COMPARATIVE STUDY OF THE WEAR CHARACTERISTIC OF RUBBER SEED OIL AND JATROPHA OIL AGAINTS VARIOUS BIO-LUBRICANT OIL

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SUPERVISOR'S DECLARATION

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

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I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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Dedicated to my parents and my siblings for their eternal love, guidance and support on the journey of my life.

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ABSTRACT

In this modern days, vegetable oils has been known for their many uses. They can be used in cooking, medicine and even automotives. Because of their potetntial, vegetable oil has been the main focus of many researchers and to fully unlock the potential of vegetable oil usage around the world. The reasons for considering plant oils as a viable option for the substitution of petroleum-based oils that have minimal supplies are biodegradability, viable graft properties and low production costs. As an alternative lubricant source, the plant oils are very attractive. Therefore the aim of this work is to compare and analyse the the tribology properties of this vegetable oils. This study is also conducted to know which vegetable oil has the highest potential in being a substitute for mineral oil. This analysis also done due to the curiousity of want to know the properties of edible and inedible vegetable and which one is better than the other.

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CHAPTER 1

INTRODUCTION

1.1 Background

Lubricant is a substance that is use to reduce friction which will cause heat through friction between two moving surfaces that is in contact with each. Usually lubricant contain 90% mineral oils with petroleum as its base oil while the other 10% are additives. The additives is used as friction and wear reducer where increases the viscosity of the lubricant, helps to resist corrosion and active oxidation. (Luna et al., 2011) Lubricant is widely use in automotive world and very important.

The lubricant is very important since vehicles contain high number of moving parts. The engine has pistons that move in high speed and produce high heat in order for the engines to operate properly. The engine produces high heat due to the combustion of fuel. If there is no lubricant the component in the engine such as piston will due to the engine become overheat due to friction. This is why lubricant is important to engine. It will reduce the friction and wear of the engine moving parts such as the piston and cools down the engine by transferring the heat away from the moving parts. (Luna et al., 2011)

Lubricant that is made of mineral oil is widely used because of its low price compared to synthetic lubricant price is much higher than the mineral oil lubricant. Since the commercial engine lubricant is made of mineral oil which is process from crude petroleum oil, it has increased the concern level of consumers due to its effects on the environment and over oil depletion. (Bahari, Lewis, & Slatter, 2018)

To overcome the problem, there has been increase of developments in using alternative lubricant to be use as a substitute for the commercial engine lubricant. Bio-lubricant is an alternative lubricant that uses biodegradable material such as rubber seed oil as base oil. Whereby, it is not harmful to the environment and renewable. (Bahari et al., 2018)

1.2 Problem Statement

The expanding urbanisation, improved living standards and growing population are expected to increase the world's energy needs. It is now apparent that biodiesels are destined to make a substantial contribution in future energy demands from the domestic and industrial economies in times when society is increasingly aware, in conjunction with environmental concerns, of the declining reserves of fossil fuels. Biodiesel production has a variety of possible feedstocks. The promising substitutes for traditional biodiesel crops for non-edible vegetable oils known as feedstocks of the second generation can be considered.

To conduct this study an analysis must be done by comparing the data of experiments that had been done on the tribology properties in order to identify the difference of tribology properties between edible and inedible oils. As the purpose of this study is to compare the tribology properties of the oils between each other, it is better when the test in the experiments are done in a condition where the environment includes high speed movement and high temperature during mechanical contact.

1.3Objectives

Objectives of this study are:

a) To conduct a comparative analysis between edible (palm oil and castor oil) and inedible oil (rubber seed oil and jathropa oil) .

b) To compare the tribological properties between edible (palm oil and castor oil) and inedible oil (rubber seed oil and jathropa oil) .

1.4 Scope

Scope of this study:

a) Content of vegetable oil used is within range of 50% to 100%

b) Speed used in the experiment is within range of 1000 rpm to 2000 rpm

c) Load used in the experiments are within range of 10kg to 40kg

d) The material that will be in contact with the oil is mostly metal that will help in determining the oil tribological properties.

CHAPTER 2

LITERATURE REVIEW

2.1 Vegetable oil.

Some seed, fruit, or nut contains oil. By using various methods such as pressing, solvent extraction or combination of this methods, the crude oil obtain then undergo through a number of refining processes both physically and chemically. Hence the oil produce from this process are known as vegetable oils that have many purposes. There are many different type of vegetable oil as they come from different type of sources. These include the popular vegetable oils such as palm oil, sunflower oil, soybean oil and many more. Since there are many different type of vegetable oils that come from different type of sources. They have different chemical properties and composition from each other and these will determine their usefulness in various applications.

The purposes of using vegetable oil in automotive sector are specifically in producing alternative lubrication. Inherent disadvantages and the availability of inexpensive options have however brought about low utilization of vegetable oils for industrial lubrication. In recent research, vegetable oil is mostly used as an additives to mineral oil. But in some cases they are applied exclusively or in blends. (Aluyor, Obahiagbon, & Ori-Jesu, 2009) The reason of increasing uses of vegetable oil in lubrication is due to their superior lubricity and composition that increase their desirability to act as an additives as they are cheaper in price. Besides that the relatively low viscosity-temperature variances of vegetable oil are one of the reasons why it is preferred by the industrial sector. The vegetable oil are known to have about twice of high viscosity indices than the mineral oil. In addition to their low volatilities as shown by their high flash point, they are significantly environmental friendly. The advantages of vegetable oil is that they have higher lubricity which result in lower friction losses. Vegetable oil also have higher viscosity indices, high shear stability, high dispersancy and high detergency that eliminate detergent additives. Due to vegetable oil is from organic resources like fruits and nut, they have rapid biodegradation that result in decrease of environmental and toxicological threats. (Aluyor et al., 2009)

2.1.1 Oxidation of oil

Oxidation is the undesirable process which results in lubricant degradation (containing C20-C70 hydrocarbons) and material growth. A broad range of oxidation products with greater or lower molecular weight relative to their original oil may be produced by oxidation in relation to the progress of the cycle, for the presence of oxidant agents like oxygen. Lacquer production and varnish production, increase in viscosity, formation of sludges and deposits and corrosion are major oxidation consequences. Because of their low thermal and oxidative stability, triglycerides from plant sources were used as biolubricants with limited application. Triglycerides also have their important advantages: low volatility, high lubricity, low toxicity, and good viscosity and temperature. (Drahansky et al., 2016)

2.1.1.1 Oxidation of oil impact on lubrication

Auto-oxidation of vegetable oils, olefins, is caused by a chain reaction where the oxygen molecule is added to a carbon atom adjacent to a double bond to form a hydroperoxide with a double intact bond. The mechanism of self-oxidation, essentially a free radical chain reaction, is made up of the following steps: begin, disperse, branch and end. These reactions are shown in the figure 2.1 as a classic representation.

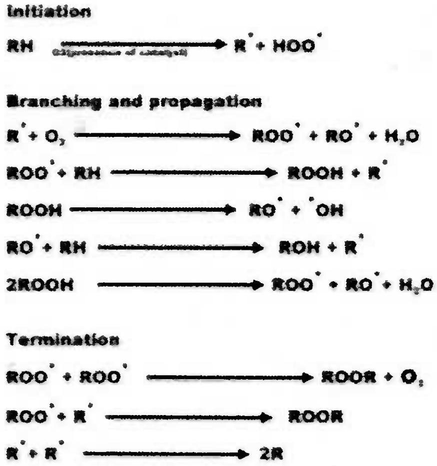

Figure 2.1 Schematic representation of oxidation reactions (Mannekote & Kailas, 2012).

The greater the degree of unsaturation, the more susceptible the oil is to oxidation since it contains insaturated fatty acids. (Mannekote & Kailas, 2012) The process is started by the formation of free radicals that act as an intermediate product with oxygen to form a peroxide radical. The lipid molecule that is radical but then attacks to form hydroperoxide and free radical, propagating the oxidation process.

