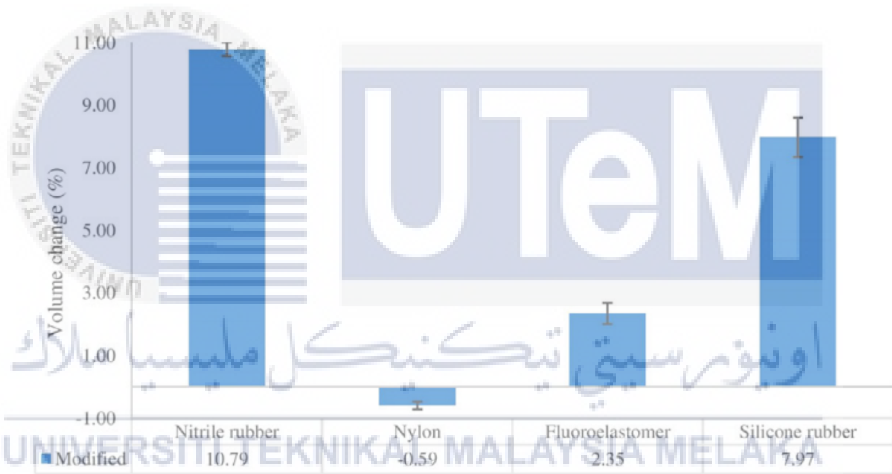

Figure 2.8: Change in volume corresponding to novel immersion investigation [20]

2.4 Element analysis of O-Ring

In determining the chemical properties and composition of O-Ring. Fourier Infrared Spectroscopy also known as FTIR spectroscopy is a technique to identify the organic, polymeric, and inorganic materials. Sanches et. al [21] studied on the infrared spectroscopy applied to materials used as thermal insulation and coatings. They used FTIR technique for the analysis of elastomer such as nitrile rubber and rubber mixtures. The surface technique used is the attenuated total reflection (ATR) and universal ATR (UATR). They observed that the transmission (liquid phase of pyrolyzate) and reflection (ATR and UATR) techniques conducted on the rubber sample which is NBR can give different information and these were used for the characterization of the polymer and filler respectively. **Figure 2.9** illustrate the result of transmission and reflection techniques on O-ring.

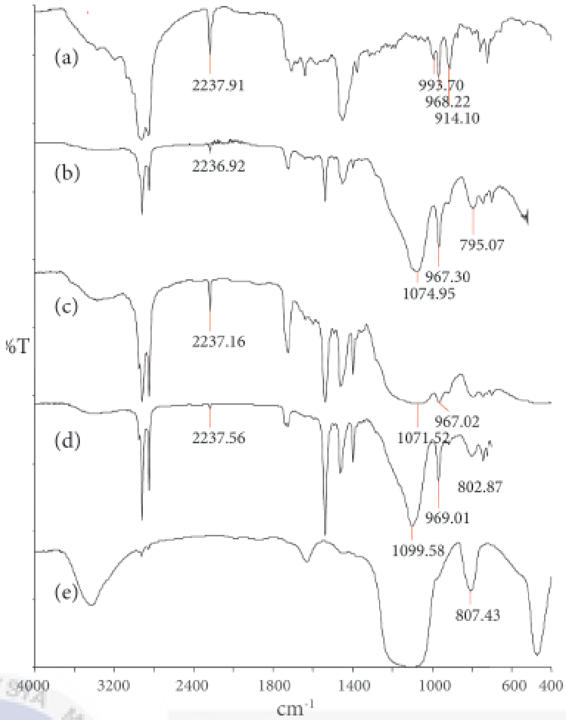

Figure 2.9: FTIR spectra obtained from analysis of the nitrile rubber through different techniques: (a) Nitrile rubber transmission pyrolyzed (liquid film), (b) Nitrile rubber – UATR, force 80, (c) Nitrile rubber – ATR/KRS-5, (d) Nitrile rubber – ATR/Ge, and (e) residue obtained after calcination of rubber on

Komariah et. al [22] did a research on O-Rings Material Deterioration due to Contact with Biodiesel Blends in a Dynamic Fuel Flow. They discovered that O-rings deterioration is due to engine operation with biodiesel as fuel (B20 and B100). It is observed from a change in volume swell, weight change, thickness changes and elongation of O-ring.

2.5 Material Characterisation of O-ring

To identify the mechanical and physical characteristic of the O-ring after soaked in biodiesel B10 and B30. The O-ring must undergo several tests such as soaking test, hardness test, tensile test, and degradation test.

Mechanical-Physical properties of FDS components

Soaking test is done before testing the mechanical and physical properties of the elastomer. Soaking test is a method to ensure the elastomer (O-ring) submerge in the biodiesel allowing chemical reaction to take place during the process. Haseeb et. al [23] studied on the compatibility of elastomer in palm biodiesel. The compatibility of three different elastomer materials namely nitrile rubber (BNR), polychloroprene and fluoro-viton A with palm biodiesel was observed by conducting immersion test in B0 (diesel), B10 and B100 at room temperature (25°C) and at 50°C for 500 hours. They observed the change in weight and volume of the elastomer after immersion as illustrated in **Figure 2.10**. Biodiesel B100 showed the most change in weight and volume after immersion for 500 h at room temperature.

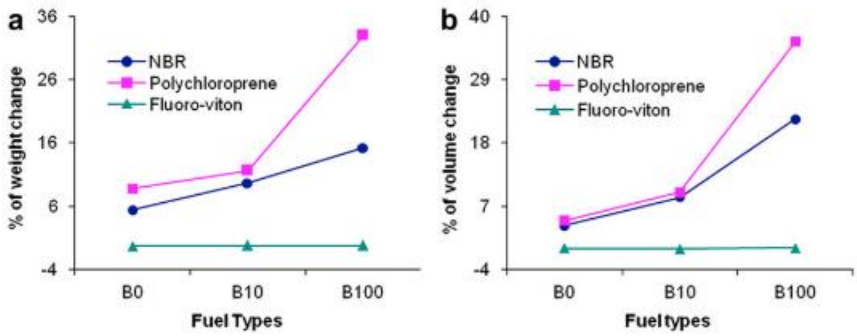

Figure 2.10: Changes in (a) weight and (b) volume of different elastomers after immersion at room temperature for 500 h [23].

In this study, hardness test is conducted to determine the mechanical properties of the elastomer after being soaked in biodiesel. Sukumar et. al [23] studied on the determination of sealing pressure in hyper elastic O-ring with different hardness using numerical method. They measured the hardness of the O-ring by using durometer in **Figure 2.11**. The compression force applied to the O-ring and compressed up to 25% of its initial weight with the help of uniaxial compression test machine in **Figure 2.12.** Then, the data obtained from the hardness test will be used in finite element analysis (FEA). The hardness versus von-Mises stress data of the finite element analysis in illustrated in **Figure 2.13.**

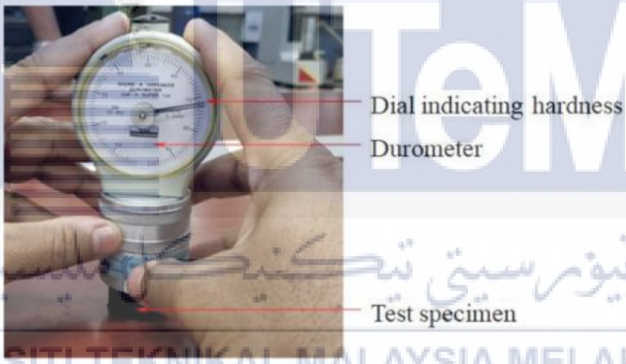

Figure 2.11: Measurement of hardness using durometer [23]

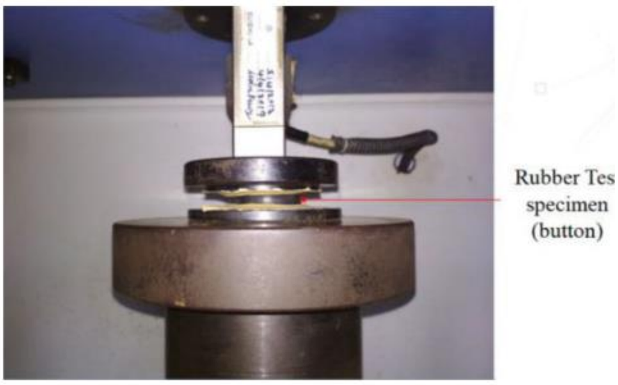

Figure 2.12: Uniaxial compression test [23]

