EXPERIMENTAL ANALYSIS OF LUBRICATION

OF B30 BIODIESEL FOR FUEL INJECTOR SYSTEM.

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2020

Declaration.

I declared the title of this project “Experimental Study of B30 Biodiesel Lubrication for Fuel Injector System "is the product of my own research, except as stated in the references.

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APPROVAL

I hereby declare that I have read this project report and, in my view, this report is adequate for the award of a Bachelor of Mechanical Engineering degree as regards scope and efficiency.

DEDICATION

To my beloved parents, family members and friends.

ABSTRACT

Biodiesel is known as monoalkyl esters, mainly methyl esters (FAME), of long-chain fatty acids obtained from vegetable oils or animal fats. Biodiesel is easy to achieve, and it is renewable resources, and it received special attention. The purpose of this research focuses on tribological properties and lubricant properties of various biodiesel blends, B0, B5, B10, and B30. The standard used for tribological properties using ASTM D4712 standard and lubricant properties is ASTM D445 standard for kinematic viscosity and ASTM D3828 standard for flashpoint temperature. The conventional biodiesel obtained from Petron Gangsa, Durian Tunggal, and Palm Oil Biodiesel received from Malaysian Palm Oil Board (MPOB). All of the properties testings have conducted at Tribological Laboratory, Universiti Teknikal Malaysia Melaka, UTeM. In summary, all of the results of tribological and lubricant properties achieved within the acceptable range of ASTM standards.

ABSTRAK

Biodiesel dikenali sebagai ester monoalkil, terutamanya ester metil (FAME), dari asid lemak rantai panjang yang diperoleh daripada minyak sayuran atau lemak haiwan. Biodiesel mudah diperoleh, sumber daya yang dapat diperbaharui, dan mendapat perhatian khusus. Tujuan penyelidikan ini untuk memfokuskan pada sifat tribologi dan sifat pelincir pelbagai campuran biodiesel, B0, B5, B10, dan B30. Standart yang digunakan untuk sifat tribologi menggunakan standard ASTM D4712, dan untuk sifat pelincir adalah standard ASTM D445 untuk kelikatan kinematik, dan standart ASTM D3828 untuk suhu titik kilat. Biodiesel konvensional diperoleh dari Petron Gangsa, Durian Tunggal dan Biodiesel Minyak Sawit diperoleh dari Lembaga Minyak Sawit Malaysia (MPOB). Semua ujian sifat telah dilakukan di Makmal Tribologi, Universiti Teknikal Malaysia Melaka, UTeM. Ringkasnya, semua hasil sifat tribologi dan pelincir telah dicapai dalam julat standard ASTM yang boleh diterima.

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LIST OF ABBREVIATION

ASTM	American Society for Testing and Materials.
EN	European standard
MPOB	Malaysian Palm Oil Board
KOH	Potassium hydroxide
NaOh	Sodium hydroxide
H_2SO_4	Sulfuric acid
CO_2	Carbon dioxide
SO_2	sulphur dioxide
PM	Promethium

HC	Hydrocarbon
NOx	Nitric Acid
US	United State
WSD	Wear Scar Diamater
PSM	Projek Sarjana Muda
RPM	Rotation per minute

LIST OF SYMBOLS

k	Wear coefficient.
P	Load
H	Hardness
L	Sliding Surface
V	Wear volume
W	Adhesive wear rate
T	Frictional torque
μ	Coefficient of friction.
W	Applied load
r	Distance from the center of the contract surface on the lower balls.

CHAPTER 1

INTRODUCTION

1.1 Background.

In today's generation, there is an all-out effort on reducing the reliance on petroleum for transportation and energy generation throughout the world (Musa, 2010b). The effects of petroleum give us harmful effects for our future generation because of unburned hydrocarbons, CO, and particulate matter emission that is being used in conventional engine oils, which is toxic and non-bio-degradable [Ali, 2013]. In other ways, engine oils may pollute the environment, water, soil, and air (Tabares, 2013). Instead of using biodiesel for general daily use, it also can be used for the replacement of biodiesel if the properties of the biodiesel are enhanced (Musa, 2010b, 2010a). In previous research, it stated that wear and friction of the engine components along with engine performance and engine exhaust emissions could be running smoothly if the quality of lubricants is high. Lubrication is a method used for reducing the wear of one or both surfaces to make the engine moving relative to each other (Musa, 2010a).

Due to the rapid growth of populations keep increasing by every year, the demand for energy in the transportation sector has been hiked (Sundus, Fazal, & Masjuki, 2017),(Reddy, Sharma, & Agarwal, 2016). Environmental pollution, such as emissions of unburned hydrocarbons, carbon monoxide, and nitrogen oxides, is affecting the world due to the high usage of fossil fuels in engine contribution (Sundus et al., 2017),(Patil et al., 2018). Thus, global warming, smog, deforestation, ozone depletion, and acidification are the factor that makes a massive impact on the environment (Sundus et al., 2017). There is an essential factor to be investigated for non-polluting, efficient, and renewable fuels for future needs due to limited energy reserves in our world (Reddy et al., 2016),(Balakumar, Sriram, & Arumugam, 2018). Bio-diesel was introduced in the United States by the National soy diesel Development Board in 1992, which has pioneered the commercialization of biodiesel in the United States (Patil et al., 2018). A technically possible, commercially reasonable, eco-friendly, and readily available should be a substitute to biodiesel compared to the diesel engine, and it is a compromising fuel because it reduces major environmental concerns (Sundus et al., 2017),(Balakumar et al., 2018). From edible and non-edible vegetables, animals fat, and waste cooking oils by the process of transesterification, biodiesel can be produced (Reddy et al., 2016). Biodiesel is regularly used because of an oxygenated, renewable, biodegradable, and environment-friendly, and it has a higher cetin number, absence of sculpture and aromatic compounds, due to its attractive characteristic of biodiesel (Patil et al., 2018).

In this research, commercially available biodiesel available on the market, compared with B20 biodiesel palm oil properties. The main focus is on the characteristic of biodiesel, which is the friction coefficient and wears rate, viscosity, and flash point temperature. The characteristics of the friction coefficient and wear determined by using a four-ball machine tester. The properties of kinematic viscosity will be determined by using viscometer. The properties of flash point temperature, which means the initial mean temperature of biodiesel ignites, by using flashpoint meter. The results of this research provide later in conclusion to discover every property of biodiesel B20 and other commercially available diesel in market fuel for injector systems.

1.2 Problem Statement.

Biodiesel is abstract from renewable resources such as vegetable oils, animal fats, and palm oil, and biodiesel, also known for good substitutional for conventional diesel fuel (Patel & Sankhavara, 2017). Besides that, biodiesel has impressive lubricant properties and can be additive for lubricity petroleum fuels (Hu, Du, Li, & Min, 2005). Many types of biodiesel have derived from non-edible stock such as Karanja, Jatropha, Palm, Jojoba, and many more (Reddy et al., 2016). In Malaysia, many biodiesel can obtain from nearby pump petrol such as B0 (100% diesel), B5 (5% biodiesel and 95% diesel) and B20 (20% biodiesel and 80% diesel). Different theories exist in the literature regarding the problem related to biodiesel problems such as the standard diesel in the market that has increased in pollutant emission (Shahid & Jamal, 2008). Next, It also stated that there is poor ignition quality because of unacceptable of atomization, engine deposit, sticking of piston ring, injector conking and excessive engine wear due to the higher viscosity of biodiesel (Mosarof et al., 2015), (Hassan & Kalam, 2013). Different types of biodiesel blends have different performance and efficiency. In this research, the properties of friction and wear, kinematic viscosity, and flashpoint temperature for each biodiesel tested are to be analyzed. Therefore, this research focuses on which biodiesel to be the most suitable for a lubricant for the fuel injector system.

1.3 Objective

The objective of the project is:

1. To investigate the tribological properties of for various blending of biodiesel.

2. To determine the kinematic viscosity, and flashpoint temperature for various blending of biodiesel.

1.4 Scope of Research.

The scope of the research are:

1. The properties of conventional biodiesel and palm oil biodiesel, B0, B5, B10, and B30 is determined before the research being conducts.

2. This research focuses on finding friction coefficient and wear rate, kinematic viscosity, flashpoint temperature by using ASTM D4712 standard for friction coefficient, ASTM D445 standard for kinematic viscosity, and ASTM D3828 standard for flashpoint temperature.

1.5 General methodology.

The details and description of the methodology to obtain the objective of this research explained later in Chapter 3. In most cases, the flow of this project is as below.

1. **Literature review.**

Obtain a legit source of journals, articles, books, websites, or any other related material about this project.

2. **Research setups.**

The sample of biodiesel B10, B20, and B30 palm oil obtained from the Malaysian Palm Oil Board (MPOB) and B0 (Diesel Max) and B5 (Euro 5) obtained from the commercially available in the market.

3. **Research and analysis.**

This research of properties of B20 biodiesel fuel with commercially available diesel in the market such as B0 (Diesel Max) and B5 (Euro 5), B10, and B30 palm oil biodiesel obtained from Malaysian Palm Oil Board (MPOB) and diesel for fuel injector systems focus on friction and wear rate, kinematic viscosity, and flashpoint temperature. The results and data, collected and analyzed to investigate the tribological performance.

4. Thesis writing.

A complete thesis composes in this research, including the data and analysis from this research. The general methodology of this research is simplified in the flow chart as shown below.

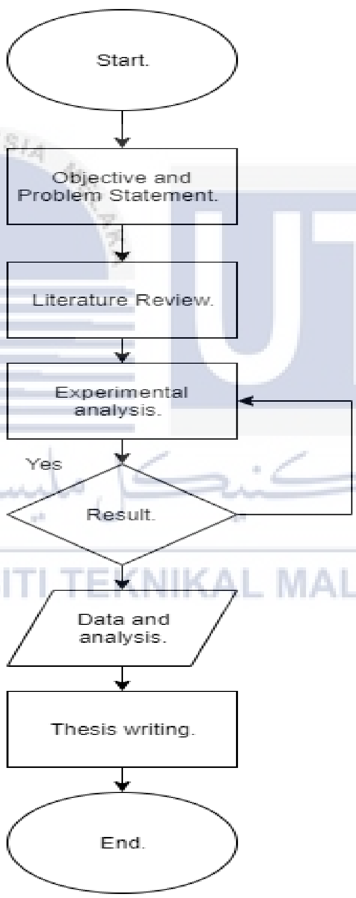

Figure 1.1: Flowchart for thesis writing.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction.

Over the years, the usage of non-renewable resources such as fossil fuel increasing in demand, and it harms the environment. A large and growing body of literature focusing on the investigation of transport industry non-polluting, clean, and practical resources energy for future needs (Reddy et al., 2016). To saves the world from decreasing the amount of using non-renewable energy used for transportation, another alternative must implement to reduce the dependence of non-renewable energy. Biodiesel introduced to replace fossil fuels because it easily obtained from seeds of crops, edible oils, and animal fats as well (Patil et al., 2018). Furthermore, biodiesel also has advantages that could lead to being the most suitable replacement for fossil fuels because of high-efficiency content, higher productivity, and wide-ranging quality of oil (Reddy et al., 2016). In this section, the production of biodiesel and palm oil biodiesel discussed further based on previous research and the impact towards the engine by using biodiesel. The main properties of biodiesel tested, which are friction,

friction coefficient, wear, wear scar diameter, viscosity, kinematic viscosity, and flashpoint focused in this chapter. The standard used for each property used in this research also discussed in this chapter. The chapter aims are to create guidelines and benchmark from previous research and study to complete this research.

2.2 Production of biodiesel.

Biodiesel is produced from the various feedstock which is renewable. Properties of biodiesel should be matched with fuel properties as specified by ASTM D6751 or EN14214 (Datta & Mandal, 2016).