2.2 Biodegradation of vegetable oil

Biodegradation is when organic substances are broken down by enzymes produced by living organisms. When substance is place in the environment, degradation occurs due to the action of substrate utilizing microorganism. Manufacturers can't claim their product is biodegradable unless it is proven its capability to decompose in common environment where it is disposed after 3 years through natural biological process.(Aluyor et al., 2009) Biodegradable substances will always gets their attention by government regulators and industries. They are interested in how the chemical and waste products are disposed either intentionally or unintentionally. The reason why is because toxic substance that are disposed to the environment will affect the ecosystem and humans. This is the reasons why vegetable oil is preferred for industrial use.

Vegetable oil has a high biodegradability potential than the mineral oil. In the world where pollution is a very serious problem, the vegetable oil presents a more renewable and eco friendly lubricants and with biodegradability range of 70% - 100% it is definitely one of the most eco friendly substance that is use in the industrial sector. (Aluyor et al., 2009) .

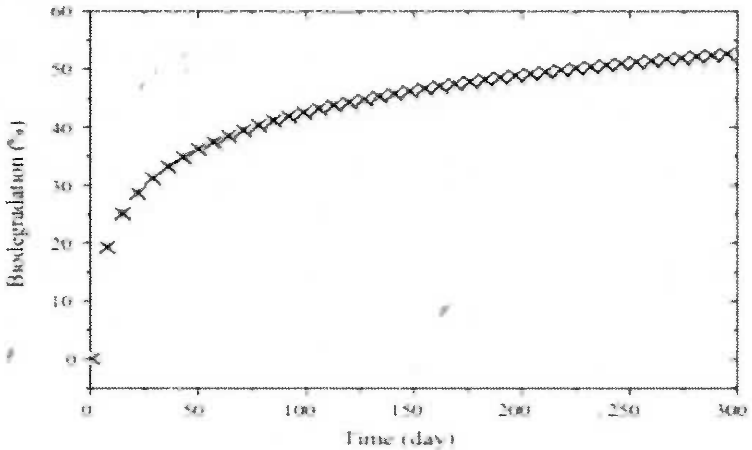

Figure 2.2 Cumulative biodegradation estimated by bio-kinetic model for mineral oil samples. .(Luna et al. 2011)

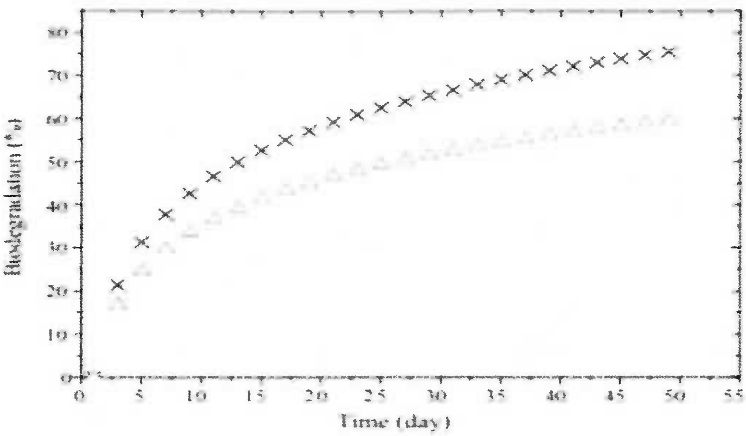

Figure 2.3 Cumulative biodegradation estimated by the bio-kinetic model for synthesized lubricant (Δ) and vegetable oil (x) .(Luna et al. 2011)

The figure above shows the biodegradation of 3 type of oil by using bio-kinetic model. On Figure 2.2 it shows the biodegradation of mineral oil which is only reach 50%-60% with the duration of 300 days. Figure 2.3 shows 2 type of oil which is the synthesized lubricant and vegetable oil. The 2 type of lubricant on figure 2.3 takes much less time than the mineral oil to breakdown which takes 50 days to reach above 70% of biodegradation for vegetable oil and above 50 % of biodegradation for synthesized lubricants. However even with the high percentage of biodegradation percentage, there are other limitations that should be considers when using vegetable oil as lubricant directly. Luna et al. (2011) stated that pure vegetable oil can only be use in low thermal requirement applications because the thermal and hydrolytic instability of the vegetable oil.

In conclusion, the vegetable oil has proved its usefulness as a biodegradable substance. Its source is from an organic substance that can be found abundance in the ecosystem and it is also renewable. When dispose to the environment, it has a rapid of biodegradation percentage which takes a short time for it to fully broken down by living organism. In addition, the vegetable oil does not release toxic substance when breaks down that is harmful to the environment and ecosystem. The only limit for the vegetable oil is a pure vegetable oil can only operates under a low thermal requirements application. Hence it is impossible to use a pure vegetable oil in a high temperature requirement automotive part like the engine as a lubricant without manipulating the composition of the vegetable oil that can breaks the thermal requirement limits for it to use as lubricant in a high thermal requirement automotive parts. (Luna et al., 2011)

2.2 Friction characterization

Friction is produce when surfaces contact with each other when in relative motion. When friction occurs, it produces heat that can lead to material wear. A material that experienced wear could lead to part damage. In automotives industries, friction and wear problems are very serious since most of the parts are in motion. Like the pistons in engine, which movement are needed for combustion process. The internal combustion process makes the piston to move in very high speed which result it to produce friction between the surface of the piston and cylinder. Frictions that are produce from the motion of the piston produce a lot of unwanted heat hence produce material wear. When the material reach its limit, it has a high possibility to crack or break, hence resulting the combustion system to fail and the engine to not work like it was intended to be. This is where the lubrication takes its place as one of the important role in reducing friction. Due to the importance of lubrication in industries especially that used system that has mechanical contacts, about 38 million metric tons per year of lubricants have been used globally in the last decade, with most of it are petroleum-based lubricants.

Coefficient of friction value can be obtained from the friction test. Where the equation of coefficient of friction (COF) is calculated as :

$$\mu = \frac{\boldsymbol{F}}{\boldsymbol{N}}$$

Where: μ is the frictions coefficients, F is the frictional force in Newton, N is the apply loads in Newton.

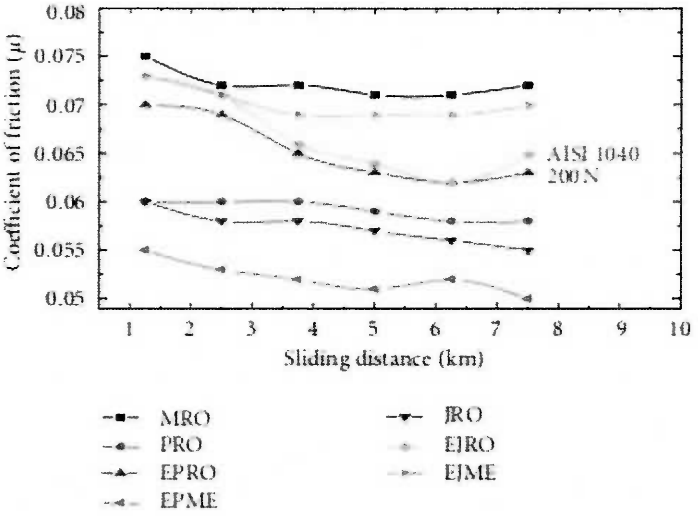

Figure 2.4 : Variation of coefficient of friction with sliding distance for 200 N (Shashidhara & Jayaram, 2012)