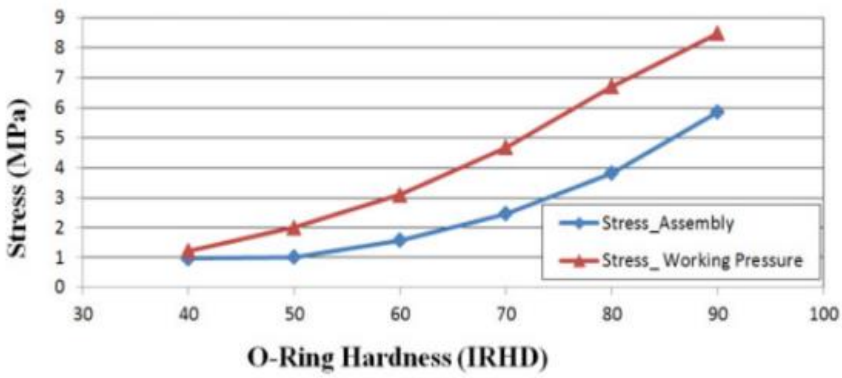

Figure 2.13: Hardness versus von-Mises stress

Tensile test is another method to test the mechanical properties of the elastomer after being soaked in biodiesel B10 and B30. Also known as tension test, it applies pulling force to a material and measure the reaction of the elastomer towards the stress. Najmi Aiman [8] studied on the physical-mechanical properties of elastomer diluted with B10 and B20 biodiesel. He determines the tensile strength of the elastomer soaked in biodiesel B10 and B20 by using Universiti Teknologi Malaysia (UTM) Instron machine. **Figure 2.14 and Figure 2.15** illustrate the tensile properties of the tested elastomer using UTM machine. The result shows that the maximum load that can be applied on the elastomer decreased as the soaking time increase.

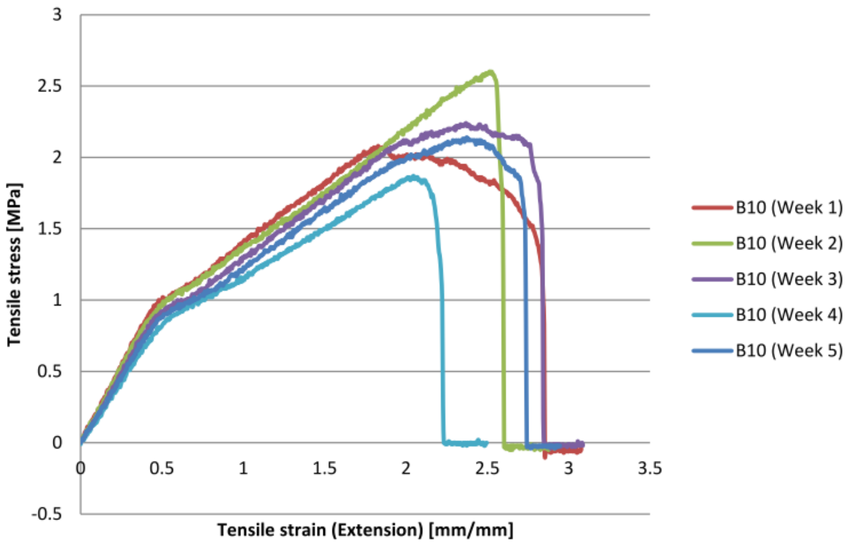

Figure 2.14: Tensile test for elastomer soaked in biodiesel B10 [8].

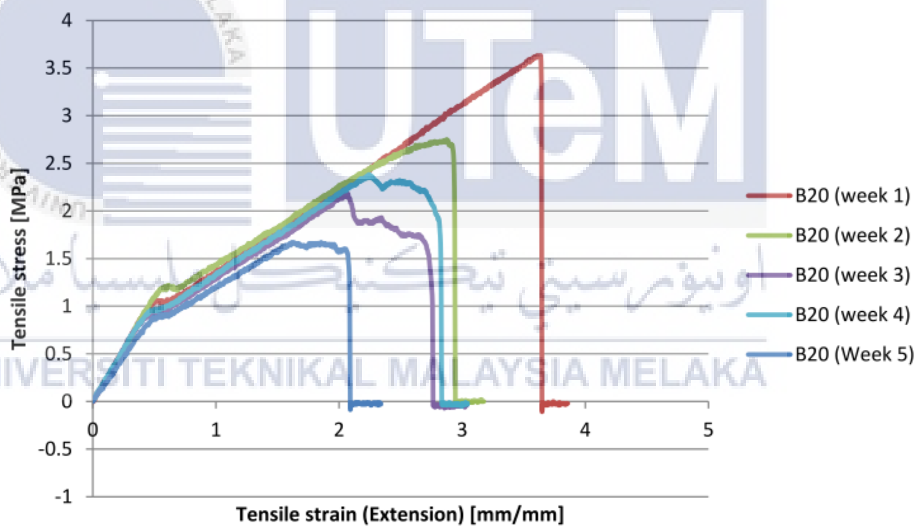

Figure 2.15: Tensile test for elastomer soaked in biodiesel B20 [8].

Degradation test is to determine the physical properties of the elastomer by referring to ASTM Standard D471-06. This is to measure the degradation of the elastomer by collecting the mass data of the elastomer before and after soaked in biodiesel. Najmi Aiman [8] done the mass test similar to the concept of degradation test. He immersed different type of elastomer in palm biodiesel and conducted mechanical and physical on the elastomer. Mass test is one of the physical tests and conducted by measuring the mass of the elastomer before and after soaking test. The result for mas test for specimen soaked in biodiesel B10 and B20 are shown in **Table 2.5** and **Table 2.6,** respectively. Both results showed increase on mass after soaked in biodiesel B10 and B20

Table 2.5: Result for mass test for specimen soaked in biodiesel B10 [8].

Specimen	M_1 (mg)	M_2 (mg)				% of mass change
		1	2	3	Average	
1	5034.9	5883.8	5892.4	5897.7	5891.3	17.01
2	5035.0	5035.0	5766.0	5764.0	5765.0	14.50
3	5031.2	5031.2	6012.0	6014.0	6012.0	19.51
4	5035.4	6008.0	6006.0	6004.0	6006.0	19.28
5	5035.2	6109.0	6112.5	6113.0	6111.5	21.38

Table 2.6: Result for mass test for specimen soaked in biodiesel B20 [8].

Specimen	M_1 (mg)	M_2 (mg)				% of mass change
		1	2	3	Average	
1	5.0412	5.5670	5.6631	5.6714	5.6338	11.7557
2	5.0359	5.5078	5.5018	5.5024	5.5040	9.2952
3	5.0401	5.8290	5.8250	5.8380	5.8307	15.6855
4	5.0357	5.8000	5.8100	5.8200	5.8100	15.3762
5	5.0341	6.0150	6.0230	6.0210	6.0197	19.5778

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will describe the methodology used in this project to obtain the result of mechanical and physical test done on the elastomer after being soaked in biodiesel B10 and B30, respectively.

In the early stage of this study, project planning needs to be conducted to ensure all work progress are done within the planned period. The flowchart of this study is illustrated in **Figure 3.1. The study** begins with the identification of the literature review, followed by project planning, material procurement sample testing, data analysis and finally completing the thesis writing and presentation.