2.2.1 Biodiesel preparation.

Biodiesel is known as monoalkyl esters, mainly methyl esters (FAME), of long-chain fatty acids obtained from vegetable oils or animal fats (Hu et al., 2005). Biodiesel is easy to obtain, and it is renewable resources, and it received special attention. Other than that, biodiesel also easy to handle, environmental friendly (Ali & Tay, 2013). Based on the previous research, it is essential to replace from using fossil fuels into biodiesel due to high viscosity and low volatility (El-Araby, Amin, El Morsi, El-Ibiari, & El-Diwani, 2018). Biodiesel production is a deceptively complex process rather than a simple process at first sight, especially if you want to produce high-quality biodiesel and a product that meets the international biodiesel specification as underlined by EN 14214 and ASTM D 6751 (Lam &

Lee, 2011). On the other hand, petroleum diesel and biodiesel that derived from palm oil having similar fuel properties (Lam & Lee, 2011). Based on previous research, there is some preparation and production of biodiesel by using different methods which is (Zahan & Kano, 2018):

i. They are blending (dilution) by preheating vegetable or animal oils blended with petrodiesel within a 10-40% (*w/w*) ratio. The results from oil-mixture applied to the diesel engine.

ii. Microemulsification by dissolving the vegetables or animals oils with a solvent, which is alcohol and tenside until the desired viscosity obtained.

iii. Pyrolysis (thermal cracking) where, the vegetable or animal oils are heated up and decomposed at elevated temperatures, more than 350°C to know the presence of the catalyst.

iv. By transesterification, where alcohol and catalysts, react with animal or vegetable oils. After that, the mixture of biodiesel and glycerol will go through the process of separation and purification steps before proceeding to the next process.

Based on these four different methods to produce biodiesels, the transesterification process is the most commonly used method to produce biodiesels (Ramalingam, Rajendran, Ganesan, & Govindasamy, 2018). This process involves raw feedstock converted into biodiesel. A catalyst usually used with excess alcohol, which shifts the equilibrium to the product side since the reaction is reversible to improve the rate of reaction and biodiesel yield. The transesterification process uses the solvents and the standard catalysts KOH, NaOH, and H_2SO_4, including ethanol or methanol. However, extensive separation process, wastewater generation, and equipment corrosion natural imperfection when this method is applied. Different studies had been run before, such as the implementation of heterogeneous catalysts to overcome the problems: solid acid and base, zeolite, and polymer, which is a group of heterogeneous catalysts. Although of heterogeneous catalyst is used, it has many disadvantages such as less effective due to long reaction time, low reaction and conversion rate, easy deactivation and high viscosity that increase the mass transfer resistance compared to homogenous catalysts (Zahan & Kano, 2018). Besides, the low-cost method is a high significance figure for the transesterification process due to shorter reaction time, and the production capacity of biodiesel is higher (Ramalingam et al., 2018).

2.2.2 Raw feedstock of biodiesel.

Biodiesel is an alternative biodegradable, non-toxic, virtually Sulphur-free gas making it unquestionably good for the environment (Lam & Lee, 2011). Biodiesel is produced from the transesterification of a vegetable or animal oil with the reaction of low molecular weight alcohol such as ethanol and methanol. Soybean, sunflower, palm, canola, cottonseed, Jatropha, rapeseed and soybean oil are several resources which are used as feedstock for biodiesel production (Ali & Tay, 2013). The most prospective biodiesel feedstock is palm oil compared to other oil seeds (Mekhilef, Siga, & Saidur, 2011). The highest oil yield in terms of oil production per the hectare of the plantation is palm plantation (Ali & Tay, 2013). On the other hand, less sunlight needed for palm oil production that leads to producing more oil per hectare (Mekhilef et al., 2011). The figure below shows the production oil yield for various source biodiesel feedstock's.

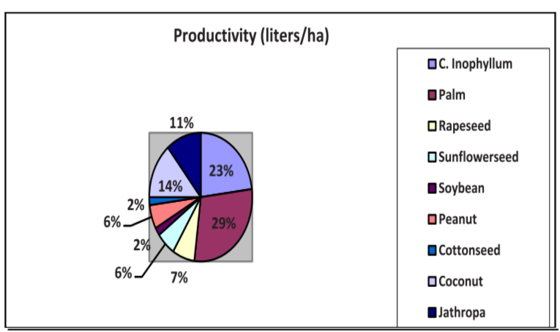

Figure 2.1: Production of biodiesel from various feedstock (Ali & Tay, 2013).

2.2.3 Advantages and disadvantages of biodiesel.

Biodiesel has some advantages and disadvantages which have been listed in the table below.

Table 2.1: Advantages and disadvantages of biodiesel (Hassan & Kalam, 2013).

Advantages of biodiesel.	Disadvantages of biodiesel.
i. Biodiesel can be renewable. ii. Fewer emissions of CO_2, CO, SO_2, PM, and HC emitted from biodiesel compared to diesel. iii. Biodiesel makes a car perform better, and it makes the engine life become long-lifetime, and low maintenance is need. iv. Locally produced biodiesel makes it more cost-efficient. v. Sulfur content, flash point, aromatic content, and	i. The emission of NOx is higher than diesel. ii. Against copper and brass, biodiesel has a corrosive nature towards the materials. iii. Due to the large molecular mass and chemical structure of vegetable oils, biodiesel have high viscosity. iv. Biodiesel decreasing the average power by 5% compared to diesel, making biodiesel have lower engine speed and power.

biodegradability of biodiesel is much better than diesel. vi. Biodiesel has a high flash point temperature and more biodegradable, making biodiesel safer and easier to handle. vii. Biodiesel has a considerable amount of combustion efficiency compared to diesel.	v. Excessive engine wear can cause by biodiesel. vi. Biodiesel is not cost-competitive with gasoline or diesel.

2.3 Palm oil biodiesel.

In this chapter, it focuses on how to process palm oil from the raw material into biodiesel and properties of palm oil biodiesel and standard properties for the biodiesel test.

2.3.1 Process of palm oil biodiesel.

Palm oil is to be the most desirable option for biodiesel feedstock compared to other oilseeds. Due to palm oil having a higher production yield rate, using low fertilizer and water for the plantation, and it may produce one ton of palm oil (Lam & Lee, 2011). In the previous research, it stated that palm oil plantation contributes less than 5% in the world but still managed to supply 25% to the global oils and fats (Lam & Lee, 2011). Palm oil extracted from the inner wall of the fruit called fleshy mesocarp required for the process (Mekhilef et al., 2011). From the mesocarp, it can get crude palm oil from refining and kernel processing. The fruit of the palm is crack to remove the shell and separated the seeds. Next, the Kernel processed to palm kernel oil and palm kernel cake and can obtain crude palm oil.

Crude oil is derived from essential palm oil to refined palm oil and used for multiple applications, including being used as a palm oil biodiesel.

Apart from that, there is another way to produce palm biodiesel. First and foremost, the crude palm oil preheated to minimize free fatty acid and increasing oxidative stability. Degumming, neutralization by caustic soda, pigment removal using bleaching earth and high-temperature vacuum deodorization are pre-treatment steps that must be taken during the analysis. The palm oil is heated to certain reaction temperatures to produce biodiesel in the presence of excess methanol and base catalysts. The excess methanol is recovered through a flashing in a flash vessel and further purified in a structured packing distillation column after the reaction is complete. Water-washing stages in cyclones are a vital part of crude biodiesel to remove the remaining catalysts and also to purify the biodiesel. At the end of this biodiesel production, the water released at the bottom of the cyclone, the washed biodiesel, is preserved under vacuum conditions to reduce its water content with a specified limit of biodiesel standards (Lam & Lee, 2011).

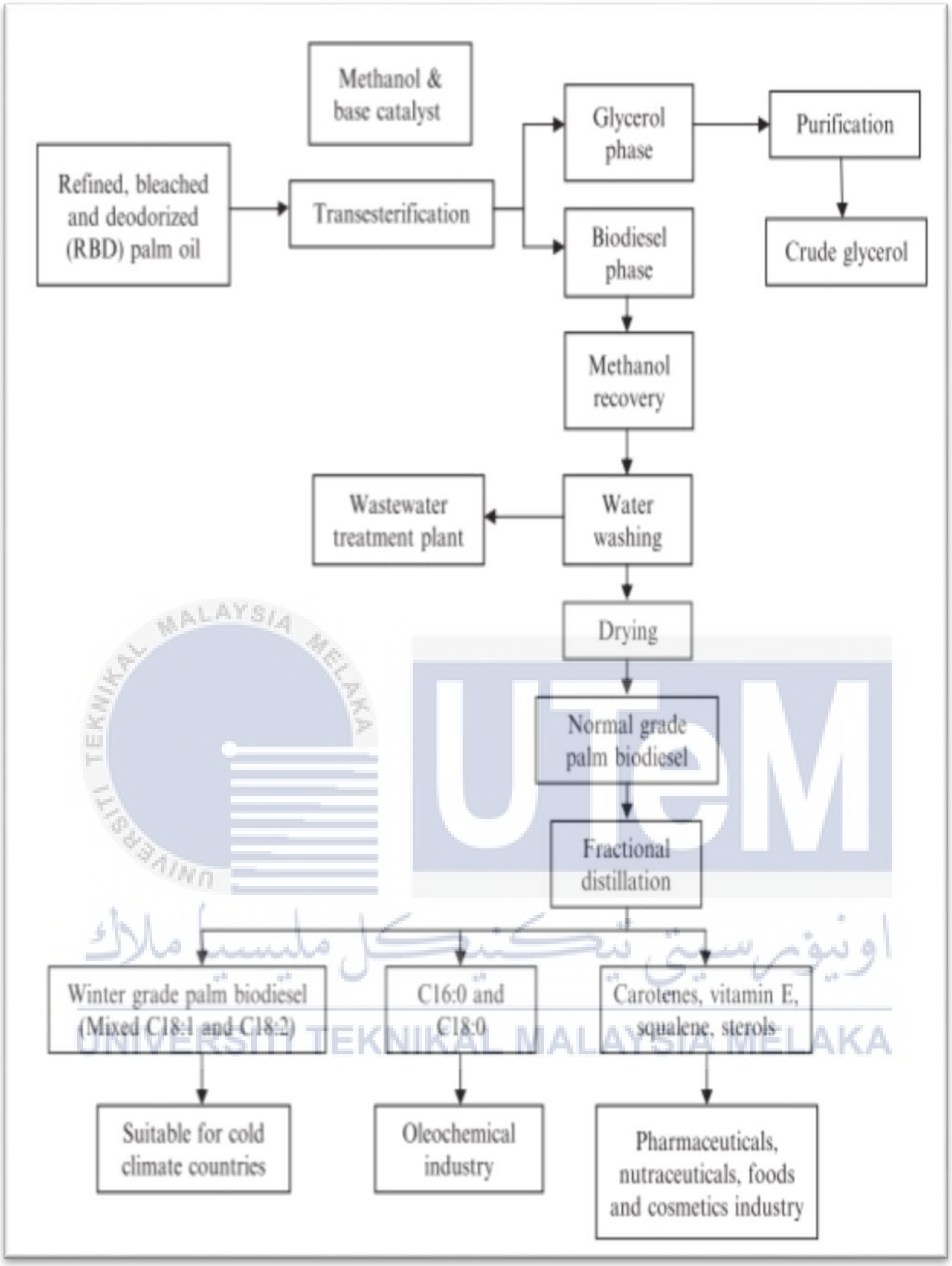

Figure 2.2: Overview on the existing palm biodiesel production process (Lam & Lee, 2011).