Figure 2.4 shows the results of friction test conducted by Shashidhara & Jayaram, (2012) to obtained COF of Pongam raw oil (PRO), Pongam methyl ester (PME), expodized Pongam raw oil (EPRO), Jatropha raw oil (JRO), Jatropha methyl ester (JME), expodized Jatropha raw oil (EJRO), expodized Pongam methyl ester (EPME) and expodized Jatropha methyl ester (EJME). Experiments are carried out with 8 mm diameter AISI 1040 steel tribometer pins of the two vegetable oils in mineral, raw and modified form.In contrast to mineral oil (MRO), PRO and EPRO show a decrease in friction of about 20% and 13% respectively. EPME, however, indicates a lower friction of some 30%. JRO and EJRO have also seen a PRO-and EPRO-like phenomenon. Nonetheless, in contrast with mineral oil, the EJME displays a marginally lower frictional quality. Depending on their polary existence and viscosity, the lower friction values of two vegetable raw oils are related.The fact that the thin surface film created during bonded lubrication is formed by the adsorption of polar compounds on the metal surface of the pair or by chemical reaction of the lubricant on the surface may lead to a significant decrease under vegetable oils. (Shashidhara & Jayaram, 2012)

2.3 Tribometer and friction free measurement

Tribometer is a generic name for a device to measure the friction force which is developed in relative motion between surfaces. The tribometers are typically used for measuring or analyzing the wear of materials, at least qualitatively. The Oxford British Dictionary edition of 1989 described a tribometer as an instrument to estimate friction sliding. The tribometer's purpose is to provide simulation in controlled conditions of friction and wear. Friction and wear are very sensitive to factors such as temperature, load or humidity variations, and therefore a system that regulates and tracks all of these factors is important. The practical advantage of promoting research is that wear and friction tests on the original equipment have not been complicated. For example, it has significant economic significance to wear between cylinders and pistons.Full-scale testing on indoor combustion engines is time and resources limited to the effect that preliminary grain testing of simplified testing machines is performed. The explanation why tribometers are used is that they can be used so that precise friction, wear and related parameters (e.g. temperature) can be calculated not in a way that traditional industrial instruments can’t. Given the fact that there are tribology problems in virtually every field, a wide range of tribometers is used to imitate all types of situations in the real world as listed below :

- Four Ball Tester
- Pin on Disc
- Ball on Disc
- Fretting Tester
- Tribometer for Railways
- Reciprocating Sliding Friction and Wear test
- Vacuum Tribometer
- Low Temperature Tribometer
- High Temperature Tribometer
- Micro/Nano Tribometers
- Falex Pin & Vee Block Test
- Dry sand rubber/wheel abrasion test
- Air Jet Erosion Tester

- Tribocorrosion Test Systems

2.3.1 Tribological test using pin-on-disk test rig

The Tribometer is made up of a flat, pin or sphere attaching to a stiff armed elastic arm, weighed to a precisely known weight test sample. At a selected speed, the sample is rotated. The elastic arm guarantees an almost fixed point of contact and a stable location in the friction path created by a pin on the specimen. During the test the kinetic friction coefficient is determined by measuring the elastic arm's deflection or by measuring the torque change directly by means of a sensor located on the pivot point of the arm.The wear rate is based on the volume or weight of the material removed from the test for the pin and the disk. The test parameters such as speed, pressure of contact (i.e .. PV) and time can be controlled with this machine.With the correct environmental container, humidity, temperature and atmospheric composition can be monitored and measured. Normally, pin-on-disk measurements are carried out using a pin-on-drive system using the ASTM G99-05 standard wear test method. (McKeen, 2010)

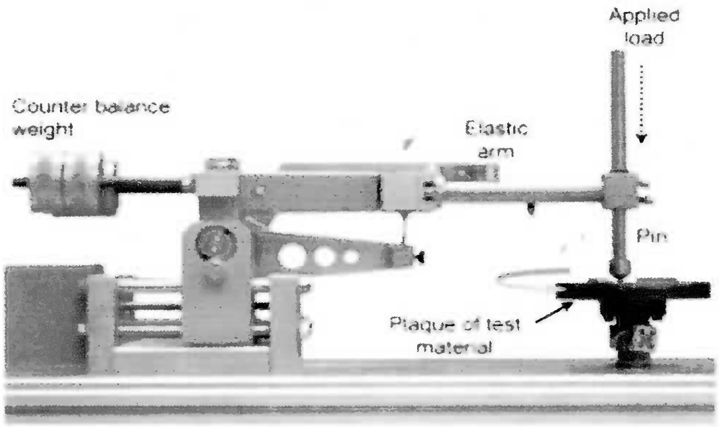

Figure 2.5 A pin-on-disk tribometer

A pin-on-disk tribometer enables travel in one direction at a range of linear velocities for an unlimited time, depending only on the pin position from the center of the disk. A reciprocal system makes the wear track wider, as the pin can be formed in a flat. A spindle-ball design allows designs that are similar to load-bearing.A pin-on-disk tribometer can be used for modeling wear and lubricant behavior when the actual components have a linear relative speed that is quite constant as the shaft in the broom. In contrast, reciprocal tribometer may be used to model the tribo-components that have reciprocal mobility like a cylinder piston ring.

2.4 Wear mechanism

Wear means that the material is weakened, deformed or slowly lost at solid surfaces. Mechanical (e.g., erosion) or chemical (e.g., corrosion) may be causes of wear. System component wear along with other processes including fatigue and creep results in deterioration of usable surfaces and subsequent material failure or functionality loss. The wear rate is affected by factors such as load types (e.g. impact, static and dynamic), motion types (e.g. sliding, rolling), temperature and lubrication, and mainly the removal from the boundary layer and the deposition phase.

2.4.1 Wear measurement method

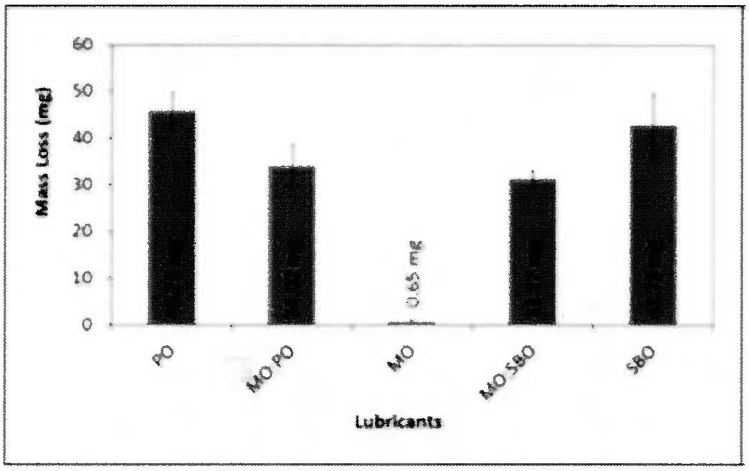

Figure 2.6 Average mass loss of specimens lubricated by palm oil (PO), soybean (SBO),mineral oil (MO), oil blends of (MO:PO) and oil blend of (MO:SBO) (Bahari et al., 2018)

In a research done by Bahari et al., (2018) it's stated that that the vegetable oil specimens resulted in much greater mass loss compared to the MO specimens, during the trial and error process, of searching for an appropriate charge. The mass loss can't be measured for MO samples with a normal load of less than 40 N. Higher load (above 40 N) raised the contact stress and thus increased the wear scar depth for samples of vegetable oil. The wear of the specimen was determined by the weight difference before and after the test. The tests were conducted three times for each lubricant, which was then calculated for the average mass loss and friction coefficient. Figure 2.6 shows the average usage data of the PO, SBO, MO and oil-mineral mixtures lubricated samples. The highest wear with 45.76 mg mass loss was generated in the PO-lubricated specimens. The SBO lubricated specimen has an approximately 7 percent difference in mass losses (42.73 mg) relative to the PO-lubricated specimens. In contrast to vegetable oils with a wear loss of 0.65 mg, the MO displayed a superior wear and tear resistance, which is 98% different from the SBO lubricated sample.

While in a study conducted by Fattah et al., (2017). The average wear scar diameter was measured using three bottom test balls. Initially they were cleaned with acetone and wiped with a fresh, free industrial wipe to dry. There was a suitable enlarged lens, and the wear scar image was focused until a clear picture on the computer screen was displayed. The photo was filmed, saved and analyzed and calculated using available software. The increase in diameter of the wear cavity is due to the rubbing and load change.