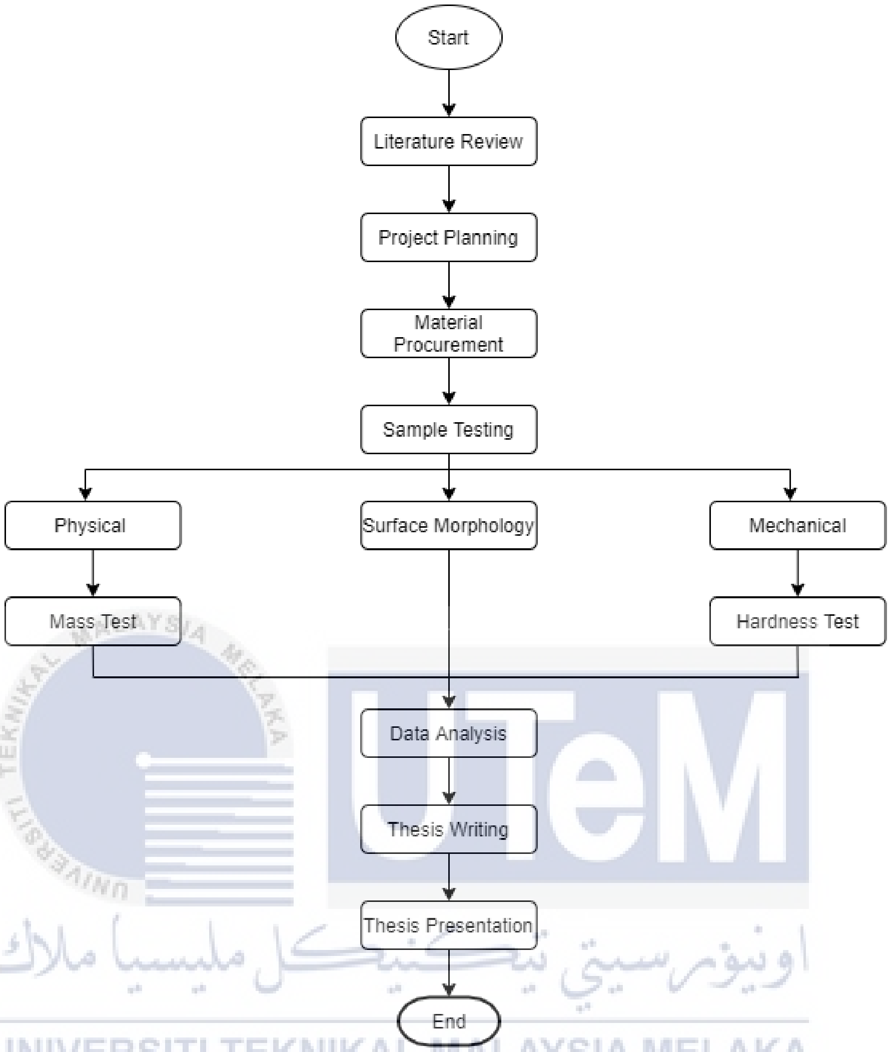

Figure 3.1: Flowchart

3.2 Materials

Material used in this study are the biodiesel B10, B30 and O-ring. The materials are described as follows:

Biodiesel B10 and B30

Materials used in this study are biodiesel B10 and B30. These biodiesels are provided by Malaysian Palm Oil Board (MPOB). The biodiesel was readily blended with specific concentration of biodiesel i.e. 10% biodiesel, 90% diesel for biodiesel B10 and 30% biodiesel, 70% diesel for biodiesel B30, respectively.

O-ring

Samples in this study is not fabricated, the O-Ring used are the one that is already market available. Polytetrafluorethylene also known as Viton© type O-Ring is used which is widely used in diesel engine vehicle. The dimension of the O-Ring is 20mm outer diameter, 15mm inner diameter and 2.5mm thickness.

3.3 Temperature Controlled Oil Bath

This bath is used as a test rig to control the temperature of the biodiesel during the soaking test. The requirements of the bath are portable, durable, and easy to use. The bath needs to be portable to easily transfer the bath to various laboratory, it needs to be durable because it will be operating for one month straight and easy to use without complicated process.

In the early stage, the planning to produce this bath was conducted. It starts with design, material selection, system integration, fabrication and lastly running a test. Temperature controlled oil bath was designed to contain at least 5 litres of biodiesel to fit all the sample to be soaked inside it. The dimension is 160 mm x 450 mm x 250 mm as illustrated in **Figure 3. 2.**. The temperature-controlled oil bath parts consist of tank, insulator, wood cover, heating element, temperature controller, temperature sensor and Arduino uno.

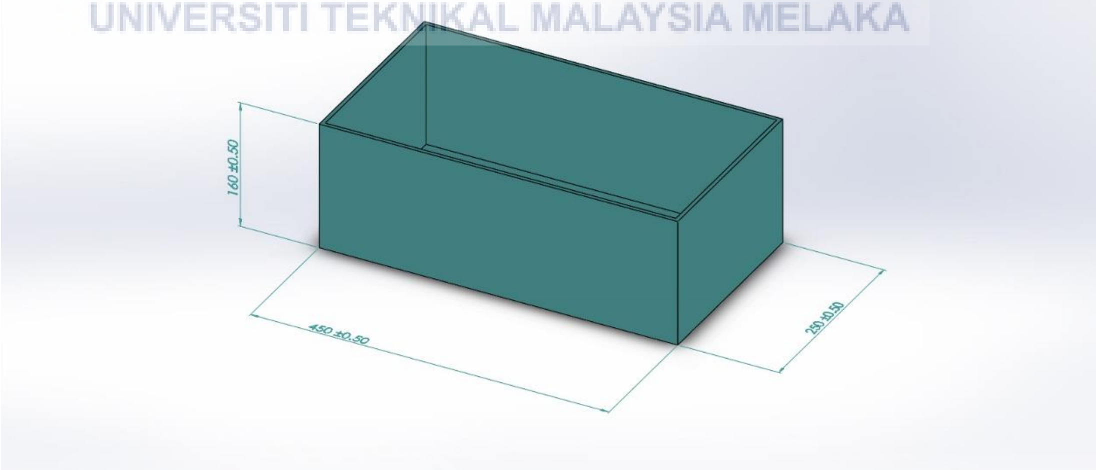

Figure 3.2: Dimension of temperature-controlled oil bath

Material selection is the critical part in producing the temperature-controlled oil bath, this is due to the chemical properties of biodiesel that is corrosive. The oil tank is made of glass that has high thermal conductivity and will not corrode when exposed to biodiesel. The insulator is made of rubber that has high thermal resistivity to maintain the temperature of biodiesel. It is also a good electricity insulator as a safety precaution for the electricity powered heating element.

Wood is used as the cover casing for the temperature-controlled oil bath, wood is a good heat insulator and easy to work on the surface finish. For the heating element, positive temperature coefficient (PTC) heating element is used. Temperature controller is used to control the temperature of the heating element. Sensor is connected to the temperature controller to detect the temperature value of biodiesel. Finally, Arduino uno is integrated into the system to record the temperature data.

Figure 3. 3: Temperature Controlled Oil Bath

3.4 *Immersion Test*

This study is done by soaking sample (O-Ring) in biodiesel B10 and B30 as stated in **Figure 3.4**. There are two parameter that must be considered in this test which is soaking duration and soaking temperature. Soaking duration length is ranged up to 4 weeks with the frequency of measurement is shown in **Figure 3.3**. While soaking temperature is ranged up to room temperature, 30℃ and 40℃ as stated in **Table 3.1**. Chemical and mechanical behaviour of sample will be recorded respectively with each duration and temperature.