2.3.2 Standard properties for biodiesel test.

As the use of mono-alkyl ester biodiesel, the standard for biodiesel stated in the early 1990s. American Society for Testing and Material (ASTM) standard biodiesel was developed by provisional specification PS121 in 1999. Nonetheless, in 2009, ASTM D6751 was the first ASTM standard for biodiesel in the United States, US. While in Europe, EN14214 biodiesel standard introduced in October 2003. Both of the standards become a pioneer in the industry and becoming a benchmark for biodiesel specifications developed in other countries. The standard for Malaysia using is MS2008:2008 in October 2008 to facilitate the local implementation of biodiesel usage. This standard is substantially similar to biodiesel specifications of EU Standard EN 14214 and US Standard ASTM D6751. Test method and intended applications are the only significant difference for both standards. In conclusion, ASTM D6751 establishes for the blend components and EN 41214 for blend stocks and neat biodiesel use as an automotive fuel.

i. American Standard.

ASTM D6751 defines biodiesel as a mono-alkyl ester of long-chain fatty acids derived from vegetable oils and animal fats. From alcohol such as methanol, ethanol, etc. as it not specified in the standard where the mono-alkyl ester obtained. The details of ASTM D6751 shown in Table 2.3.

Table 2.2: Standard properties for standard ASTM D6751 and EN14214 on biodiesel properties (Zahan & Kano, 2018).

Properties	**ASTM D6751**	**EN 14214**
Flash point, min (°C)	100-170	>120
Cloud point (°C)	-12.00	
Pour point (°C)	-15.00	
Kinematic viscosity at 40°C (mm^2/s)	1.9-6.0	3.5-5.0
Specific gravity at 15°C (kg/L)	0.88	0.86-0.90
Density at 15°C (kg/m^3)	820-900	860-900
Cetane number, min	47.00	51
Iodine number, max		120
Acid number, max (mg KOH/g)	0.50	0.5
Ash (wt %)	0.02	
Sulphated ash, max% (*m*/*m*)	0.02	0.02
Oxidation stability, min (*h*, 110°C)	3.00	6
Water and sediment, max (*v*/*v*%)	0.05	0.03
Water content, max	0.03 (v/v)	500 (mg/kg)
Free glycerol, max (mass %)	0.02	0.02
Total glycerol, max (mass %)	0.24	0.25
Sulphur content, max	0.05% (m/m)	10 mg/kg
Phosphorus content, max	0.001 (m/m)	10 g/kg

ii. European Standard.

The European biodiesel specification, EN 14214, only applies to mono-alkyl esters made up of methanol and fatty acid methyl esters (FAME). The European standard is more specific and restrictive. It is because mono-alkyl ester made with other than ethanol, not considered of meeting the requirements of the standard. The standard specifications of EN 14214 biodiesel show in detail in Table 2.3.

Table 2.3: European Standard for Biodiesel (EN14214) (Mat Yasin et al., 2017).

Properties	Units	Limits		Test Method
		Minimum	Maximum	
FAME content	% (m/m)	96.5		pr EN14103
Density at 15 °C	kg/m^3	860	900	EN ISO 3675/ EN ISO 12185
Viscosity at 40°C	mm^2/s	3.5	5	EN ISO 3104
Flash point	°C	>101		EN CD 3679e
Sulfur Content	mg/kg		10	
Tar remnant (at 10% distilation)	% (m/m)		0.3	EN ISO 10370
Cetane number		51		EN ISO 5165
Sulphated ash content	% (m/m)		0.03	ISO 3987
Water Content	mg/kg		500	EN ISO 12937
Total contamination	mg/kg		24	pr EN 12662
Copper band corrosion (3h at 50°C)	Rating	Class 1	Class 1	EN ISO 2160
Oxidation Stability	H	6		pr EN 14112k
Acid value	mgKOH/g		0.5	pr EN 14104
Iodine Value	% (m/m)		120	pr EN 14111
Linoleic acid methyl ester	% (m/m)		12	pr EN 14103d
Polyunsaturated (4 double bonds) methyl ester	% (m/m)		1	
Methanol content	% (m/m)		0.2	pr EN 141101
Monoglyceride content	% (m/m)		0.8	pr EN 14105m
Diglyceride content	% (m/m)		0.2	pr EN14105m
Triglyceride content	% (m/m)		0.2	pr EN14105m
Free glycerine	% (m/m)		0.02	pr EN14105m/ pr EN14106m
Total glycerine	% (m/m)		0.25	pr EN14105m
Group I metals (Na + K)	mg/kg		5	pr EN14108/ pr EN14109
Group II metals (Ca + Mg)	mg/kg		5	pr EN14538
Phosphorus content	mg/kg		4	pr EN14107p

2.4 Palm oil biodiesel lubricant characteristic and properties.

2.4.1 Tribological properties.

2.4.1.1 Friction.

Friction is a challenge of an object moving relative to another. Friction divided into two types, which are static friction and kinetic friction. Static friction stands for two objects that are not moving relative to each other, while kinetic friction stands for two or more objects that are moving relative to each other (Ghose, 2013). The friction causes the energy of a system is wasted because of the temperature rises and producing wear of the mating surfaces (Sundus et al., 2017). In a tribological research, friction, wear, and lubrication are the main component of this research. The term of tribology is widely used in 1966 after it has published by The Jost Report. Peter Jost stated that the term of tribology came from Greek, stands for 'the study of things that rub.' The mechanisms of tribology need to be used and studied to enhance technology. It is consists of clutches, cables, gears, and bearings which require speeds, forces act on the moving object to from the output of friction force, wear, and temperature.

2.4.1.2 Friction coefficient.

The coefficient of friction measured with friction, which coefficient of friction is dimensionless quantity. The friction coefficient defined as the ratio of the two forces between normal and parallel force subjected to the surface force to an interface between two bodies under relative motion (Sundus et al., 2017).

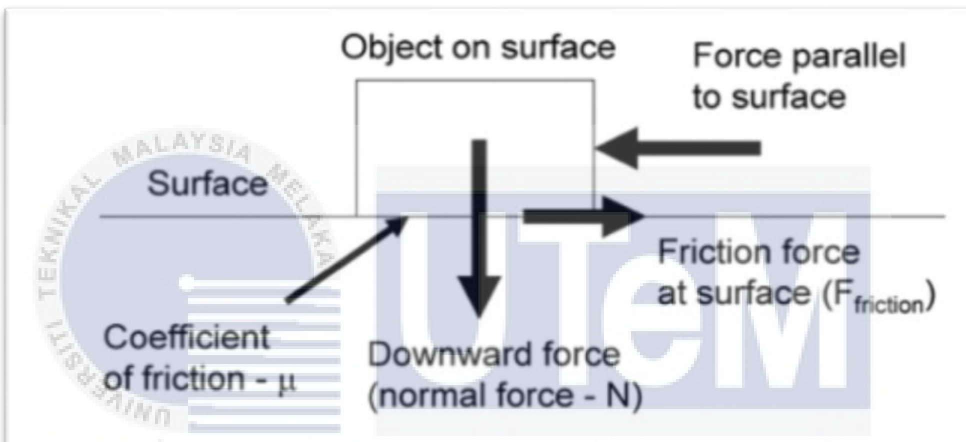

Figure 2.3: Basic definition of coefficient of friction (Sundus et al., 2017).

From the figure above, it shows the detailed concept of friction coefficient and eqn. (3.1) is an equation for the friction of coefficient that used in this research. Based on previous research, it stated that when biodiesel concentration is increasing in concentration, the average friction coefficient becomes lower. Comparing with two biodiesel, which is petroleum diesel (B0) and biodiesel (B100), the average friction coefficient for biodiesel is lower compared to diesel fuel. It is because of the presence of non-uniform availability of the heteroatom, such as oxygen and sulfur in biodiesel blends, which contributes the most critical role for the lubricating film. From the graph, it shows that biodiesel at the contact surface is more effective compared to diesel fuel to reduce the friction. In the previous research on the friction of coefficient for biodiesel, the researcher stated that the quantity of oxygen in biodiesel is higher, and it can reduce the friction compared to diesel fuel. By referring to figure 2.4 below, shows that the average friction coefficient decreases with the increase of biodiesel concentration (Fazal, Haseeb, & Masjuki, 2013a).

$$\text{Coefficient of friction } (\mu) = \frac{T\sqrt{6}}{3Wr} \quad (2.1)$$

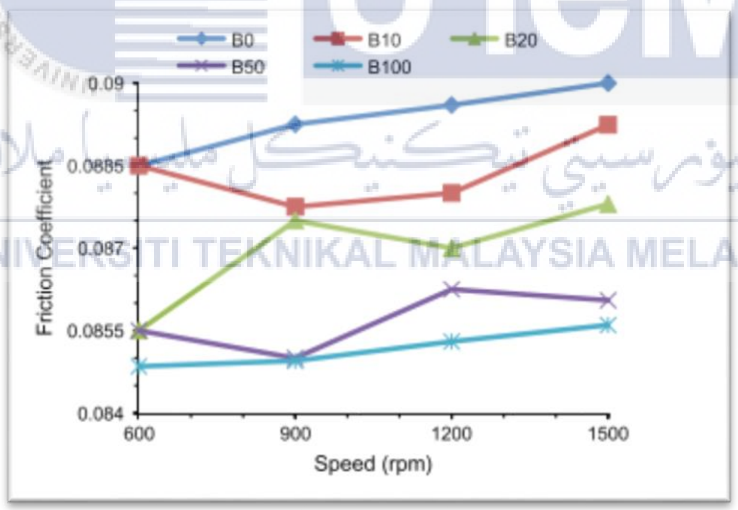

Figure 2.4: Effect of speed on average friction coefficient in different fuel under a fixed load of 40 kg at temperature 75°C (rpm) (Fazal et al., 2013a).

2.4.1.3 Wear.

Wear stands for the progressive losses of materials from contacting surfaces between two or more objects in relative motion. Other than that, it also can be described as the removal of a solid surface due to mechanical action (Rabinowicz, 1976). There are there major limiting factors the life and performance of an engineering system, whether the system is a heavy machine or a tiny small electronic device. The three limiting factors of the machine are fatigue, corrosion, and wear. From the impact of wear, generally, it gives the component reducing the dimension of the machine or component which causes high vibration, high noise, system malfunction and the efficiency of the system in poor condition. A general formula used to calculate the wear rate shown below.

$$\text{Wear rate} = \frac{\text{Wear volume loss}}{\text{Sliding distance x Applied load}} \tag{2.1}$$

There are two types of wear which is abrasive wear and adhesive wear. Abrasive wear occurs when a hard surface or hard particles pass over a soft surface, causing losses of material. Abrasive wear also can be found on the wear track even though it sliding into the same materials (Kato, 1997). During the wear process caused by work hardening, phase transformation, and third body formation at the interface, the abrasive particles may form due to the process occurs (Rigney, 1997). There are two types of abrasive wear, which are two-body abrasive wear and three-body abrasive wear (Moore, 1974). The rubbing of a softer surface causes Two-body abrasive wear by a hard and rough surface, while three-body abrasive wear is caused by entrapped between two sliding surfaces (Arnell, 2010). The figure below shows that the two types of abrasive wear, which are two-body abrasive wear and three-body abrasive wear.