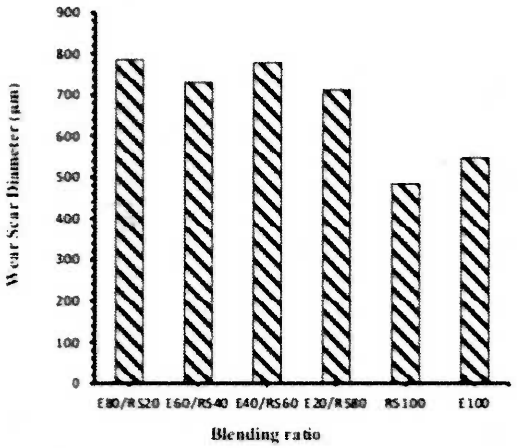

Figure 2.7 Wear scar diameter (WSD) for different blending ratio (%) (Fattah et al., 2017)

The effect was determined using a special microscope for wear scar diameters for the three bottom steel balls and the mean values for three were estimated. The WSD distinction between rubber seed oil blends, rubber-clean seed oil and commercial lubricant is shown in Figure 2.7. From the calculation, the WSD for the clean rubber seed oil could be inferred to be below the value of another oil sample. In the blending of rubber grain, E20/RS80 with 721.6µm showed lower wear than in the case of the pure rubber oil with 485.4 µm and in the case of mineral oil with 546.4 µm. The clean rubber seed oil therefore showed better wear-resistant performance than other oil samples.

2.5 Lubrication

Lubrication is the control of friction and wear by introducing a friction-reducing film between moving surfaces in contact. A liquid, solid or plastic substance may be the lubricant used. A variety of materials may be used for lubricating a surface. The most popular is oil and grease. Grease consists of oil and a thickener in order to achieve its consistency, while oil lubricates. Oils can be, and mixture of, organic, vegetable or mineral. The specification decides what oil to use, commonly known as the base oil. Synthetic oils can be useful under extreme conditions. Vegetable base oils may be used where the environment is concerned. Oil containing lubricants have additional properties within the base oil that improve, add or suppress. The quantity of additives depends on the type of oil used and on its application.

2.5.1 Lubrication regimes

The dimensions free film thickness parameter ' λ ' is added according to its appropriate range for each lubrication scheme to distinguish between different lubrication regimes. The lambda factor is determined in the following ratio:

$$\lambda = \frac{h_{min}}{R_q}$$

λ is the dimensionsless thickness ratio of the film, while Rq is the average roughness of the surfaces contacting it. The relationship between the λ and the lubrication system is as set forth in Table 2.1 according to EHL theory. (Zulkifli et al., 2016)

Table 2.1 Dimensionless film thickness parameter range for lubrication regimes. (Zulkifli et al., 2016)

λ	$\lambda \geq 3$	$3 > \lambda > 1$	$\lambda \leq 1$
Lubrication regime	Full fluid film	Mixed film	Boundary lubrication

2.5.2 Mineral oil lubrication

Mineral oils are produced by distilling refined petroleum hydrocarbons. They are used to encourage restricted or solid film lubrication as hydrodynamic lubricants and as additive carriers.

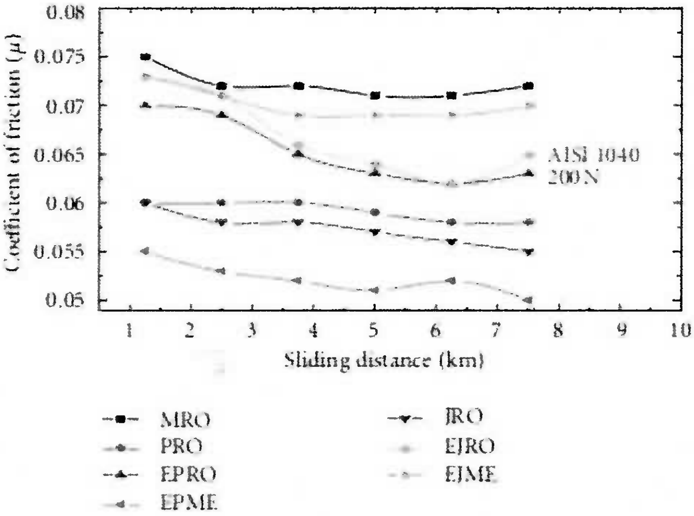

Figure 2.8: Variation of coefficient of friction with sliding distance for 200 N. (Shashidhara & Jayaram, 2012)

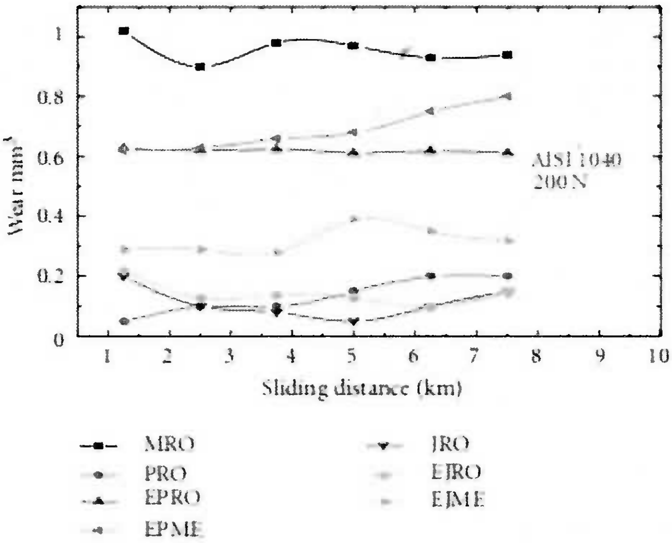

Figure 2.9 : Variation of wear with sliding distance for 200 N. (Shashidhara & Jayaram, 2012)

A study conducted by Shashidhara & Jayaram, (2012) it shows that the mineral oil (MRO) has higher COF and wear diameter than the other vegetable oil as shown in Figure 2.8 and Figure 2.9.

2.6 Tribological performance of vegetable oil lubricant

For conventional lubricants, vegetable oils are an attractive substitute, especially in areas of environmental sensitivity such as agriculture, forestry, and mining, as they have low toxicity, high biodegradability, low friction, wear and improve surface finishing. Nonetheless, organic triglycerides, including a low flash point and limited thermal stability, have certain disadvantages.

2.6.1 Performance of pure vegetable oil

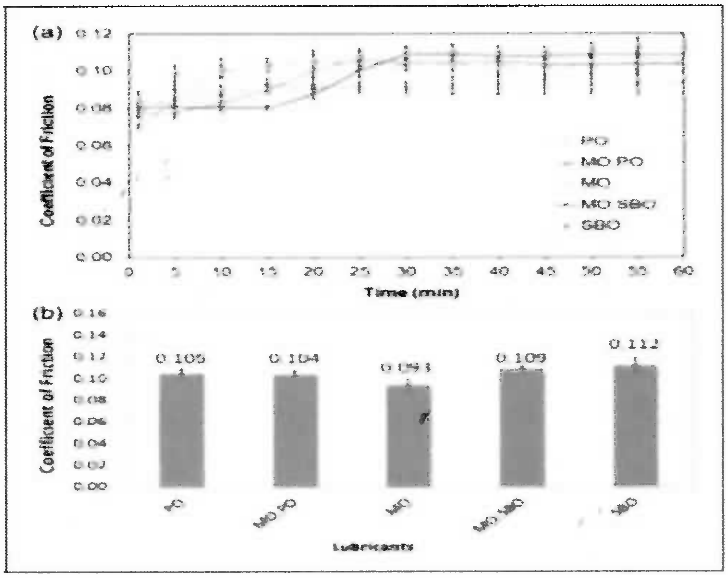

Figure 2.10 (a) Average COF of friction versus time for Palm oil (PO), soybean oil (SBO), mineral oil (MO) and the oil blends and (b) COF value at 60 min. . (Bahari et al., 2018)

The experiment showed less COF (0.105) of PO than the equivalent of SBO (COF = 0.112), while the mineral engine oil showed the lowest COF (0.093). The strong polarity of fatty acids in vegetable oils helps to form a mono-molecular layer by attracting the metal surfaces of carboxy group (COOH). The difference between

COF for PO and SBO could be dependent on the composition in vegetable oil of saturated and insaturated fatty acids. (Bahari et al., 2018)

Palm oil was comparable in the friction quality with that of the mineral motor oil. As shown in figure 2.10 it shows that the mineral oil is far more superior in war resistance than the pure vegetable oils.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will show the test or method used on the oils in order to know their tribological properties. From sample preparation to testing rig method that were used, the results will also undergoes a comparative analysis in order to know the difference between each of the oils. Then the oil will be compared between the eadible and ineadible ones. The results of the analysis will be discussed and documented in a report.