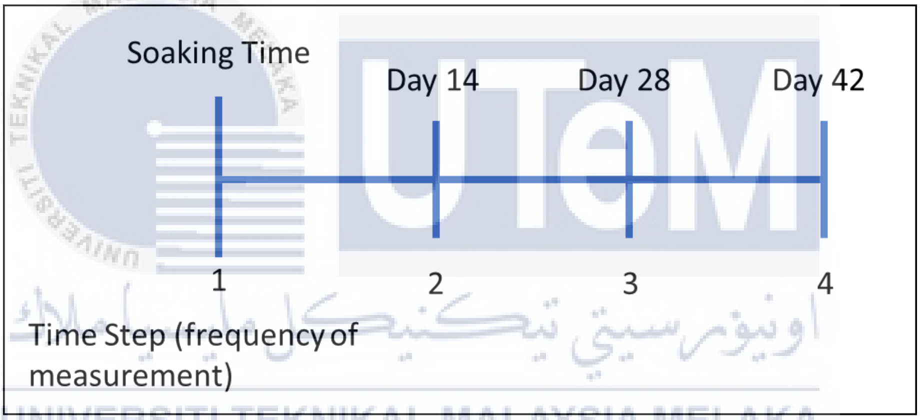

Figure 3.4: The Timeline of Soaking Test

Table 3.1: Soaking temperature and number of samples

Temperature \ Day	14	28	42
Room Temperature	3	3	3
40℃	3	3	3

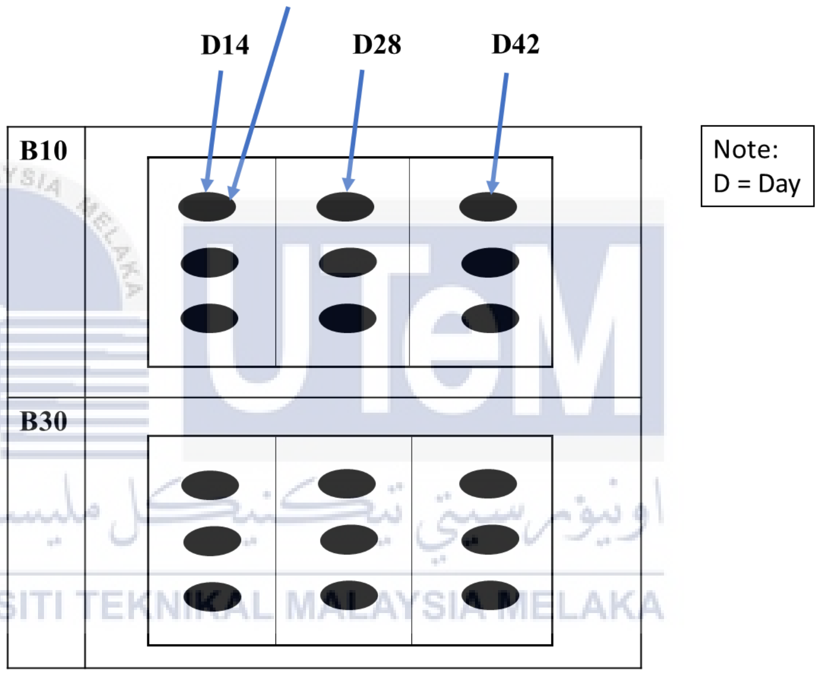

Figure 3.5: Type of Biodiesel in Soaking Test and Number of Sample

3.5 Mechanical-Physical Characterisation

The characterisation of O-ring is the crucial part in this study, every steps and method used requires precaution and standards to be followed.

Hardness test

For hardness test, the sample is tested by using durometer. The ASTM Standard D2240-15 is used as reference for standard test method for rubber property. This method measures the hardness by indentation on the O-ring on a specified period. For test specimen O-ring, a support table is required to conduct the test as illustrated in **Figure 3.5**. The surface of the O-ring shall be flat and parallel over an area to permit pressor foot to contact the specimen of at least 6.0 mm from the indenter point.

Figure 3.6: Small specimen support table

Figure 3.7: Durometer

Hardness test also can be done by using nano indenter machine. This machine measures the surface hardness of sample by applying nano indentation onto the sample. The machine is configurate by setting the depth of the sample, the intensity of applied force and the force applied time. The hardness value given is in many formats such as Vickers hardness, Rockwell hardness and Brinell hardness.

Mass test

Mass test is done by measuring the change in mass of the O-Ring. ASTM Standard D471-06 section 10 is used as reference for this test. The mass test is done by measuring the mass of O-ring before and after immersed in biodiesel. The mass is used to calculate the rate of swelling of the O-ring. The equation used for the swelling test are:

$$\Delta M, \% = \frac{(M2 - M1)}{M1} \cdot 100$$

Where,

ΔM = change in mass, %

M1 = initial mass of O-ring

M2 = mass of O-ring after immersion

Correlation Calculation

Correlation value will be done to determine the correlation value between the hardness and the mass of O-ring after immersion test. If both data is strongly linked together then it is considered to have high correlation. The correlation value is calculated by the following formula:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

Where:

$$(\mathcal{X}i - \bar{\mathcal{X}}) = \mathcal{X} - value\ minus\ mean\ of\ \mathcal{X}$$

$$(\mathcal{Y}i - \bar{\mathcal{Y}}) = \mathcal{Y} - value\ minus\ mean\ of\ \mathcal{Y}$$

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

From the equipment and methodology stated in **Chapter 3**, the result of all the test will be discussed in this chapter. Observation and analysis were done and will be discussed accordingly in this chapter. Immersion test of O-ring in biodiesel B10 and B30 was done at room temperature and 40°C, respectively. The test was run throughout 42 days duration. The initial mass and after immersion mass were recorded and analysed. Moreover, hardness test was conducted and will be discussed in this chapter.

4.2 Result

4.2.1 B10 at Room Temperature

The mass of the O-ring was recorded before and after soaking, the purpose is to get the mass difference of the O-ring after being immersed in biodiesel B10 at room temperature in 42 days. The initial mass and the mass of O-ring after immersion were recorded in **Table 4.1** and **Table 4.2**, respectively.

Table 4.1: Initial mass of O-ring before immersion test

Days	**14 Days**			**28 Days**			**42 Days**		
Sample	**14-1**	**14-2**	**14-3**	**28-1**	**28-2**	**28-3**	**42-1**	**42-2**	**42-3**
Mass 1, (g)	0.946	0.927	0.946	0.931	0.945	0.929	0.939	0.928	0.927
Mass 2, (g)	0.946	0.927	0.945	0.931	0.945	0.929	0.938	0.928	0.927
Mass 3, (g)	0.946	0.927	0.946	0.930	0.944	0.929	0.939	0.928	0.927
Average, (g)	0.946	0.927	0.946	0.930	0.945	0.929	0.938	0.928	0.927

Table 4.2: Mass of O-ring after immersion Test

Days	**14 Days**			**28 Days**			**42 Days**		
Sample	**14-1**	**14-2**	**14-3**	**28-1**	**28-2**	**28-3**	**42-1**	**42-2**	**42-3**
mass 1, (g)	0.930	0.924	0.938	0.934	0.948	0.932	0.941	0.930	0.931
mass 2, (g)	0.929	0.924	0.938	0.934	0.947	0.932	0.942	0.930	0.930
mass 3, (g)	0.929	0.924	0.937	0.934	0.948	0.932	0.942	0.930	0.930
Average, (g)	0.929	0.924	0.938	0.934	0.948	0.932	0.942	0.930	0.930

Based on table above, in 14 days, the average mass of O-ring before and after immersion are 0.9397g and 0.9303g, respectively. The O-ring loss 1% of its mass after immersion. In 28 days, the average mass of O-ring before and after immersion are 0.9348g and 0.9377g, respectively. The O-ring gained 0.31% of its mass after immersion. In 42 days, the average mass of O-ring before and after immersion are 0.9311g and 0.9340g, respectively. The O-ring gained 0.32% of its mass after immersion. The data obtained were illustrated in **Figure 4.1** below.

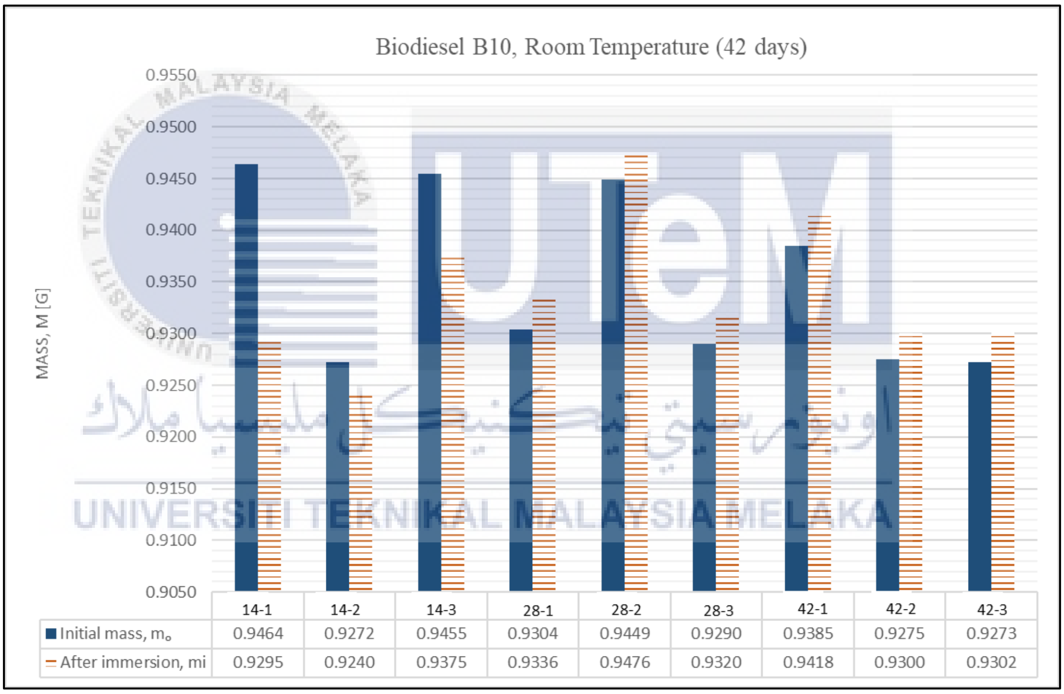

Figure 4.1: Result for mass test for sample immersed in B10 at Room Temperature.