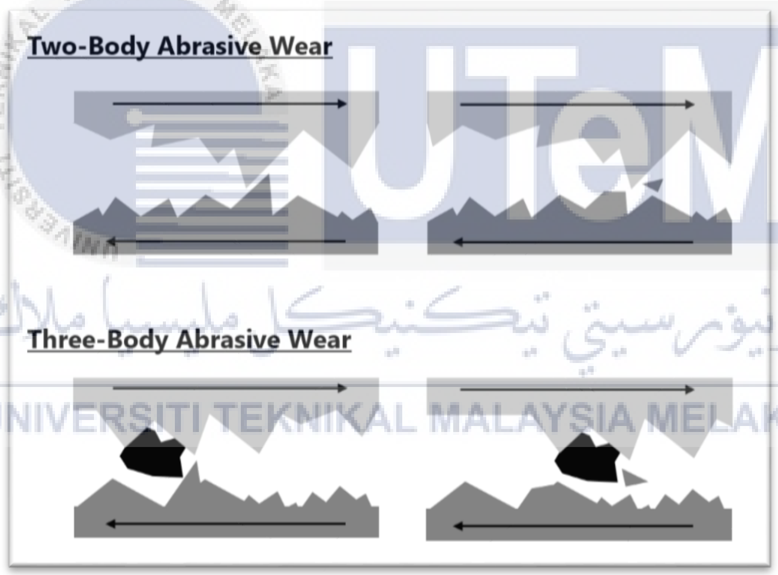

Figure 2.5: Two-body and three body abrasive wear (Sundus et al., 2017).

The volume loss in abrasive wear can predicted. Under an applied load of P is inversely proportional to the hardness (H) of the surface abraded. As the sliding of the two surfaces occurs, the particle cut the surface and producing a trench. If the sliding distance, L, the wear volume (V) can be expressed as:

$$V = k \cdot \frac{PL}{H} \tag{2.2}$$

Where k is wear coefficient of reflecting influences of geometries and properties of the particles involved. However, the volume of the wear loss can be reduced by decreasing the contact load, reducing the sliding distance, and reducing the value of k by encountering the surface roughness and disposing of the presence of hard particles on the surface. On the other hand, adhesive wear is another type of wear that usually occurs. Abrasive wear occurs due to localized bonding between contacting solid surfaces leading to material transfer between two surfaces or loss from either surface (Arnell, 2010). When a two surface undergoes continuous motion, losses of the material or inside the original materials depending on which surface is weaker. The material loss wore minimal if the strength of the adhesion junction is relatively low. If the tearing occurs inside of a softer material, the soft material dragged away and adhering to the harder surface, and this process known as a material transfer.

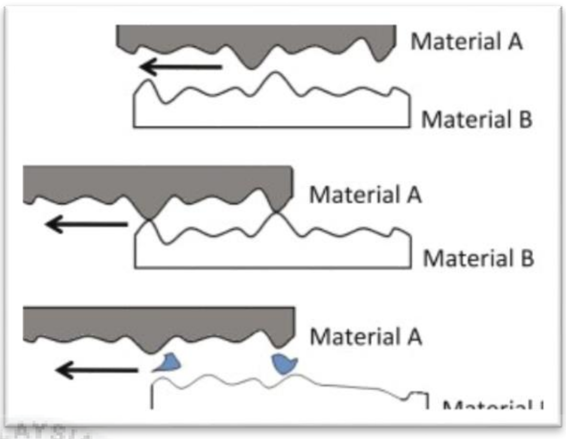

Figure 2.6: Adhesive wear (Sundus et al., 2017).

Adhesive wear is dominated by the material transfer and the removal of the transferred material. The adhesive wear rate, W can be predicted by using the following equation

$$\boldsymbol{W = K\,\frac{P}{H}} \tag{2.3}$$

Where P is the applied normal load, K is wear rate coefficient and H is the hardness of the soft material. Adhesive wear resistance can be better by improving the hardness and strength of the contacting material and select a proper material or changing the chemical nature of the surfaces of the materials.

Surveys such as that conducted by Fazal (2013) have investigated the wear and friction of palm oil biodiesel by using a four-ball machine using ASTM D4712 standard and speed of 600 rpm to 1500 rpm instead of using 1200rpm (Fazal, Haseeb, & Masjuki, 2013b). The results obtained show that increasing the rotating speed of rotation affects wear and friction. A higher concentration of biodiesel gives a good impact where it has a consistent reduction of wear at almost 20% lower than that of diesel at 1500 rpm. The lubricity in terms of wear and friction decreases with high speed at above 20% biodiesel concentration (Mosarof et al., 2015).

2.4.1.4 Wear Scar Diameter.

Wear scar diameter is the most critical factor in lubrication performance (Mosarof et al., 2016). Wear means losses of materials from contacting surfaces between two or more objects in a relative motion while wear scar diameter expressed as the mean of the two axes given in microns. Wear and wear scar diameter is highly relatable. Researchers attempted to evaluate the impact of wear scar diameter and rotating speed. The relationship between wear scar diameter and rotating speed is the higher the speed of the rotating speed of the machine, the wear scar diameter increase too (Fazal et al., 2013b). Lubricant oil plays a bigger involve of a role in reducing wear (Golshokouh, Ani, & Syahrullail, 2012). Pure biodiesel oil blends or higher biodiesel blends caused less wear compared to the lower biodiesel blends. The effects of this impact are because of pure biodiesel blends, or higher biodiesel blends have a more stable film to separate the adjacent surfaces and limit to metal contact. The reduction of wear is like seemed to observed on range from 10-20% concentration of biodiesel blends (Fazal et al., 2013a)

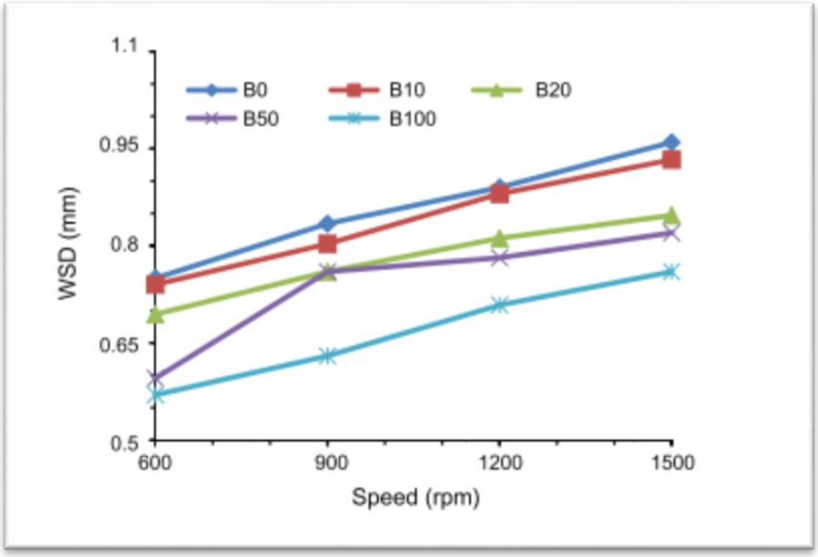

Figure 2.7: Effect of speed on wear scar diameter (WSD) in different fuels under a fixed load of 40 kg at temperature of 75°C for 1h (Fazal et al., 2013a).

2.4.2 Lubricant Properties.

2.4.2.1 Viscosity.

Viscosity is one of the essential fuel properties of biodiesel and conventional diesel (Knothe & Steidley, 2005). Viscosity means that resistance or internal friction of a substance to flow in a system (Ramírez-Verduzco, García-Flores, Rodríguez-Rodríguez, & Del Rayo Jaramillo-Jacob, 2011), and it also affects the wear rate of the sliding surface. Viscosity can be measured by using the formula shown below.

$$Viscosity = \frac{Shear\ stress}{Shear\ rate} \tag{2.4}$$

As the temperature of the substance or biodiesel oil is increasing, the viscosity decrease and creating a significantly perfect flow of the substance (Ramírez-Verduzco et al., 2011). Other than that, it also produces less friction in the fuel injector system, which can affect fuel consumption to be more efficiency and increasing the life-time of the system or an engine. One of the reasons to decrease the oil viscosity in an engine for lubricant is to decrease the oil film thickness. If the viscosity of the lubricant is high, it gives a high impact of the fuel injector causes poor fuel atomization during spray and also giving high carbon deposition on the fuel filter (Tesfa, Mishra, Gu, & Powles, 2010). Other than that, it also requires more energy consumption from the fuel pump, and it leads to the low net power output from the engine (Das, Sarkar, Datta, & Santra, 2018) which affects the main parameters, engine performance and exhaust emission (Tesfa et al., 2010). There are some methods to enhance the viscosity and density of the biodiesel that is used for lubricants by preheating the biodiesel or mixing the diesel with biodiesel (Tesfa et al., 2010).

The most critical parameter that requires biodiesel and petro diesel standards is kinematic viscosity at 40°C (Knothe & Steidley, 2005). The commonly used standards for determining the density and kinematic viscosity are ASTM D-941 and D-455 methods

(Ramírez-Verduzco et al., 2011). The information on density was associated by a linear formula, while the polynomial second order reflected the cinematic viscosity in the biodiesel concentration (Ramírez-Verduzco et al., 2011)

Table 2.4: Standards diesel fuel for kinematic viscosity (Knothe & Steidley, 2005).

Standard	Location	Fuel	Method	Kinematic Viscosity (mm2/s)
ASTM D975	United States	Petrodiesel	ASTM D445	1.0-4.1
ASTM D6751	United States	Biodiesel	ASTM D445	1.9-60
EN 590	Europe	Petrodiesel	ISO 3104	2.0-4.5
EN 14214	Europe	Biodiesel	ISO 3104	3.5-5.0

Under the guidelines of ASTM standards, the biodiesel oil has a cinematographic viscosity of approximately 1.9 mm^2/s up to 6 mm^2/s. It ranges from 3.5 mm^2/s to mm^2/s according to the EN standards. Next, this varies between 2.5 mm^2/s and 6 mm^2/s according to Indians specifications (D. Singh, Sharma, Soni, Sharma, & Kumari, 2019).

Table 2.5: Kinematic viscosity properties of biodiesel tested (El-Araby et al., 2018).

Types of biodiesel	Kinematic viscosity properties of biodiesel used.
B0 (Petron)	Viscosity at 40°C : 2.5 mm^2/s
B5 (Euro 5)	Viscosity at 40°C : 3.100 mm^2/s
B10	Viscosity at 40°C : 2.49 mm^2/s
B30	Viscosity at 40°C : 2.85 mm^2/s

2.4.2.2 Flashpoint.

Flashpoint means that the fuel catches fire when in contact with fire sources such as spark or fire at the lowest temperature of that diesel or biodiesel involved (D. Singh et al., 2019). Flashpoint plays an important characteristic that must take in terms of handling, transportation, storage, and product use (Aleme & Barbeira, 2012). Hence, higher flashpoint temperature gives safer conditions for transportation or storage within the duration. Usually, a flashpoint of biodiesel is much higher compared to conventional petroleum diesel, thus making it much safer and less volatile for transportation and storage purposes (Sundus et al., 2017). The flashpoint temperature for biodiesel is more than 150°. The usually used standard for determining flash point temperature is ASTM D3828 and EN ISO 3697 (Aleme & Barbeira, 2012; Mohd Noor, Noor, & Mamat, 2018). For standard ASTM D3828, the test is carried out by pouring a sample diesel into a closed cup until it gets to a specific temperature test, and then the diesel sample is exposed into a source of fire such as spark or flame and is detected by a quick flash (Aleme & Barbeira, 2012).

Table 2.6: Properties flashpoint temperature of biodiesel and diesel used for this research

(El-Araby et al., 2018).,

Types of biodiesel used.	Flashpoint properties of biodiesel used.
B0 (Diesel Max)	Flashpoint : 40°C
B5 (Euro 5)	Flashpoint : 68°C
B10	Flashpoint : 69°C
B30	Flashpoint : 82°C

2.5 Conclusion.

Based on the literature review that has done, many researchers have researched biodiesel and characteristic of biodiesel from all around the globe. By referring to the previous research, it may be used for my research as a reference and a benchmark to get a stable result. Moreover, the literature review providing a piece of proper knowledge and basic idea to run my research. All of the main properties tested play essential roles for the engine, such as is friction, friction coefficient, wear, wear scar diameter, viscosity, kinematic viscosity, and flashpoint. The properties conducted using the ASTM or EU standard procedure to consider safe to use commercially. In simpler terms, literature review helping and providing lots of knowledge on how to conduct this research for further use.