3.2 Sample preparation

The preparation of the sample refers to how a sample is processed before examination. In most analytical techniques the planning is a very necessary step as the techniques are often insufficient in the form of the analysis or the outcome is skewed by species-interfering. Dissolution, extraction, reaction to certain chemical compounds, powdering, treatment by a chelating agent, masking, filtering, dilution, sub-sampling or a variety of other processes can also be part of sample preparation. Processing shall be performed by different analytical equipment to prepare the sample in a shape ready for analysis. Preparedness of samples may include: crushing and dissolution, acid or alkaline chemical digestion, sample extraction, cleaning and pre-concentration of samples.

In the study of tribological properties of the vegetable oils, the oils will be mix with commercial mineral oil with the ratio range of 10%, to 100%

3.3 Tribology tester apparatus.

3.3.1 Pin-on-disc tribometer

The tribometer pin-on-disk is comprised of a plate, circle, or sphere attached to the rigid elastic neck, which is weighted to a (coated) test sample with a specified weight, precisely. At a selected speed, the sample is rotated. The elastic arm ensures that the pin on the sample has a relatively fixed contact point and a stable location inside the friction line. The kinetic friction coefficient is measured by the calculation of the elastic arm deflection or by means of direct calculation of the torque shift by a sensor at the pivot of the arm. Wear levels are determined for the pin and disk by the quantity or weight of the material taken during the study. Test parameters like speed, contact pressure (thus PV) and time can be managed. With the right space, the effects of moisture , temperature and atmospheric composition can also be monitored and calculated. Measurement of the sliding disk is normally carried out with a sliding disk unit by the Standard ASTM G99-05 Wear Test Process.(McKeen, 2016)

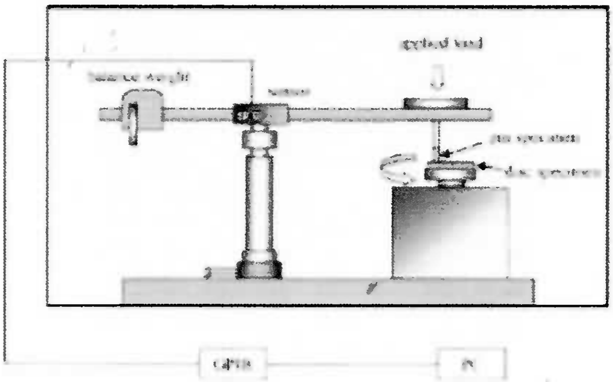

Figure 3.1 shows pin-on disc schematic

According to study conducted by (Kumar, Kanth, Ramki, & Jagadish, 2019) about Experimental Investigations on the Tribological Properties of Jatropha Oil by the Addition of Graphite Nanoparticles, the system has been designed for charging up to 100 N and the velocity is between 200 and 2000 rpm. Friction and wearing characteristics of two sliding contact matting surfaces are the performance parameters which can be analyzed. Among a spinning disc and a stationary plate, the parameters are determined. Distinct rpm, load and track diameter are the input variables. The performance parameters – tangential friction strength and wear are calculated by means of electronic sensors.

Figure 3.2 shows pin-on-disc tribometer

3.3.2 Four Ball Tribometer

Four Ball Tester as shown in figure 3.3 is used to describe the properties of lubricants, such as wear protection, intense pressure and frictional behaviour. The test consists of 4 balls in an equilateral tetrahedron configuration as shown in the figure below. The top ball rotates and is in contact with the three balls in a fixed position. The capacity of a lubricant to work under extreme pressure conditions is determined when the extreme pressure properties of a lubricant are tested. The check begins at 'small' loads where the lubricant is functioning properly, a good lubricant film is produced and no seizure is observed. The load is slowly raised according to the check norm before the lubrication fails, which means that the lubricant coating can no longer distinguish the surfaces and there is surface to surface contact. The last step is to increase the load until a catastrophic loss takes place. This last failure is known as the welding, and is marked by increased noise, rapid friction signal shifts, and so on. Different formulations can be established based on the output of a lubricant in this study. In addition, four ball tests can be used to calculate the lubricant 's wear quality. The top ball is rotated to the rest of the set balls during the test. In relation to the intense pressure check, the load is carried out at set conditions (size, temperature, rpm, etc.). After the study, tests of the wear scar are carried out using optical profilometry for example and can be used for assessment of wear quality by a lubricant. In this test, the friction force is also measured and thereby analysed.

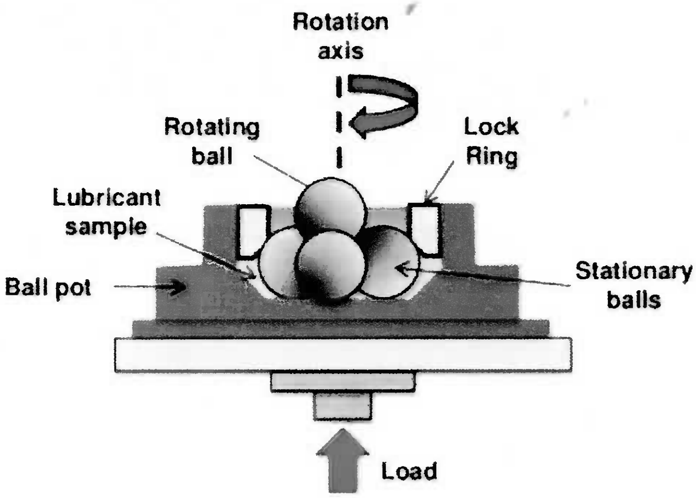

Figure 3.3 shows four ball tribometer schematic

Based on the study conducted by (Gallardo-Hernández et al., 2017) , the device was built and installed in compliance with the normal measurement system, ASTM D2596, D2783, D266 and D4172, concerning extreme pressure calculation of lubricating turf. The procedure is implemented by using a clear tension on a spinning metal ball within a container with the lubricating oil evaluated on three static spheres. Essentially, the touch area must be defined in two separate areas, including the nominal and the actual contact surfaces, since the surfaces are not completely smooth on a certain length scale. The actual area then depends largely on the strain exerted to both sides, because the load is mostly borne by the touching asperities. A guided pneumatic actuator applied three separate loads on the three fixed balls and calculated and registered the friction coefficient with a computer as the experiments were all performed for around 20 min. The balls used in this work were made of high carbon steel 12.7 mm diameter (AISI 52100) with an average surface ruggedness of 0,04µm. Prior to the test, the balls were washed and dried later with air using an ultrasonic acetone wash. It should be remembered that only once measurements of the specified conditions were carried out in accordance with the requirements.

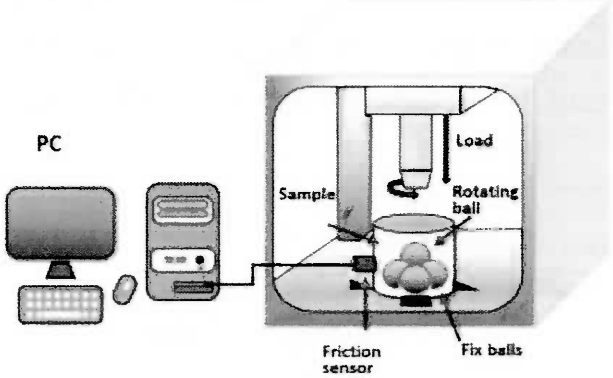

Figure 3.4 shows four ball tribometer

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the tribology properties of the vegetable oil will be shown and discussed. This chapter will discuss on several factor that affecting the tribology performance of the oil which is friction and wear. After that, the vegetable oil will be compare with each other based on this factors. The vegetable oil performance as lubricant will be also compared between the edible and ineadible vegetable oil.