Table 4.3 shows the result for hardness test for sample immersed in B10 at room temperature. The correlation between the mass of O-ring after immersion test and its hardness is illustrated in **Figure 4.2**.

Table 4.3: Result for hardness test for sample immersed in B10 at room temperature

Days	**14 days**			**28 days**			**42 days**		
Sample	**14-1**	**14-2**	**14-3**	**28-1**	**28-2**	**28-3**	**42-1**	**42-2**	**42-3**
Hardness 1	67.5	70.5	69.0	68.0	70.0	69.0	67.5	69.5	68.5
Hardness 2	69.0	68.0	68.5	70.0	72.0	70.0	70.0	68.0	69.0
Hardness 3	70.0	71.5	67.5	68.5	70.5	71.0	70.5	70.0	69.0
Hardness 4	68.5	69.5	70.0	67.0	68.0	69.0	68.0	68.0	70.5
Average	**68.8**	**69.9**	**68.8**	**68.4**	**70.1**	**69.8**	**69.0**	**68.9**	**69.3**

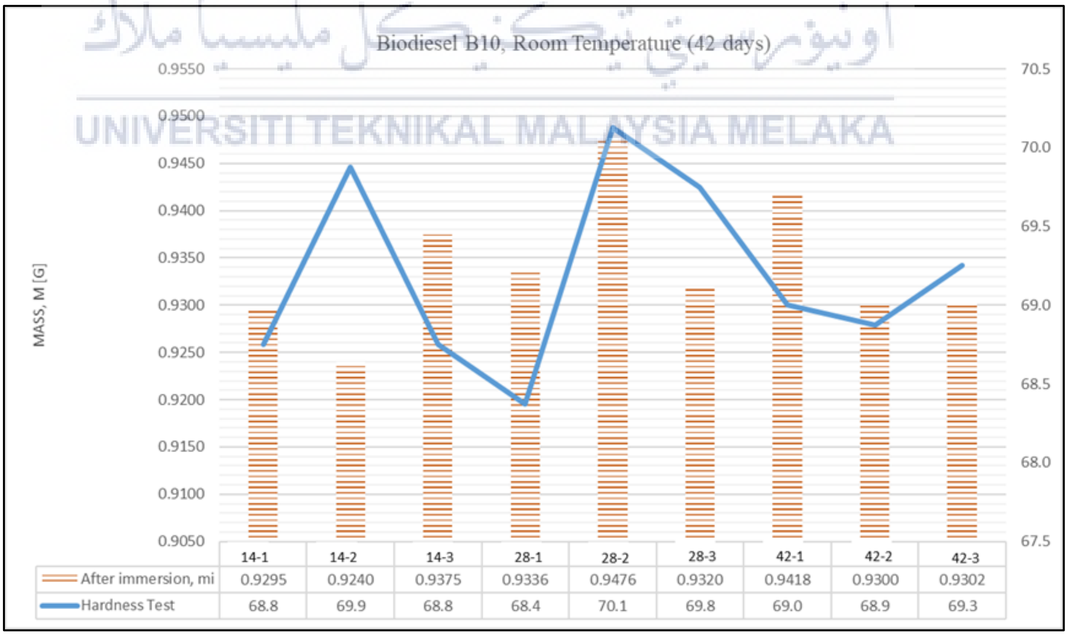

Figure 4.2: Correlation of hardness with after immersion mass for sample immersed in B10 at room temperature

4.2.2 B10 at 40°C

The initial mass and the mass of O-ring after being immersed in biodiesel B10 and 40°C were recorded in **Table 4.4** and **Table 4.5**, respectively.

Table 4.4: Initial mass of O-ring before immersion test

Days	**14 days**			**28 days**			**42 days**		
Sample	**14-1**	**14-2**	**14-3**	**28-1**	**28-2**	**28-3**	**42-1**	**42-2**	**42-3**
Mass 1, (g)	0.927	0.922	0.934	0.930	0.935	0.935	0.938	0.938	0.932
Mass 2, (g)	0.927	0.922	0.934	0.930	0.935	0.935	0.938	0.938	0.932
Mass 3, (g)	0.927	0.922	0.934	0.930	0.935	0.934	0.938	0.938	0.932
Average, (g)	0.927	0.922	0.934	0.930	0.935	0.934	0.938	0.938	0.932

Table 4.5: Mass of O-ring after immersion Test

Days	**14 days**			**28 days**			**42 days**		
Sample	**14-1**	**14-2**	**14-3**	**28-1**	**28-2**	**28-3**	**42-1**	**42-2**	**42-3**
Mass 1, (g)	0.934	0.952	0.938	0.938	0.934	0.927	0.936	0.947	0.923
Mass 2, (g)	0.934	0.952	0.937	0.937	0.933	0.927	0.936	0.946	0.923
Mass 3, (g)	0.934	0.952	0.937	0.937	0.933	0.927	0.936	0.947	0.923
Average, (g)	0.934	0.952	0.937	0.937	0.933	0.927	0.936	0.947	0.923

Based on the table above, in 14 days, the average mass of O-ring before and after immersion test are 0.9276g and 0.9410g, respectively. The O-ring gained 1.5% of its mass after immersion. In 28 days, the average mass of O-ring before and after immersion are 0.9330g and 0,9325g, respectively. The O-ring loss 0.05% of its mass after immersion. In 42 days, the average mass of O-ring before and after immersion are 0.9359g and 0.9350g, respectively. The O-ring loss 0.09% of its mass after immersion. The data above were illustrated in **Figure 4.3** below.

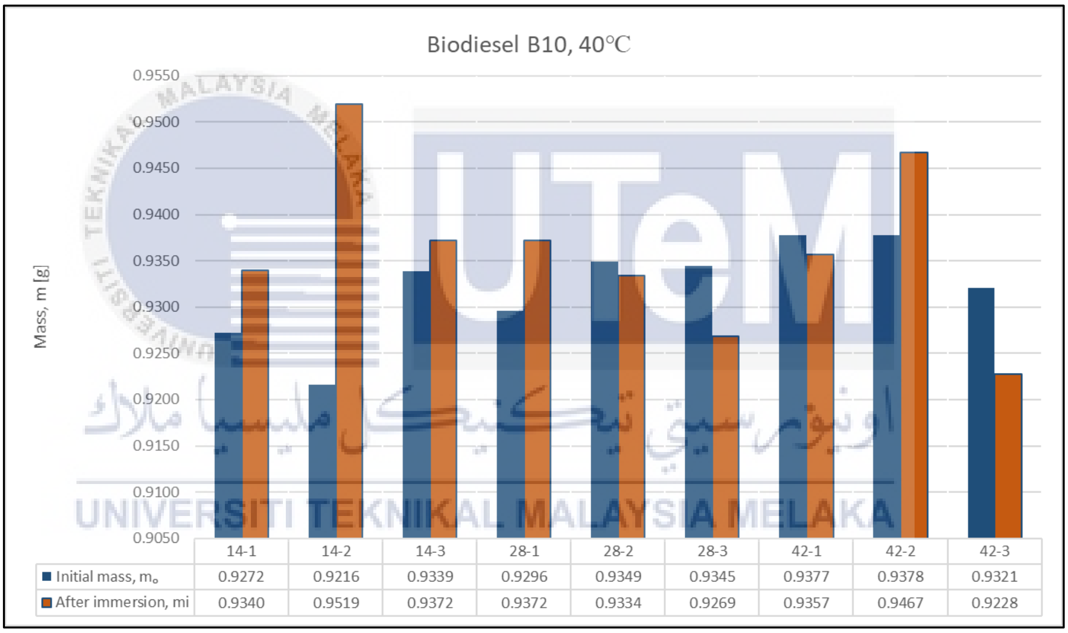

Figure 4.3: Result for mass test for sample immersed in B10 at 40℃

Table 4.6 shows the result for hardness test for sample immersed in B10 at room temperature. The correlation between the mass of O-ring after immersion test and its hardness is illustrated in **Figure 4.4**.