CHAPTER 3

METHODOLOGY

3.1 Introduction.

In this chapter, the overall setup for the research discussed further. Determination of friction and wear properties using a four-ball tribometer according to ASTM standard, viscosity index using viscometer according to ASTM standard, and flashpoint temperature using flashpoint meter discussed through this chapter. The palm oil biodiesel used in this research is B0, B5, B10, and B30. All of the test conducted during this research is according to ASTM Standard and involve three main biodiesel properties which are friction and wear, viscosity index, and flash-point temperature.

The flowchart below will provides the idea and overall view of this research methodology. This methodology uses to complete the objective of the research.

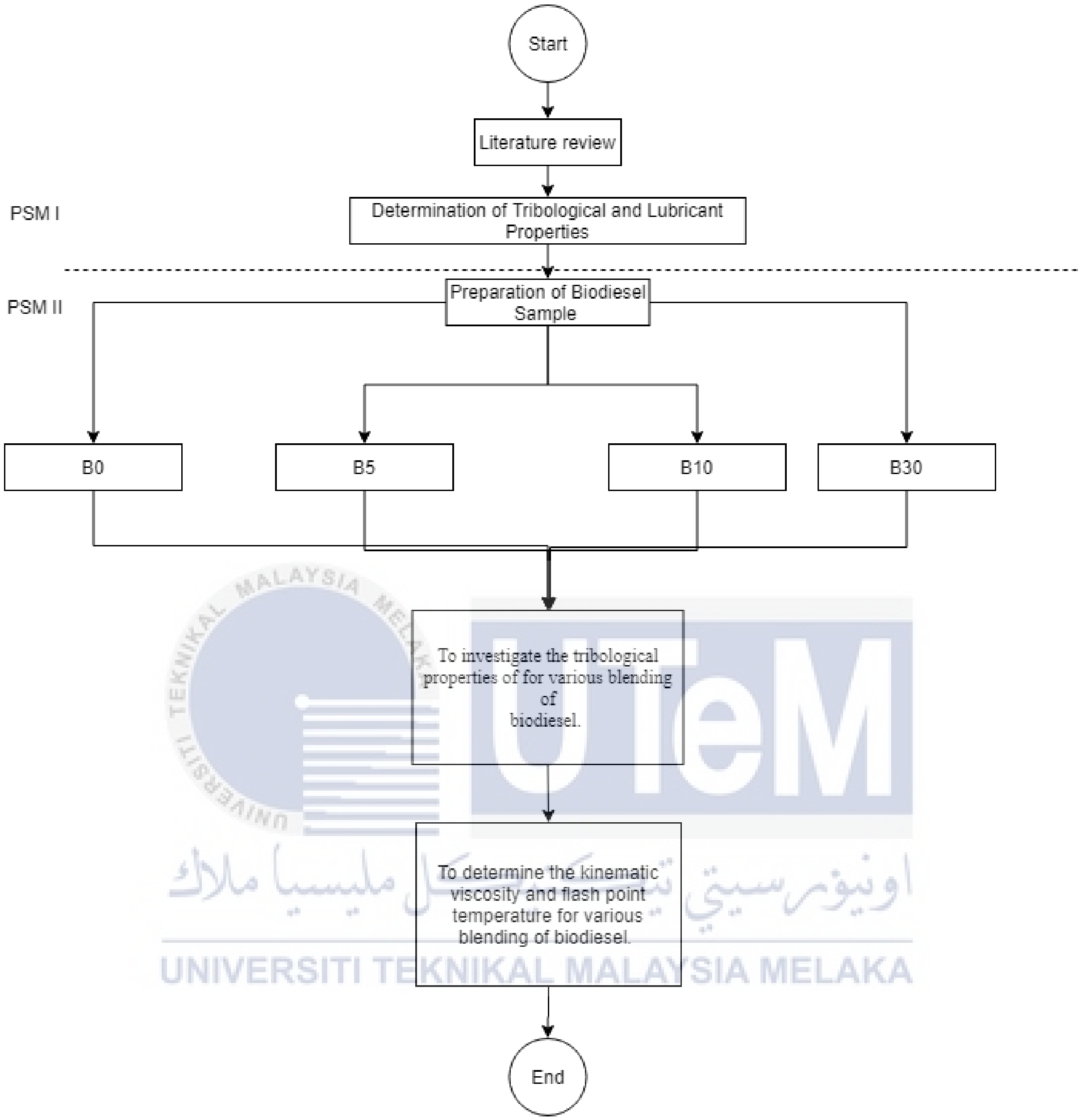

Figure 3.1: Flowchart of experimental analysis for palm oil biodiesel.

3.2 Types of biodiesel used for this research.

Figure 3.2: B0 diesel.

Figure 3.3: B5 biodiesel.

Figure 3.4: B10 palm oil biodiesel.

Figure 3.5 : B30 palm oil biodiesel

In this research, five types of biodiesel used to run this research. Two of the biodiesel is commercially available biodiesel in the market, which is B0 (Diesel Max) and B5 (Euro 5), and the three biodiesel remaining obtained from the Malaysian Palm Oil Board (MPOB) which is B10, B20, and B30. The figure below shows the biodiesel used for this research.

3.3 Biodiesel Properties Test Method.

This research is testing all of the properties using a regulated standard test that been set by the American Society for Testing and Materials (ASTM). All of the properties from this research are referring from ASTM D6751. The standard ASTM D6751 guide and show test method that aligns with its standard for each of properties

3.3.1 Friction and wear.

The friction and wear properties tested by using ASTM 4712 standard as a guideline. Friction and wear properties tested using the Four-Ball Machine tester. The standard used to test this friction and wear of biodiesel is ASTM 4712-B. Stainless steel balls used for this research test. Firstly, four balls must properly wash with toluene and wiped with a dry tissue to dry these balls. One ball is rotating on top of the three stationary balls. To run this research, at least 10 mL of tested oil was poured into the steep cup until the three stationary balls covered with oil in depth of 3mm. The four-ball wear machine connected to a computer and Winducom 2008 software is was used to record the frictional torque of tested biodiesel for this research. The ASTM 4712-B with 40kg loads and a temperature of 75 °C used for this research. Frictional torque measured by a calibrated spring attached to the friction measuring device. Last but not least, the coefficient of friction for tested biodiesel is using the eqn 3.1.

$$T = \frac{\mu \times 3W \ \times r}{\sqrt{6}} \tag{3.1}$$

Where T is the frictional torque in Nm (kg/mm), W is the applied load in (kg), r is the distance from the center of the contact surface on the lower balls to the axis of rotation (which is 3.67mm) and μ is the coefficient of friction.

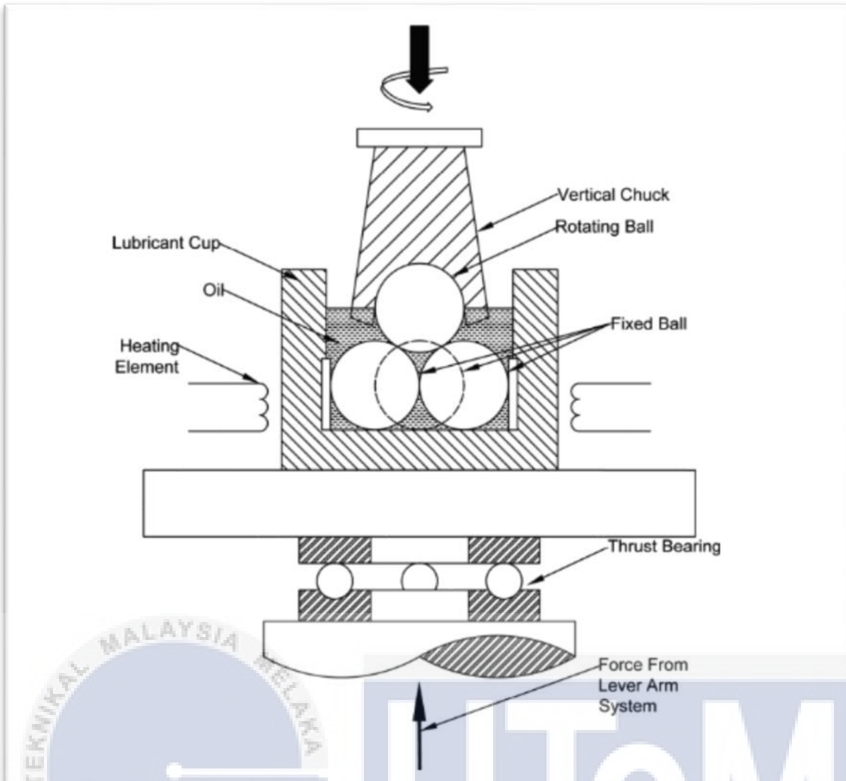

Figure 3.6: Schematic diagram of four ball tester (P. Singh, Varun, & Chauhan, 2017).

Fixed parameters used for this research:

Table 3.1: List of fixed parameters according to ASTM standard.

Parameters	Value of Parameter
Load	40kg
Duration	3600s (1hour)
Temperature	±72°C
Speed	1200±60 rpm

3.3.2 Kinematic viscosity.

The method used to determine the kinematic viscosity in this research is by using HK-1005A Kinematical Viscosity (Ubbelohde) and HK-265A Kinematic Viscosity Apparatus. This apparatus used to test the kinematic viscosity of biodiesel that used for this research, both transparent and opaque, by measuring the time for a volume of liquid to flow under gravity through a calibrated glass capillary viscometer. This research will be held according to the ASTM D445 standard. The initial temperature of the HK-1005A Kinematical Viscosity apparatus rises at a temperature of 40°C. The range of temperature for this apparatus can be heated up to 100°C. Results obtained from this research must be up to four or five significant figures to get accuracy which means it gives an accurate reading and reliable results. The figure below shows the HK-1005 Kinematical Viscosity.

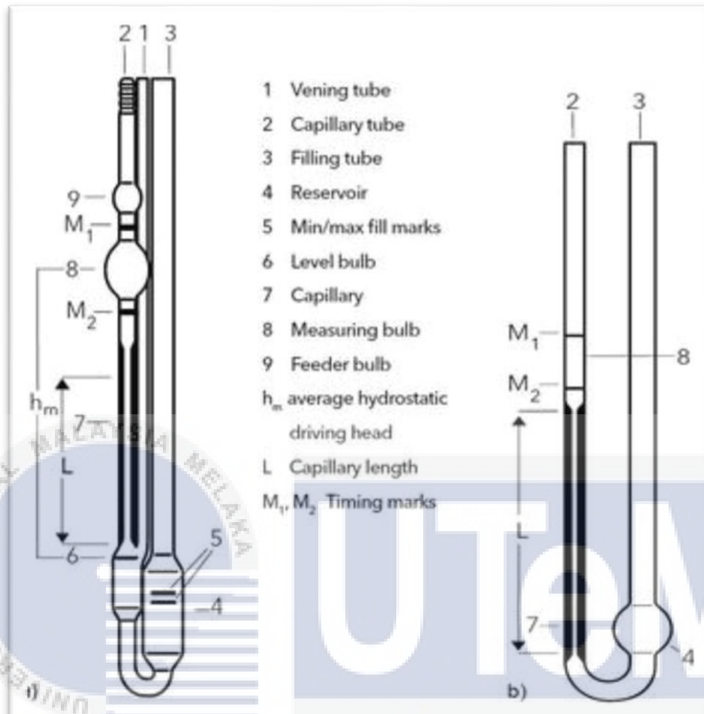

Figure 3.7: HK-1005A Kinematical Viscosity (Ubbelohde).