4.2 Coefficient of friction of vegetable oils.

Friction coefficient (COF) is a dimensional-free number defined as the frictional force-standard frictional force relation (H Zhang, 2016). Products with COF less than 0.1 are called lubricating products. COF relies on the quality of the materials and the roughness of the surface. Currently, ASTM D1894-14 is the most commonly used method of COF calculation. This approach requires a rubber layer or a film with a set weight at the end. The sample of the polymer is drawn over the stainless steel surface under dry or wet conditions and the friction force is then determined by a force meter (Figure 4.1). The standard force in this test is equal to the force of gravity of the weight.

Figure 4.1 shows sample of polymer drawn over stainless

4.2.1 COF of Jathropa Oil

Study conducted by (Ruggiero, D'Amato, Merola, Valášek, & Müller, 2016), experiments have been carried out under the American Society for Testing and Materials (ASTM) at various temperatures and loads. In this study the conditions were: (120 ± 60) rpm, period ± (120 ± 60) minutes and load: (200, 400 and 600 N), (55 and 95 and 125 ° C). The following were the conditions of testing. In comparison, when different loads were added and load was constant at 392N, temperatures were kept at 75 ° C, even when different temperatures were being felt. Jatropha oil has its lubricant properties examined with a four-ball tribotester.Various temperatures and costs. The experiments offer an opportunity to address Jatropha oil as an alternative source of friction and antiwear. Compared to mineral oil-based lubricants, lubricant oil. Equation (1) indicates the relation Friction, temperature and load coefficient. The friction coefficient has an inverse temperature and load relationship. Fig.4.2 shows the effect incremental temperature change in Jatropha and hydraubic oil concentrations at 55, 95 and 125 degrees Celsius. The friction coefficient of jatropha oil remained stable with variations in temperature Fig.4.2 clearly shows. Yet with a rise in the temperature, friction coefficients in hydraulic oil increase. The figure indicates that therein Jatropha oil has a greater antifriction than hydraulic mineral oil-based condition lubricating agent. The chart explicitly shows that friction coefficient increases with an increased load for Jatropha and hydraulic oils. Fig.4.3 further demonstrates the influence of load on coefficient of friction. The Jatropha oil friction coefficient was however greater than the hydraulic oil.

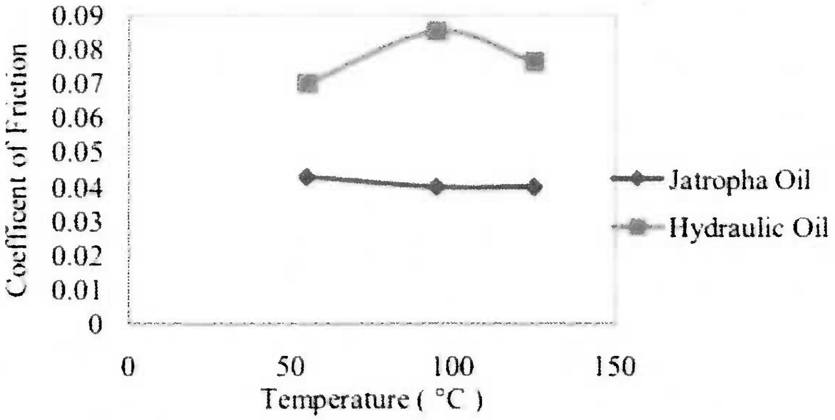

Figure 4.2. Effect of Temperature on coefficient of friction for Jatropha, engine and hydraulic oil in 55, 95and 125°C(Ruggiero, D'Amato, Merola, Valášek, & Müller, 2016)

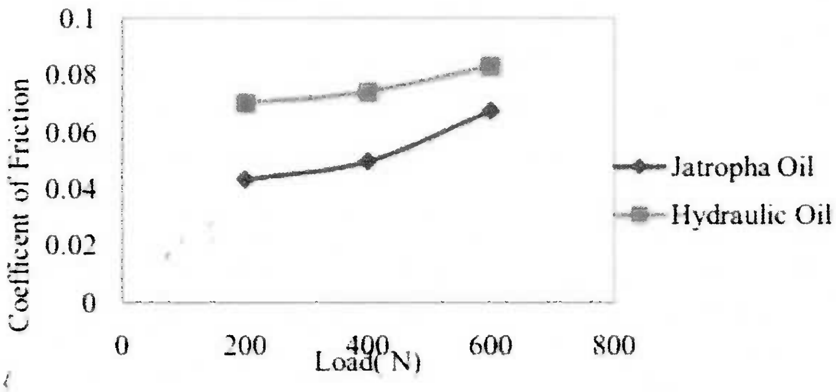

Figure 4.3. Effect of load on coefficient of friction for Jatropha and hydraulic oil in 200, 400and 600N. (Ruggiero, D'Amato, Merola, Valášek, & Müller, 2016)

4.2.2 COF of Rubber Seed Oil

In the experiment done by (Fattah, Ariff, Hassan, Nasir, & Teknologi, 2017), it is said that through this experiment, rubber seed oil may become a biolubricant of partial substitute, as wear and lubrication effects were not influenced by the mixtures. This is shown by the results from the investigation that were conducted. The friction torque of the four-ball tribotester has been documented with a different data acquisition method. Originally, the traction torque increased quickly but after 10 minutes it became steady and strong. The average friction torque was recorded and the friction coefficient, was calculated according to IP-239, as shown in equation :

$$M = (T\sqrt{6})/3Wr$$

where μ is the coefficient of friction T shall be the frictional torque in kg mm, W shall be the application of loads in kg and r shall be the distance between the middle of the lower ball contact surfaces and the axis of rotation, as norm of 3.67 mm for the particular diameter of the sphere.At the 1200 rpm rotational speed and at the bulk oil temperature at 75 ° C over an hour, the friction torque of the mixtures of rubber seeds were studied under regular load of 392.4 N. The friction torque check graphs for different oil mixtures of rubber seeds were illustrated in Figure 4.4. Rubber seed oil mixtures were equivalent to mineral engine oil (E100) and clean rubber seed oil (RS100). The lowest torque of friction was E40 / RS60 with 0.094 Nm as compared to RS100 with 0.0992 Nm and 0.1442 Nm for mineral engine oil.

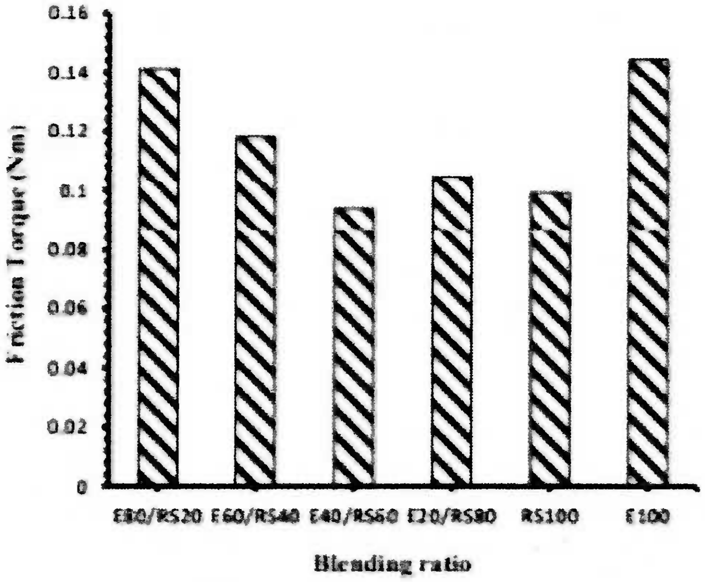

Figure 4.4 Friction Torque for different blends. (Fattah, Ariff, Hassan, Nasir, & Teknologi, 2017)

The rubber seed mixtures, clean rubber seed oil (RS100) and industrial lubricant (E100) were analyzed. The COF was measured, tabulated and the outputs were shown in figure 4.5 for each experimental scenario. Of the rubber blends, E40 / RS60 (0.0533) was the lowest COF (0.0563) as compared to RS100, and E100 (0.0815), respectively. Among the rubber mixtures, rubber seeds oil is the least COF. There are also 60 percent more lubricants of rubber seed oil blended with 40 percent mineral oil and used as a lubricant than tidy rubber seeds oil and consumer mineral lubricants. This results in greater lubrication performance.