Table 4.6: Result for hardness test for sample immersed in B10 at 40°C

Days	14 days			28 days			42 days		
Sample	**14-1**	**14-2**	**14-3**	**28-1**	**28-2**	**28-3**	**42-1**	**42-2**	**42-3**
Hardness 1	68.5	68.5	68.0	70.0	68.5	67.0	70.0	68.0	71.5
Hardness 2	67.0	69.5	68.0	71.5	68.5	69.5	67.0	68.5	69.5
Hardness 3	68.0	69.0	69.0	72.0	67.5	70.5	68.5	68.5	68.5
Hardness 4	71.0	69.5	68.0	68.0	67.5	68.0	67.5	70.5	69.5
Average	68.6	69.1	68.3	70.4	68.0	68.8	68.3	68.9	69.8

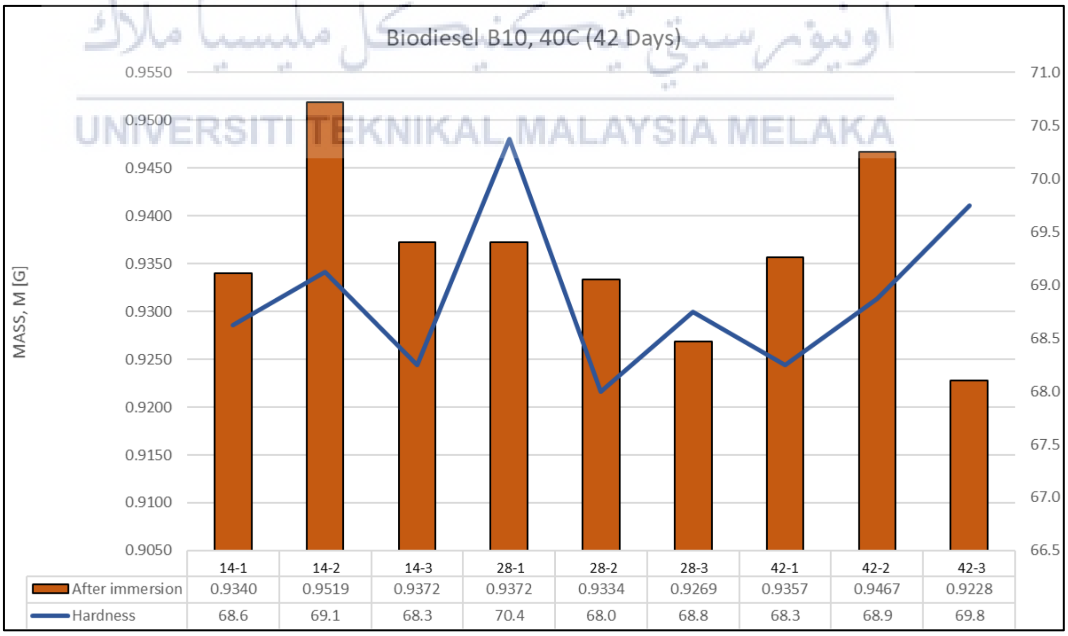

Figure 4.4: Correlation of hardness with after immersion mass for sample immersed in B10 at 40°C

4.2.3 B30 at Room Temperature

The initial mass and the mass of O-ring after being immersed in biodiesel B10 and 40°C were recorded in **Table 4.7** and **Table 4.8**, respectively.

Table 4.7: Initial mass of O-ring before immersion test

Days	**14 Days**			**28 Days**			**42 Days**		
Sample	**14-1**	**14-2**	**14-3**	**28-1**	**28-2**	**28-3**	**42-1**	**42-2**	**42-3**
Mass 1, (g)	0.945	0.928	0.929	0.934	0.930	0.924	0.933	0.944	0.920
Mass 2, (g)	0.945	0.928	0.929	0.934	0.930	0.925	0.932	0.943	0.920
Mass 3, (g)	0.945	0.928	0.929	0.935	0.930	0.924	0.932	0.943	0.920
Average, (g)	0.945	0.928	0.929	0.934	0.930	0.924	0.933	0.943	0.920

Table 4.8: Mass of O-ring after immersion Test

Days	**14 Days**			**28 Days**			**42 Days**		
Sample	**14-1**	**14-2**	**14-3**	**28-1**	**28-2**	**28-3**	**42-1**	**42-2**	**42-3**
Mass 1, (g)	0.949	0.930	0.949	0.933	0.938	0.938	0.941	0.940	0.935
Mass 2, (g)	0.949	0.931	0.948	0.932	0.938	0.938	0.941	0.941	0.935
Mass 3, (g)	0.949	0.931	0.948	0.932	0.938	0.938	0.941	0.940	0.935
Average, (g)	0.949	0.931	0.948	0.932	0.938	0.938	0.941	0.940	0.935

Based on the table above, in 14 days, the average mass of the O-ring before and after immersion are 0.9340g and 0.9426g, respectively. The O-ring gained 0.91% of its mass after immersion. In 28 days, the average mass of the O-ring before and after immersion are 0.9295g and 0.9360g, respectively. The O-ring gained 0.66% of its mass after immersion. In 42 days, the average mass of the O-ring before and after immersion are 0.9319g and 0.9388g, respectively. The O-ring gained 0.74% of its mass after immersion. The data above were illustrated in **Figure 4.5** below.

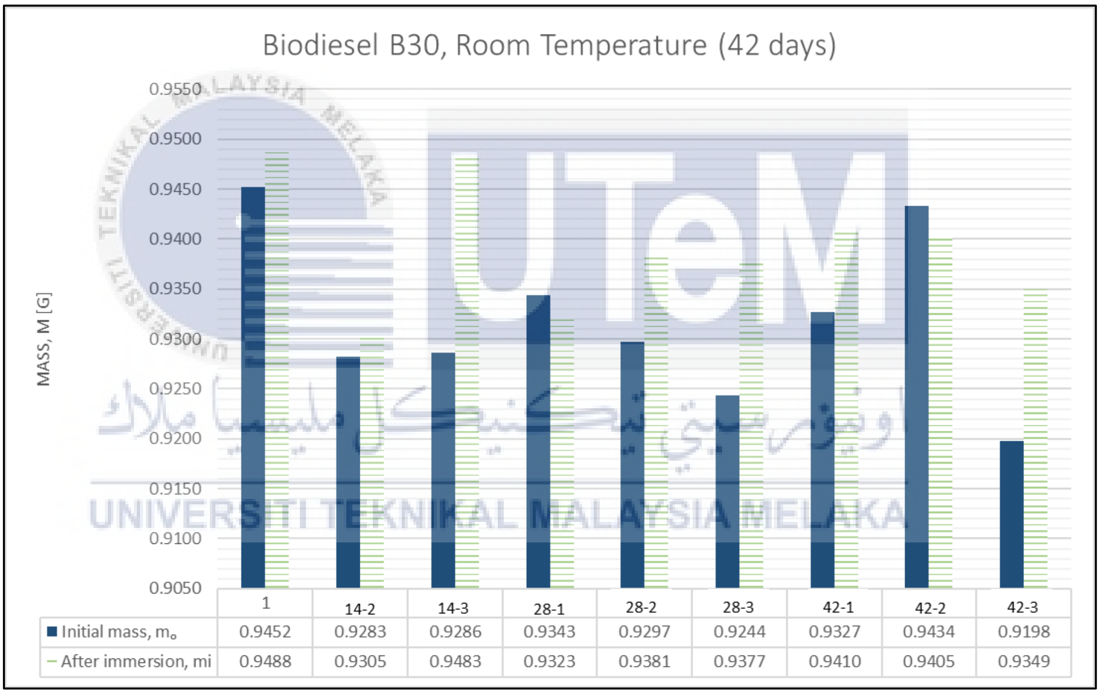

Figure 4.5: Result for mass test for sample immersed in B30 at room temperature

Table 4.9 shows the result for hardness test for sample immersed in B10 at room temperature. The correlation between the mass of O-ring after immersion test and its hardness is illustrated in **Figure 4.6**.