3.3.3 Flash point temperature.

The flashpoint tested by using ASTM D3828 as a guideline. Determination of flashpoint tested by using Setaflash Series 3 flash point tester (Closed Cup – 33000-0) with the ASTM D3828 standard. These apparatus measure the flashpoint of tested biodiesel at the point where the lowest temperature at which the application of ignition source causes the starting point of biodiesel to ignite. Setaflash Series 3 flash point tester (Closed Cup – 33000-0) was able to measure flash point temperature from range 0°C up to 300°C. This apparatus displays the show test parameters, instrument status, and the test of results. Other than that, this apparatus heated at a rate of 2°C per minute from the starting temperature. The total volume of biodiesel that inserted into the closed cup is 2mL. Before this research start, set the expected flashpoint temperature. When it reaches the expected temperature, pull back flame lever to test whether the expected temperature makes the biodiesel flash or not. This machine shows whether "FLASH" if the flashpoint temperature achieved or not showing nothing on the screen display. The results of the test are taken and analyzed by comparing it to the theoretical value of the flashpoint temperature of the biodiesel used.

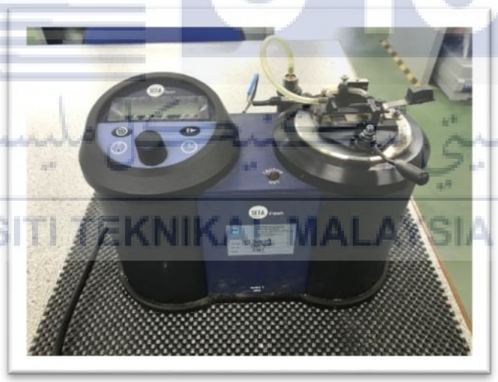

Figure 3.8: Setaflash Series 3 flash point tester (Closed Cup – 33000-0).

3.3.4 Wear scar diameter observation.

Magnified image of the ball specimen after completion of finding the coefficient of friction by using a four-ball tester machine obtained by using a 3D non-contact profilometer. This machine able to focus on wear track and produce a 3D profile of the magnified image. For this research, 3D non-contact profilometer used to obtained wear scar diameter.

Figure 3.9: 3D non-contact profilometer.

CHAPTER 4

RESULT AND DISCUSSION

4.0 Overview.

In this particular chapter, the result of this research will be shown and discussed further. The main properties that been tested are friction coefficient, wear rate, kinematic viscosity, and flashpoint temperature of each biodiesel. All of the testing properties are under control and in line with the standard of ASTM biodiesel. Equipment that is used for this research is according to the standard operating procedure of each property. Based on the results obtained from this research, it will be analyzed and discussed afterward. At the end of the chapter, each of the biodiesel tested will be determined. The sample has the best characteristic for lubrication performance based on the ASTM standard test guidelines.

4.1 Flashpoint Results.

The flashpoint temperature for conventional biodiesel and palm oil biodiesel obtained from this research may be seen from the bar graph above. By referring to Figure 4.1, it clearly stated that palm oil biodiesel, B30 have the highest value of flashpoint temperature, 83°C and conventional diesel, B0 have the lowest flashpoint temperature, 43°C. For conventional biodiesel, B5 and palm oil biodiesel, B10 clearly shows that the value for flashpoint temperature is 70°C and 76.5°C, giving their range in between 70°C to 80°C. From the overall trend of the bar graph shown above, it clearly shows that trend of the flashpoint temperature starting from B0, B5, B10, and B30 having an increasing trend.

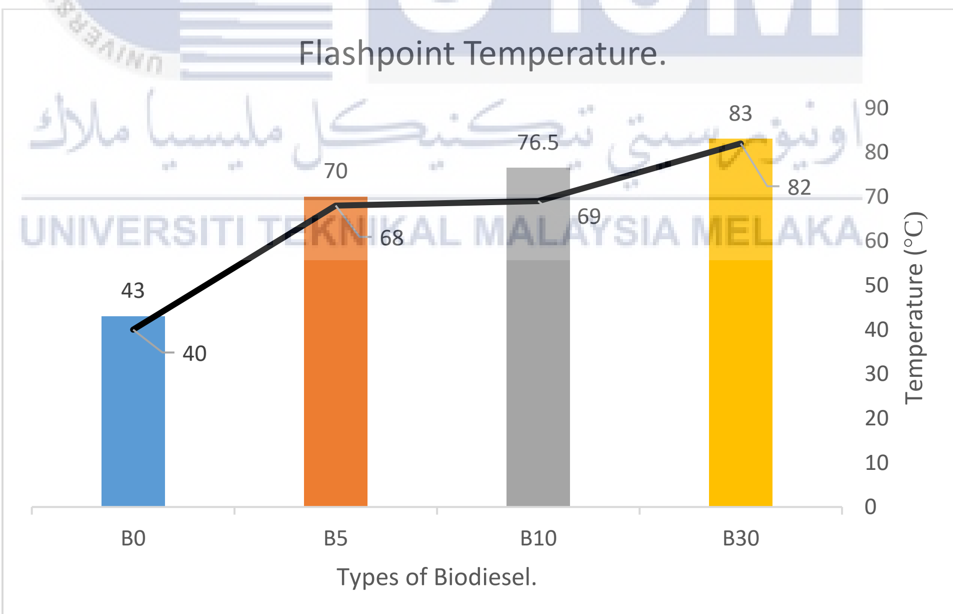

Figure 4.1: Flashpoint temperature bar graph.

4.1.1 Discussion of Flashpoint Temperature Results.

By referring to Figure 4.1, the overall trends for biodiesel B0, B5, B10, and B30 is linearly increased from 43°C to 83°C. The increment of biodiesel blends from 5% to 30%, resulting an adequate biodiesel quality for the flash temperature. The initial results for B0 diesel are 43°C, and the theory for B0 diesel flashpoint temperature is 40°C, the resulting difference between these two results is three value. Next, the B5 biodiesel flashpoint temperature is 70°C, and the theoretical results for B5 biodiesel are 68°C, resulting in differentiation for two costs in between for theory and research. And then, followed up by B10 palm oil biodiesel resulting in the research value for 76.5°C, and the theoretical value for B10 palm oil biodiesel is 69°C resulting in the difference is 7.5°C. Finally, the results obtained for B30 palm oil biodiesel 83°C and the theoretical value are 82°C resulting in the difference between theory and research value of 1°C. Based on this research, every biodiesel blends have a gap between theoretical value and research value, and the most difference based on four biodiesel blends. B10 palm oil biodiesel has the highest difference, which is 7.5°C.

The main reason this problem happens and causing a massive difference in theoretical and research value is the oxidation of biodiesel while storage or contains the biodiesel. Assuming that the B10 biodiesel blends do not contain properly will affect the properties of the biodiesel. Therefore, B30 biodiesel blends have the most stable flashpoint temperature, while B0 has the lowest point of flashpoint temperature.

4.2 Kinematics Viscosity Results.

Referring to Figure 4.2, it shows that the value of kinematic viscosity for conventional biodiesel, B0, and palm oil biodiesel, B10 have a slightly similar amount, which gives a difference of both kinematic viscosity is 0.03 mm^2/s. However, the value of kinematic viscosity for conventional biodiesel, B5, has the highest value, which is 3.13 mm^2/s compared with the higher number of biodiesel blends, from palm oil biodiesel, B30 contained only 2.87 mm^2/s. The difference between these two results gives a different value of 0.26 mm^2/s.

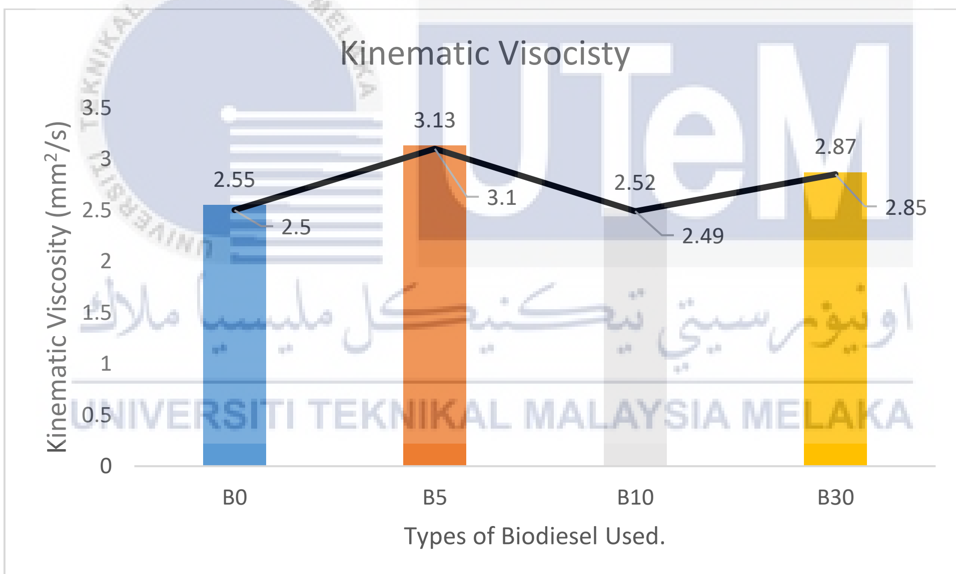

Figure 4.2: Results for Kinematic Viscosity of Each Biodiesel Tested.

4.2.1 Discussion of Kinematics Viscosity Results

Based on the kinematic viscosity results shown in Figure 4.2, the kinematic viscosity value obtained from this research is tally with ASTM D6751 ranging from 1.9 up to 6.0 mm^2/s (Fazal et al., 2013a). By referring to Figure 4.2, the value kinematic viscosity for B0 and B10 is 2.55 mm^2/s, and 2.52 mm^2/s respectively, and giving the difference value between both biodiesels is 0.03 mm^2/s. For biodiesel B30, kinematic viscosity cost is 2.87 mm^2/s, while biodiesel B5 has 3.13 mm^2/s value of kinematic viscosity. The trends for the biodiesel blends from B0 to B30 are stable due to the cost of kinematic viscosity taken near the others except for B5 biodiesel. By referring to Figure 4.7, the relationship between kinematic viscosity and the coefficient of friction is relatively high. From the examination of the average ratio of resistance and kinematic viscosity results, the lowest quality of the biodiesel properties is Palm Oil Biodiesel B10, which had 2.52 mm^2/s and 0.20 coefficient of friction. Next, Diesel Max B0 with 2.55 mm^2/s with 0.06 ratio and resistance. Followed up with Palm Oil Biodiesel B30 with 2.87 mm^2/s and 0.10 coefficient of friction. The top quality of biodiesel blends is going with Biodiesel Euro Max 5, B5 with 3.13 mm^2/s, and 0.12 coefficient of friction. The relationship between the kinematic viscosity and coefficient of friction,; if the kinematic viscosity has the lowest value, the coefficient of friction has a high value. In conclusion, there is no significant effect on the mixture of all biodiesel that has been tested.

4.3 Wear Scar Diameter Results.

The results of wear scar diameter for each biodiesel tested may refer to Figure 4.3. The overall trend line of wear rate shows a decrease as the biodiesel increase. Based on the figure shown below conventional biodiesel, B0 has the highest wear scar diameter, which is 1629.83 µm. Then, followed by palm oil biodiesel, B10 has the second-highest value, which is 1436.86 µm. Next, conventional biodiesel, B5, has a low cost of wear scar diameter value of 567 µm. Based on previous results, the value of the results decrease in a significant amount of value from 1629.83 µm, and 1461.86 µm. Resulting in the difference between the two values with B5 is more than 600 µm. Lastly, the lowest cost for wear scar diameter contained by palm oil biodiesel, B30, resulted in 514 µm. It shows the difference between B5 and B30 is 53 µm.