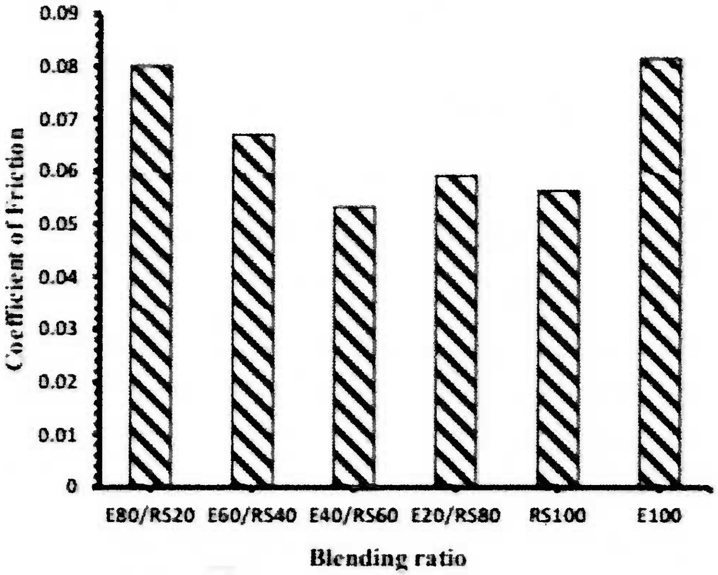

Fig. 4.5. CoF values for different blends. (Fattah, Ariff, Hassan, Nasir, & Teknologi, 2017)

4.2.3 CoF of Palm Oil

Figure 4.6 shows the findings of (Zulkifli, Kalam, Masjuki, Shahabuddin, & Yunus, 2013) experiment about palm oil TMPS ester shows the difference in friction coefficient for different loads of the added lubricant TMP ester. The size of the friction coefficient indicates that both elasto hydrodynamic and border lubricants were the lubrication regime in the rubber field. According to OL, much of the TMP ester had lower friction coefficient (COF). Compared to petroleum-based, traditional lubricants, COF for TMP 1, TMP 3, TMP 5 and TMP 7 seemed to be lower while TMP 10 and TMP 100 displayed higher COF across the load range. In terms of FSL (Final Seizure Load), OL, TMP 1 and TMP 3 were found more stable than that specified as the burden at which lubricant films completely break up and test ball materials are welded. TMP 1 imparted the lowest COF up to initial seizure (ISL) load, but after FSL the lowest COF was found to be TMP 3. It can also be noted that TMP 1 received substantial wear. means that the TMP 1 and TMP 3 are the most capable of holding their characteristics to the load of 220 kg without cracking the lubricating film. That can be due to the fact that the lubricating film density is slimmer at higher loads than other asperities in the limits. The long chain of fatty acid and esters of biolubricants are known as surface active products, however, covering these asperities. TMP 1 and TMP 3 demonstrated optimal output to minimize CF, which can be interpreted as the fatty acid present in TMP esters as an active surface material suitable for these two grain substances and, however, as the rubbing contact surface is completely filled with the acid, it does not contain fatty acid. The significant aspect is that the TMP negatively affects the consistency of the lubricant over 3 percent.

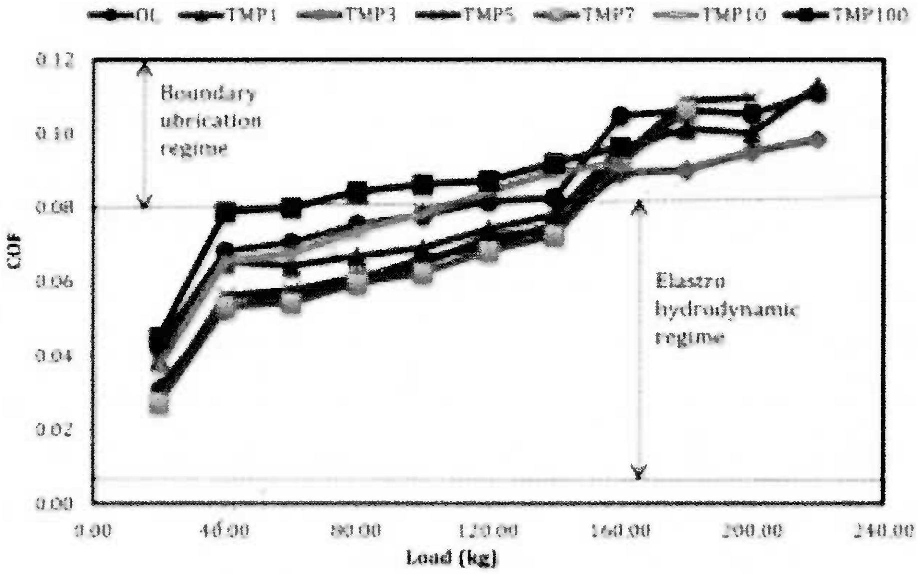

Fig. 4.6. Variation in coefficient of friction at different load under extreme pressure condition. (Zulkifli, Kalam, Masjuki, Shahabuddin, & Yunus, 2013)

4.2.4 CoF of Castor oil

For this experiment, Husain et al. used ball bearings and manufactured in combination with the following significant parameters, AISI E-52100 chromium and (alloy) steel combinations: dia 12,7 mm; extra polish (EP) grade 25; hardness 64 – 66 HRC (Rockwell C Hardness). Castor oil was used as a lubricant in a trial study. The oil was mixed with PETRONAS / SAE40 engine oil in quantity from 20 to 80 percent. Experimental findings with beverage oil were contrasted with commercial mineral oil (ENG100 percent) at various volumetric merging ratios. With washed, new dried lint and acetone, the ballpoint and the steel boules were completely cleaned. Once lubricants were applied and the materials put together, no trace of a solvent was left. The steel balls were inserted into the pot and a torque wrench was used to repair the test set-up so that the base steel ball did not slip through the experiments. The turning ball at the top of the ball was pushed onto the spindles on the inner side of the ball and the test oil was poured in the ball jar. At a fixed point of 75 ° C, the motor was triggered to drive balls at the desired speed. The motor was turned on. For the ball bearing washing, the test oil was drained from an oil cup and the fresh lint free industrial wipe was added. The lubricance of the test lubricants and three balls with their wear scar diameter was measured. A machine optical software was used to calculate wear scar and to test by means of an electronic loupe and a photomicrographer. The COF was measured, tabulated and the results were presented in Figure 4.7. The lowest COF for castor oil blends occurred at 80 percent (0.06102) as shown in Figure 4 below. Therefore, since 80 per cent of castor oil mixes have been used as lubricants, they can have a greater lubricant efficiency in terms of friction relative to plain castor oil and 100 per cent industrial lubricant.