Table 4.9: Result for hardness test for sample immersed in B30 at room temperature

Days	**14 days**			**28 days**			**42 days**		
Sample	**14-1**	**14-2**	**14-3**	**28-1**	**28-2**	**28-3**	**42-1**	**42-2**	**42-3**
Hardness 1	69.5	69.5	71.0	70.0	68.0	69.5	68.5	67.5	69.5
Hardness 2	68.0	70.0	69.5	69.5	69.0	70.0	68.0	68.0	68.0
Hardness 3	69.5	69.0	69.5	69.5	71.0	70.0	67.5	69.0	69.0
Hardness 4	69.0	70.5	71.5	69.0	69.0	70.0	69.5	68.5	69.0
Average	69.0	69.8	70.4	69.5	69.3	69.9	68.4	68.3	68.9

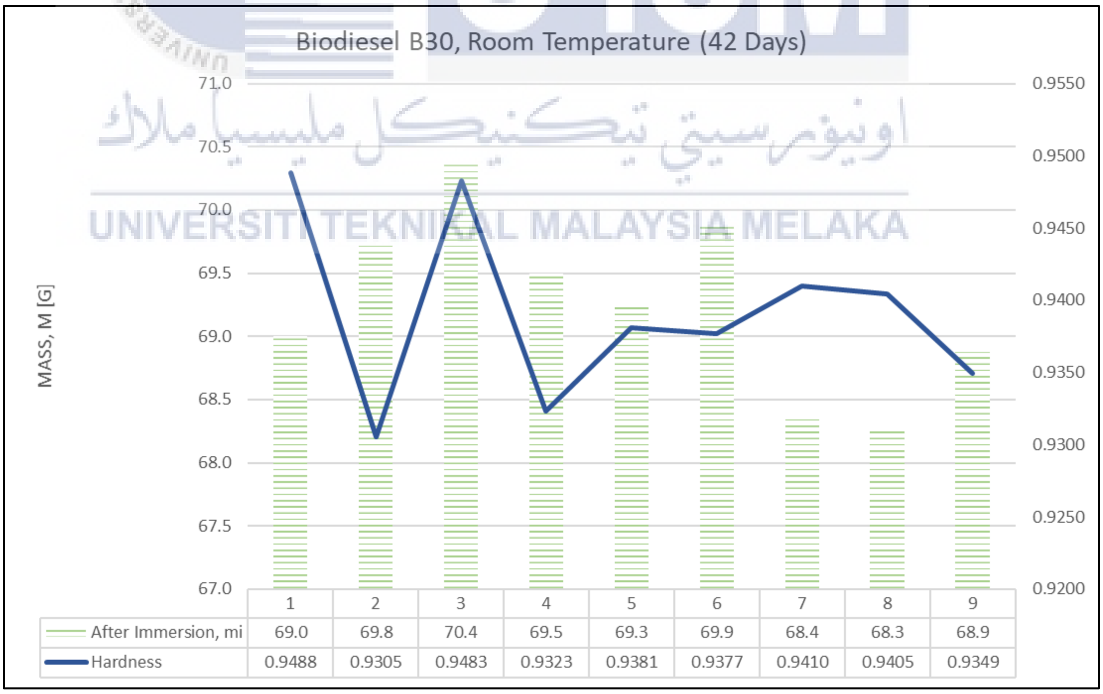

Figure 4.6: Correlation of hardness with after immersion mass for sample immersed in B30 at room temperature

4.2.4 B30 at 40°C

The initial mass and the mass of O-ring after being immersed in biodiesel B10 and 40°C were recorded in **Table 4.10** and **Table 4.11**, respectively.

Table 4.10: Initial mass of O-ring before immersion test

Days	**14 Days**			**28 Days**			**42 Days**		
Sample	**14-1**	**14-2**	**14-3**	**28-1**	**28-2**	**28-3**	**42-1**	**42-2**	**42-3**
mass 1, (g)	0.930	0.948	0.940	0.929	0.913	0.934	0.938	0.926	0.933
mass 2, (g)	0.930	0.948	0.940	0.929	0.913	0.935	0.938	0.926	0.933
mass 3, (g)	0.930	0.948	0.939	0.930	0.913	0.935	0.938	0.925	0.934
Average, (g)	0.930	0.948	0.940	0.929	0.913	0.935	0.938	0.926	0.933

Table 4.11: Mass of O-ring after immersion Test

Days	**14 Days**			**28 Days**			**42 Days**		
Sample	**14-1**	**14-2**	**14-3**	**28-1**	**28-2**	**28-3**	**42-1**	**42-2**	**42-3**
mass 1, (g)	0.794	0.948	0.931	0.916	0.933	0.938	0.941	0.930	0.938
mass 2, (g)	0.795	0.949	0.931	0.916	0.932	0.938	0.941	0.930	0.938
mass 3, (g)	0.795	0.948	0.931	0.916	0.933	0.938	0.941	0.930	0.938
Average, (g)	0.794	0.948	0.931	0.916	0.932	0.938	0.941	0.930	0.938

Based on the table above, in 14 days, the average mass of the O-ring before and after immersion are 0.9439g and 0.9396g, respectively. The O-ring loss 0.46% of its mass after immersion. In 28 days, the average mass of the O-ring before and after immersion are 0.9257g and 0.9289g, respectively. The O-ring gained 0.32% of its mass after immersion. In 42 days, the average mass of the O-ring before and after immersion are 0.9323g and 0.9362g, respectively. The O-ring gained 0.42% of its mass after immersion. The data above were illustrated in **Figure 4.7** below.

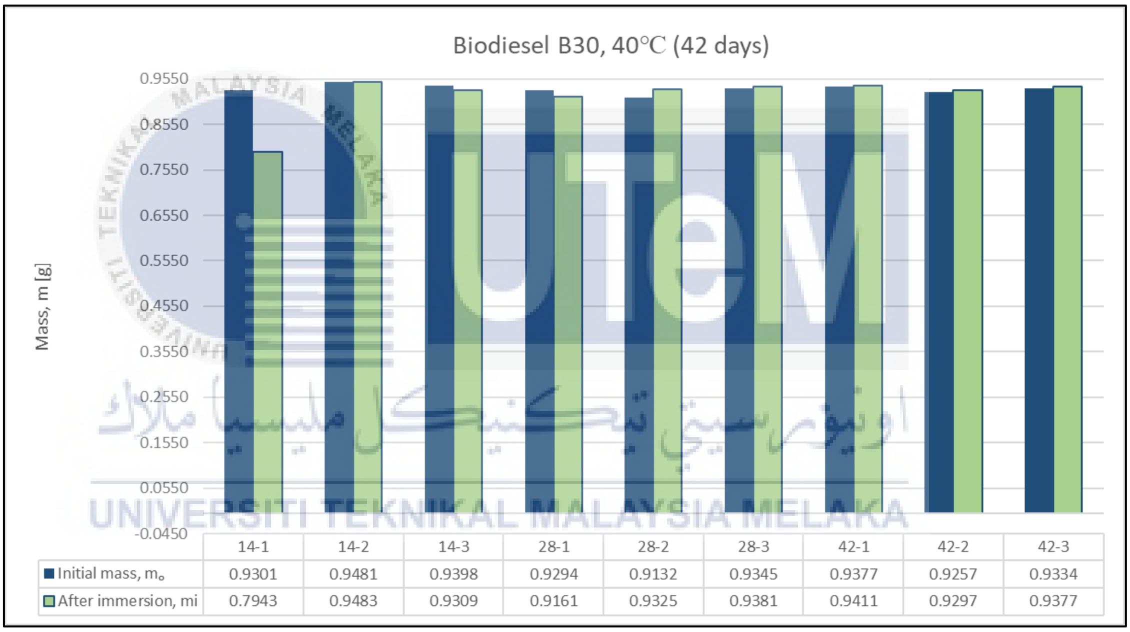

Figure 4.7: Result for mass test for sample immersed in B30 at 40°C

Table 4.12 shows the result for hardness test for sample immersed in B10 at room temperature. The correlation between the mass of O-ring after immersion test and its hardness is illustrated in **Figure 4.8**.