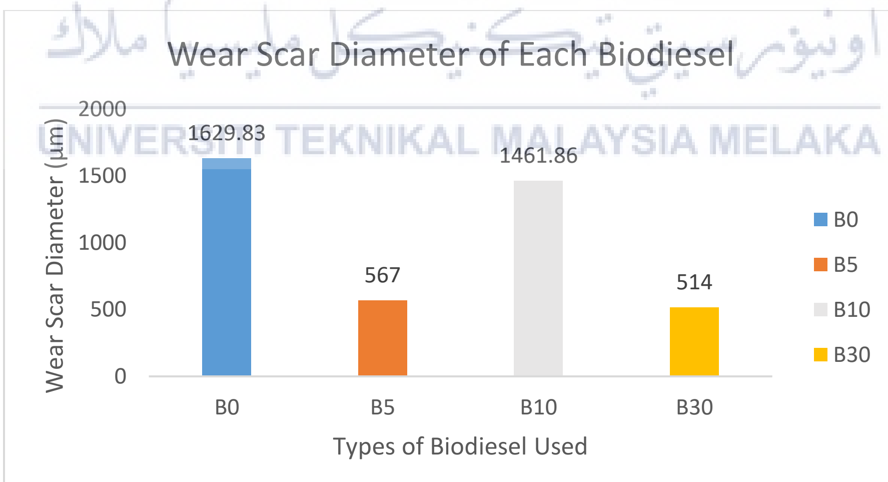

Figure 4.3: Wear Scar Diameter Result for Each Biodiesel Tested.

4.3.1 Discussion of Wear Scar Diameter Results.

Based on the results of Figure 4.3, it clearly shows that the conventional diesel, B0 have the highest value of wear scar diameter, which is 1629.83 μm due to the pure diesel state and followed by palm oil biodiesel B10 resulting in the importance of wear scar diameter to 1461.86 μm. By referring to Figure 4.2, kinematic viscosity, the cost for B0 and B10 is 2.55 and 2.52, respectively. Moreover, there is some evidence that high results of kinematic viscosity have a considerable impact on fuel injector spray and damage the internal parts of the engine due to high viscosity (Tesfa et al., 2010). Next, the value of wear scar diameter for biodiesel, B5, and B30 has a minimal difference, which is 53μm due to the high kinematic viscosity by 3.13 mm2/s and 2.87 mm2/s respectively. By referring to figure 4.4, wear scar observation for B5, and B30 biodiesel, have a similar pattern, but the surface wears scar of B30 biodiesel has much a lower gaps compared to the B5 biodiesel. A high value of kinematic viscosity will give a good advantage to the fuel injector and long-life term for the engine to operate without having any casualty (Tesfa et al., 2010). In that case of reduced wear, scar observation may see-through by referring figure 4.4; a lower kinematic viscosity may cause a massive failure on certain parts on engines due to high internal frictional forces.

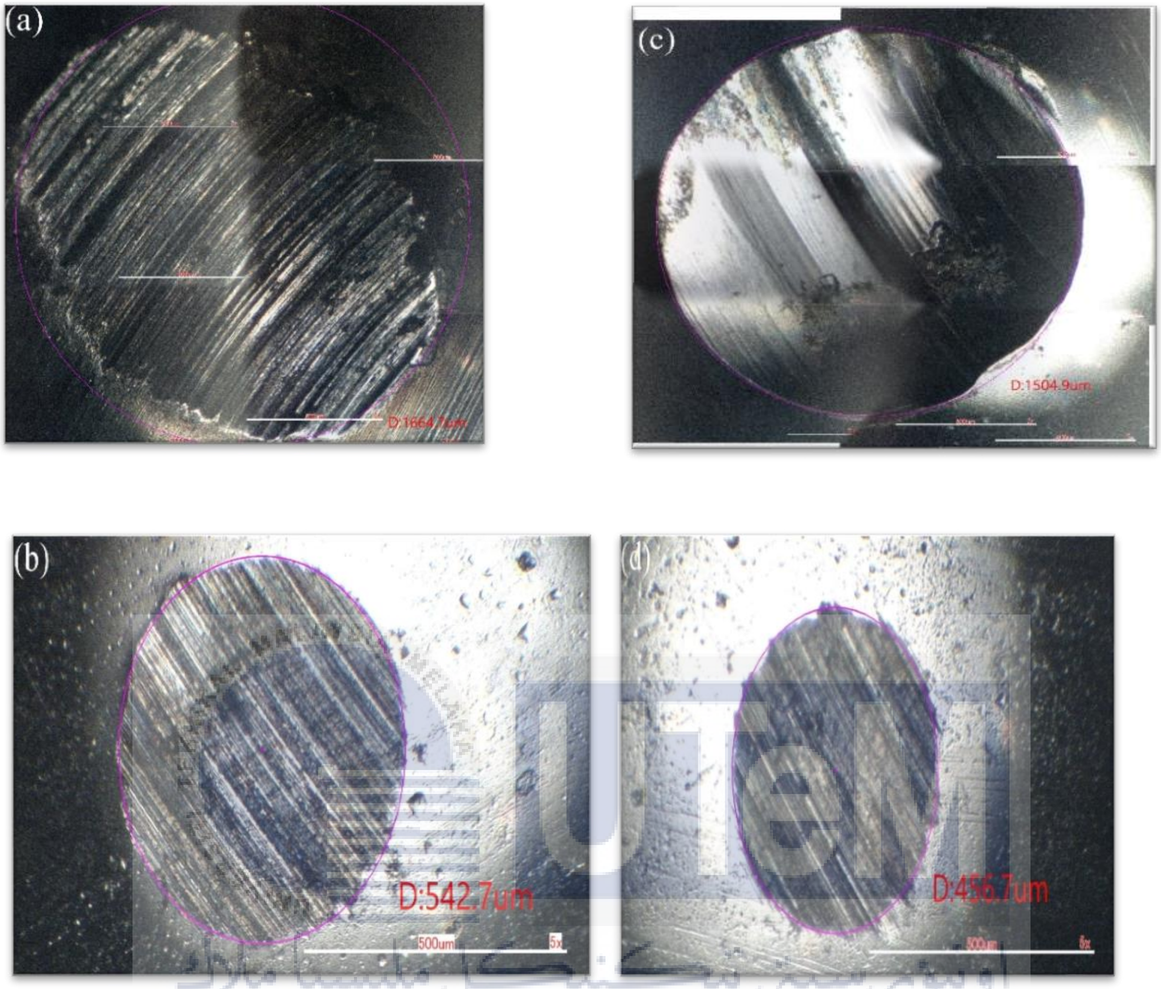

Figure 4.4 Wear Scar Diameter Results for Each Biodiesel Tested. (a) B0. (b). B5 (c). B10 (d). B30

4.4 Coefficient of Friction Results.

4.4.1 Comparison of Coefficient of Friction of each biodiesel against Sliding Time.

The coefficient friction of biodiesel tested in this research is obtained and shown in the figure above. Referring to Figure 4.5 it shows the palm oil biodiesel, B10 having an increment of the unstable coefficient of friction graph. At the end of this research, conventional biodiesel, B10 still has the highest value of the coefficient of friction compared to the others. The trend of traditional biodiesel, B5, and palm oil biodiesel, B30, has a similar trend line but different in the value of the friction coefficient. The initial reading of conventional diesel, B0 having an unstable ratio of friction value until in the middle research, there is a slight downtrend of the coefficient of friction and stable until the experiment ends.

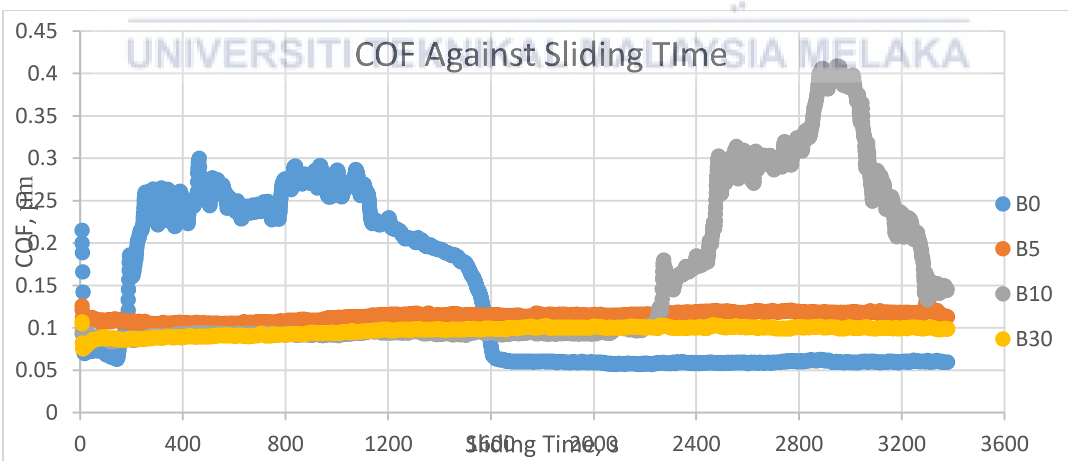

Figure 4.5: Coefficient of Friction against Sliding Time.

4.4.2 Run-in Period of each biodiesel against Sliding Time.

The Run-in period starts from the beginning of the machine until a specified time for the biodiesel to have a stable coefficient of friction reading. By referring to Figure 4.6, it clearly stated that the run-in period time is between from 0s to 20s. Palm oil biodiesel, B30 have a low time in a high coefficient of friction, estimated under 5s to drop for value at a stable ratio of resistance compared with conventional biodiesel, B0 have more than 5s, below 10s to reach a stable coefficient of friction. For palm oil biodiesel, B10 has a minimal value of the ratio of resistance in a short period. Lastly, the conventional biodiesel, B5, also has a short period for the biodiesel to reach a stable coefficient of friction. Overall, palm oil biodiesel, B10 have the minimum value of the ratio of resistance in a short term period.

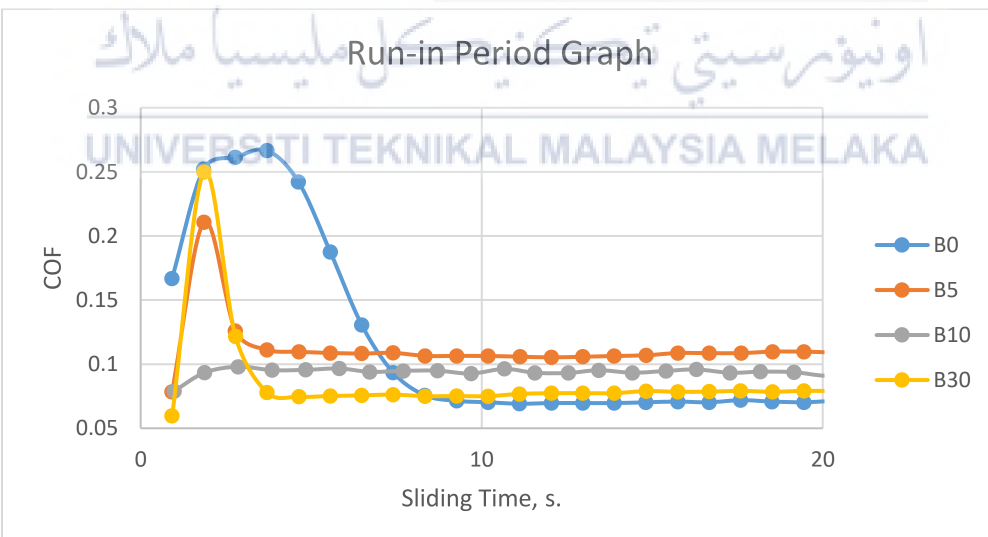

Figure 4.6: Run-in Period Graph.

4.4.3 Steady State Period of each biodiesel against Sliding Time.

The steady-state condition means that the process of a variable does not change in value or has a stable profit with increasing time. Based on the graph shown above, the amount of coefficient of friction for conventional biodiesel, B0, and B0, and palm oil biodiesel, B30, have a stable value of the coefficient of friction. But for palm oil biodiesel, B10 has a drastically increased with time compared with three biodiesel tested in this research.

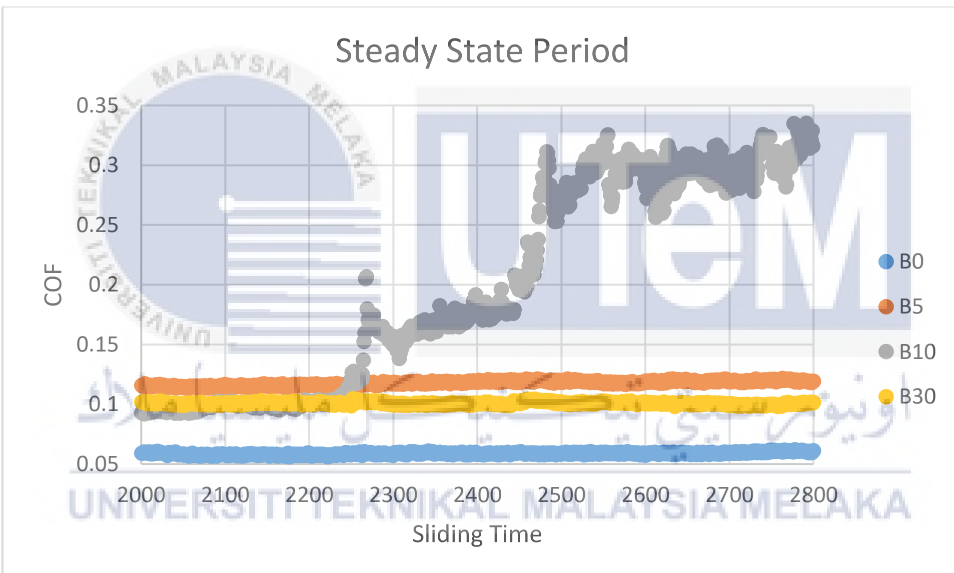

Figure 4.7: Steady State Condition.

4.4.4 Average Coefficient of Friction of each biodiesel against sliding time.

The average coefficient friction of biodiesel tested in this research taken from the steady-state period starting from the 2000s to the 2800s. By referring to Figure 4.8, it clearly stated that the average coefficient of friction for conventional biodiesel, B0 is 0.06. Afterward, followed by traditional biodiesel, the B5 value is 0.12. The increasing cost is 0.6 based on previous. Next, the palm oil biodiesel, B10, the average amount of the coefficient of friction is 0.2. Lastly, the value of the average ratio of friction for palm oil biodiesel, B30, is 0.1.

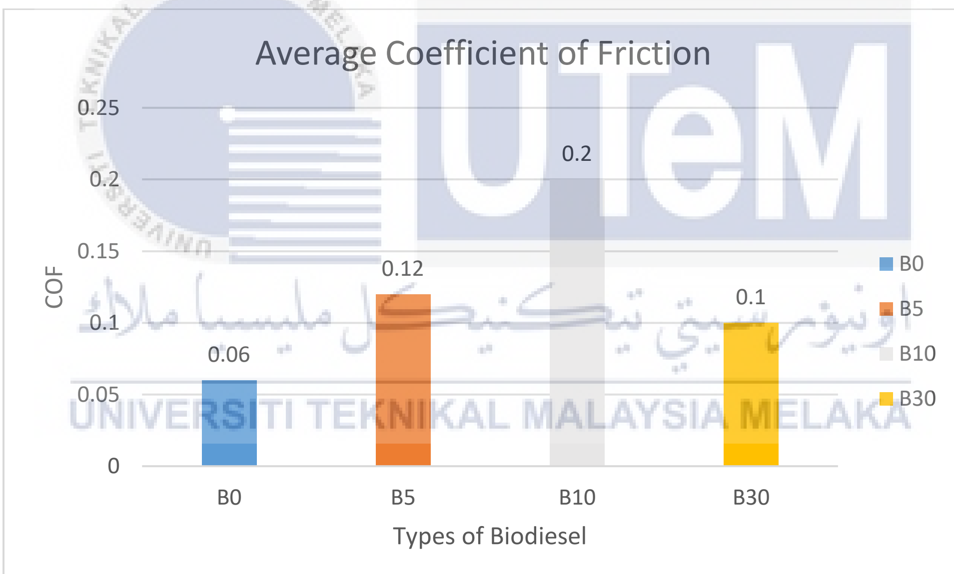

Figure 4.8: Average Coefficient of Friction bar Graph.

4.4.5 Discussion of Coefficient of Friction Results.

Based on the results of the run-in period graph obtained, by referring to Figure 4.6, the coefficient of friction at the initial stage of research is high until up to 0.25. At this initial stage of research, this machine has a high pitch sound frequency due to the high friction of biodiesel blends. After several seconds of running, the friction coefficient has dropped to their optimal value ranging from 0.14 to 0.05.

After several hours of research have been conducted, the friction coefficient goes into a phase of the steady-state period. At a certain period, the reading value of the friction coefficient became stable for each biodiesel blends except for B10 palm oil biodiesel. By referring to Figure 4.7, the reading for the coefficient of friction from the 2000s to the 2800s does not have a steady text for friction coefficient. On the contrary, the ratio of resistance for B0, B5, and B30 biodiesel have stable state reading of coefficient of friction starting from the 2000s to 2800s compared to B10 palm oil biodiesel. One of the reasons that B10 palm oil biodiesel has a high ratio of friction is due to oxidizes of biodiesel during the storage that affects the coefficient of friction of the palm oil biodiesel.

Next, in the steady-state period, the value of the average coefficient of friction for each biodiesel tested can be determined. By referring to Figure 4.8, it clearly shows that B0 diesel has the highest value of the coefficient of friction, 0.2. Compared with the others, the amount of coefficient friction for B0, B5, and B30 having a low-value coefficient of friction, which is 0.06, 0.12, and 0.1, respectively. Comparing the biodiesel B0 and B30, the amount of coefficient of friction respectively 0.06 and 0.1, resulting in the ratio of resistance for B0, is the most stable reading of coefficient of friction, will have a low impact on the engine wear because of low coefficient of friction. On the other hand, biodiesel B30 have more biodiesel blends compared with B0, resulting in B30 is the most stable coefficient of friction value due to its stability and biodiesel blends in diesel.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion.

In this research, the results of tribological properties for the various blending of biodiesel, wear scar diameter results, coefficient of friction have obtained to meet the requirement of objectives. The biodiesel blends obtained from Petron Gangsa Mas, and palm oil biodiesel, derived from the Malaysian Palm Oil Board (MPOB). Sample of conventional diesel, B0, and B5, and palm oil biodiesel, B10, and B30, is conducted based under the guidelines of biodiesel testing, ASTM D4712.

The following lubricant properties, kinematic viscosity, and flashpoint temperature of biodiesel various blending conducted at Tribology Lab, Universiti Teknikal Malaysia Melaka, UTeM. The data and results recorded have been achieved the acceptable range as discussed in Chapter 4 by using the ASTM D445 standard for kinematic viscosity, and ASTM D3828 standard for flashpoint temperature.

5.2 Recommendations for Future Work.

Future work of the area investigating the tribological and lubrication properties of conventional diesel and palm oil biodiesel is as follows:

1) Biodiesel samples should have more than four samples to obtain better results in determining the tribological and lubricant properties.

2) Biodiesel sample is added with strong or neutral additive to obtain much precise data due to a solid biodiesel has an inaccuracy in data reading.

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APPENDIX A

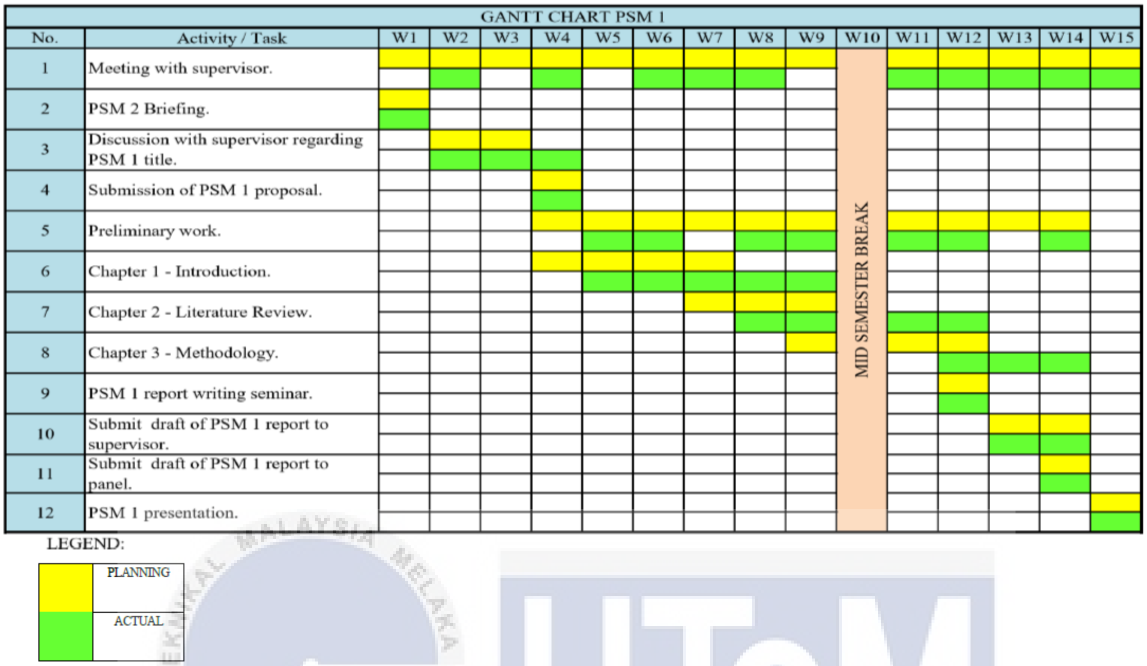

Figure A1: Gantt chart.

APPENDIX B

B30 Palm Oil Biodiesel Sample Data

Time (s)	Normal Load (N)	Friction Torque
0.922	395.4	0.106
1.86	396.07	0.445
2.782	397.05	0.217
3.703	396.39	0.139
4.641	396.49	0.133
5.563	396.81	0.134
6.485	396.76	0.135
7.407	396.84	0.136
8.344	397.06	0.134
9.266	396.97	0.134
10.188	397.07	0.134
11.11	396.89	0.137
12.047	396.8	0.138
12.969	396.8	0.138
13.891	396.75	0.138
14.828	396.95	0.141
15.75	397.13	0.14
16.672	396.24	0.14
17.594	396.51	0.141
18.532	396.73	0.14
19.453	396.21	0.141
20.375	396.69	0.141
21.313	396.45	0.141
22.235	396.48	0.141
23.157	396.91	0.14
24.078	396.79	0.141
25.016	396.9	0.142
25.938	396.65	0.146
26.86	396.82	0.143
27.797	396.93	0.146
28.719	396.02	0.146
29.641	396.7	0.147
30.563	396.74	0.147