Table 4.12: Result for hardness test for sample immersed in B30 at 40°C

Days	**14 days**			**28 days**			**42 days**		
Sample	**14-1**	**14-2**	**14-3**	**28-1**	**28-2**	**28-3**	**42-1**	**42-2**	**42-3**
Hardness 1	69.0	68.0	69.0	67.0	68.5	69.5	68.5	68.0	69.5
Hardness 2	68.0	70.0	71.0	68.5	69.0	69.0	69.5	70.5	69.0
Hardness 3	70.0	68.5	68.5	70.0	69.5	69.0	70.5	69.0	69.0
Hardness 4	69.5	69.0	70.0	69.0	69.5	70.5	68.0	69.0	69.0
Average	69.1	68.9	69.6	68.6	69.1	69.5	69.1	69.1	69.1

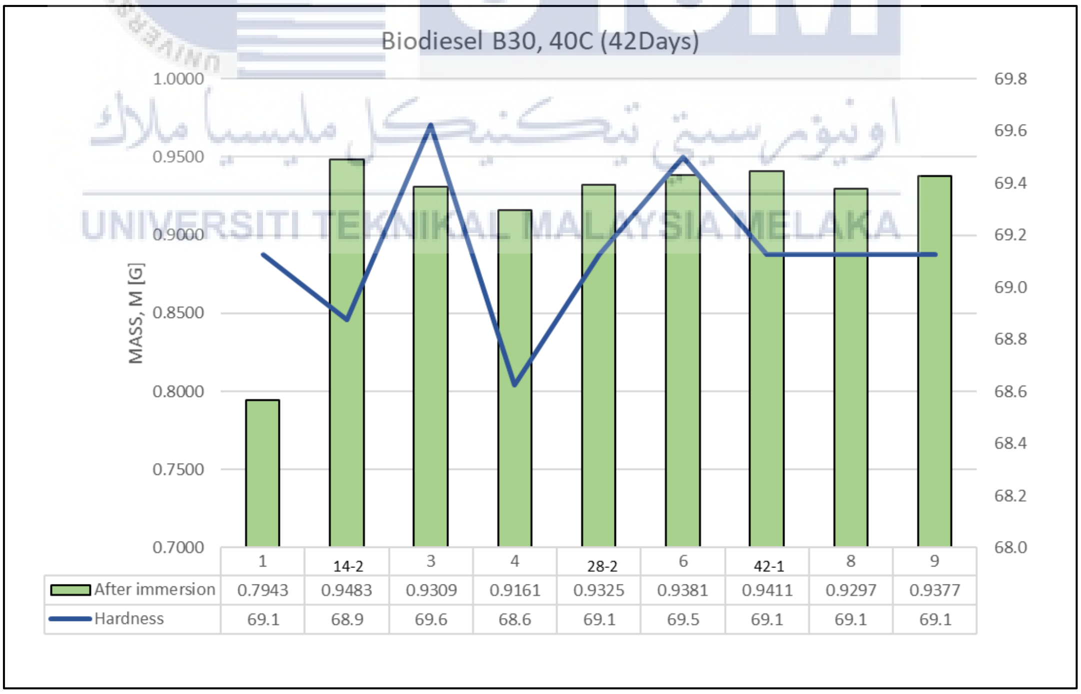

Figure 4.8: Correlation of hardness with after immersion mass for sample immersed in B30 at 40°C

4.3 Discussion

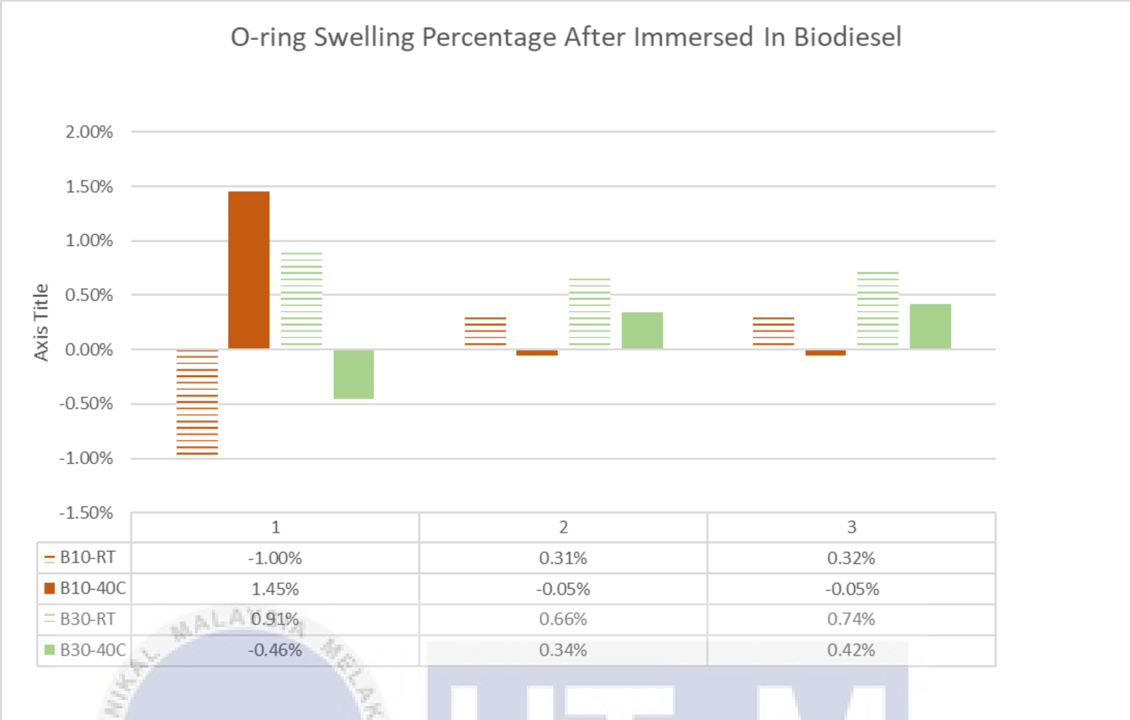

Figure 4.9: O-ring Swelling Percentage After Immersed in Biodiesel

Based on the **Figure 4.9**, it can be observed that O-ring immersed in B10 at room temperature has the same swelling pattern as O-ring immersed in B30 at 40℃. Both O-ring undergo degradation on the first 14 days. It is assumed that crazing is present on the O-ring causing the it to degrade. Later in day 28 to 42, both O-ring in B10 and B30 at room temperature and 40℃, respectively, starts to swell. However, for O-ring immersed in B10 at 40℃ and B30 at room temperature, it shows opposite pattern which it starts to swell first on the first 14 days then decrease in mass on days 28 to 42.

Table 4.13: Correlation between hardness and mass of O-ring

Biodiesel	**B10-RT**	**B10-40C**	**B30-RT**	**B30-40**
Correlation	0.73886	-0.97736	0.214366	0.924093

Table 4.13 shows the correlation between hardness and the mass of O-ring after immersed in biodiesel with their respective concentration and temperature. Correlation refers to the strength of relationship between two variables which in this case is between hardness and the mass of O-ring after immersed in biodiesel. High correlation means that the two variables have strong relationship. However, negative correlation value does not mean no relationship. The table shows that the temperature of the biodiesel has effect on the hardness of the O-ring. Higher temperature of biodiesel has more effect on the O-ring compared with low temperature biodiesel.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS FOR FUTRE RESEARCH

5.0 Conclusion

In conclusion, the objective of this study is to determine to effect of soaking time and biodiesel's temperature on the swelling properties of O-ring. The result shows various pattern of swelling properties of O-ring for different soaking time and temperature. However, higher temperature of biodiesel influences the hardness of the O-ring after being immersed by 42 days.

Furthermore, the other objective is to investigate the swelling properties of O-ring after being immersed in two different types of biodiesel, B10 and B30, respectively. In this study, biodiesel B10 and B30 does not have distinctive difference in term of corrosiveness and swelling properties of the O-ring.

5.1 Recommendation

For future research, tensile test should be done to determine the tensile strength of the O-ring before and after immersion. During this project, a tensile test jig was designed and fabricated but due to Movement Control Order (MCO) by government of Malaysia, the tensile test could not be done. The tensile test jig is available at UTeM for future study. Additional surface morphological test can be done to investigate the material and element present in the O-ring such as scanning electron microscope (SEM) test and Energy Dispersive X-Ray Analysis (EDX) test. Lastly, the mechanism of swelling properties of the O-ring could be determine for better understanding of the effect of soaking time, temperature, and biodiesel concentration on the O-ring.

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