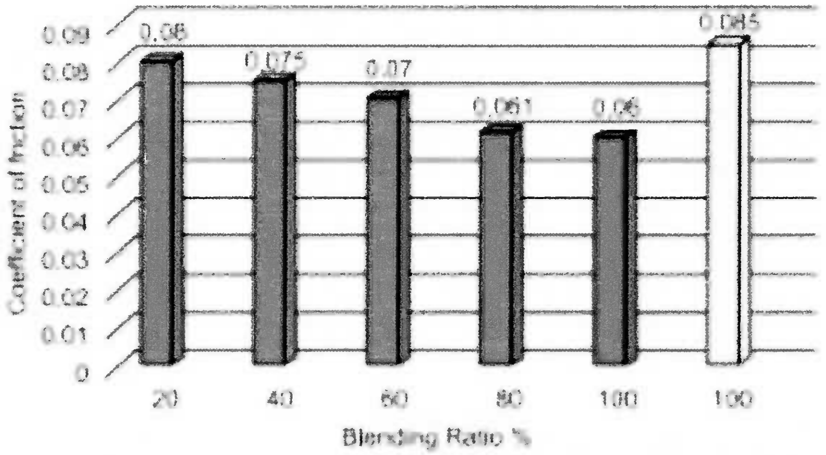

Figure 4.7: COF vs Blending Ratio (Husain et al, 2018)

4.3 Wear Scar Diameter (WSD)

According to (Lam & Lam, n.d.) the wear scar diameter is a fluid quality metric and is the ability to act as a lubricant to reduce friction and damage to touch surfaces under a load of relative motion by means of a fluid or combination (petrol fuel). The smaller the cut, the lower the wear, and hence, the more lubricating the fuel has been. This significant decrease in the wear scar diameter, which improves the gravity of the air, would significantly increase the longevity of equipment which prevents premature wear and makes the equipment work in compliance with its design life. This lubrication improvement increases motor performance directly and reduces maintenance requirements.

4.3.1 WSD of Jathropa

The Jatropha and hydraulic oil wear scar diameter are shown in Fig . 4.8 at various temperatures. According to this figure, the friction coefficient increases as Jatropha oil temperature increases and the temperature of hydraulic oil increases.Figure. 4.9 indicates the Jatropha and hydraulic oil wear scar diameter in multiple container loads. This figure shows clearly that the diameter of the Jatropha oil is smaller than that of hydraulic oil. Fig.4.9 indicates the wear scar decreases as the load of experimental oils decreases. On average, the number of wearing scars in Jatropha oil ball specimens was smaller than in hydraulic oil, suggesting that Jatropha's wearing capacity is greater than the number of hydraulic oil. (Ruggiero et al., 2016)

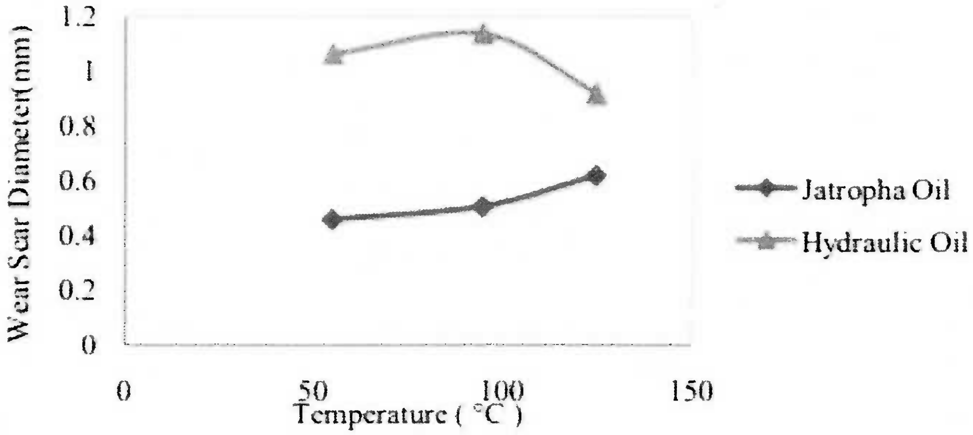

Figure 4.8. Effect of Temperature on Wear Scar Diameter (WSD) for Jatropha and hydraulic oil in 55, 95and 125°C (Ruggiero et al., 2016)

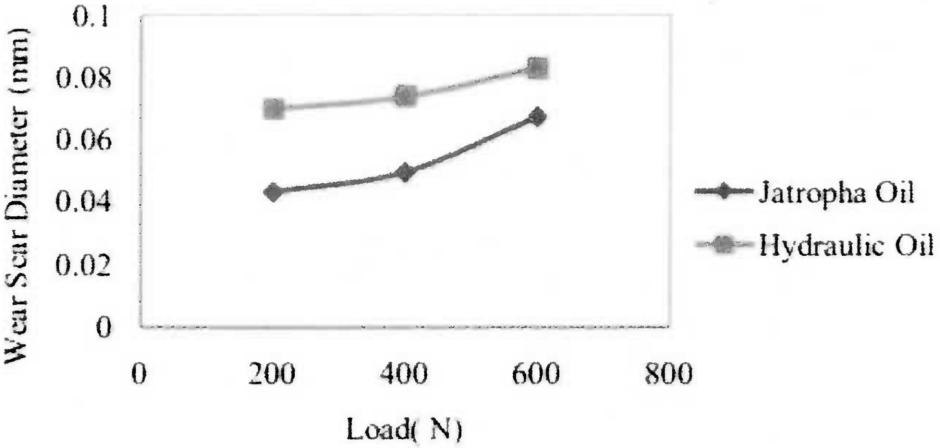

Figure 4.9. Effect of load on wear scar diameter for Jatropha and hydraulic oil in200, 400 and 600N (Ruggiero et al., 2016)

4.3.2 WSD of Rubber Seed Oil

The scar diameter was determined using the electron microscope (SEM) in the experiment (Fattah et al . , 2017) and then the sum of the 3 diameters estimated to determine the final scar diameter, then gathered and tracked, and shown in the figures 4.10. The wear scar diameter for both oil samples (clean rubber oil and hydraulic oil) was changed with higher loading values based on the findings of this test. In contrast with mineral hydraulics with the low-load (484 μm under 40 kg), net rubber seed oil (Rubber 100) provided a lower rate of wear scar diameter than 546,4 μm at the same standard load on hydraulic oils. High wear scar-diameter values (864.7 μm under 80 kg) of 721.1 μm below 80 Kg using hydraulic oil have been shown by the ruber seed oil at higher loads.

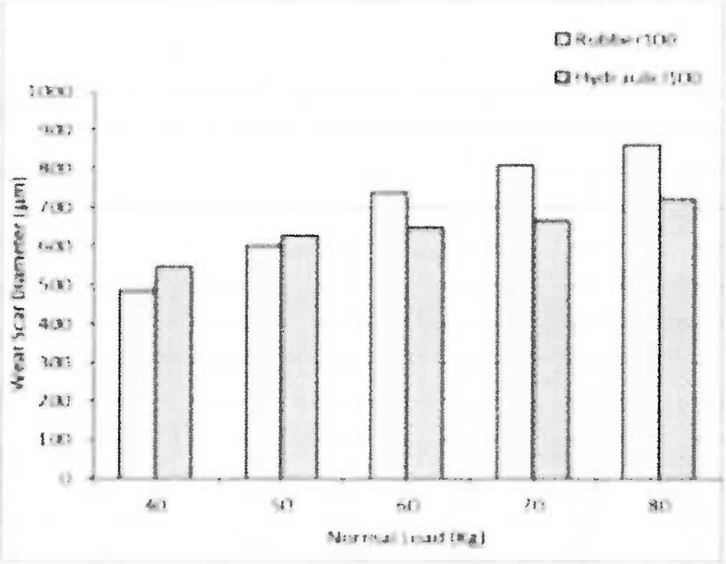

Fig. 4.10. Wear scar diameter (WSD) for fluid specimens under various loads. (Fattah et al . , 2017)

4.3.3 WSD of Palm Oil

Zulkifli et al, studies show that the COF (friction coefficient) values for the different lubricant samples are illustrated in this figure. 4.11. There's a pattern close to WSD. Overall, the introduction of Palm oil-based TMP ester, with the exception of TMP100, will decrease the COF. It was found that the TMP 3 achieves the highest lubricity based on the importance of COF and WSD. The WSD is up to 0.78 mm at TMP 100.

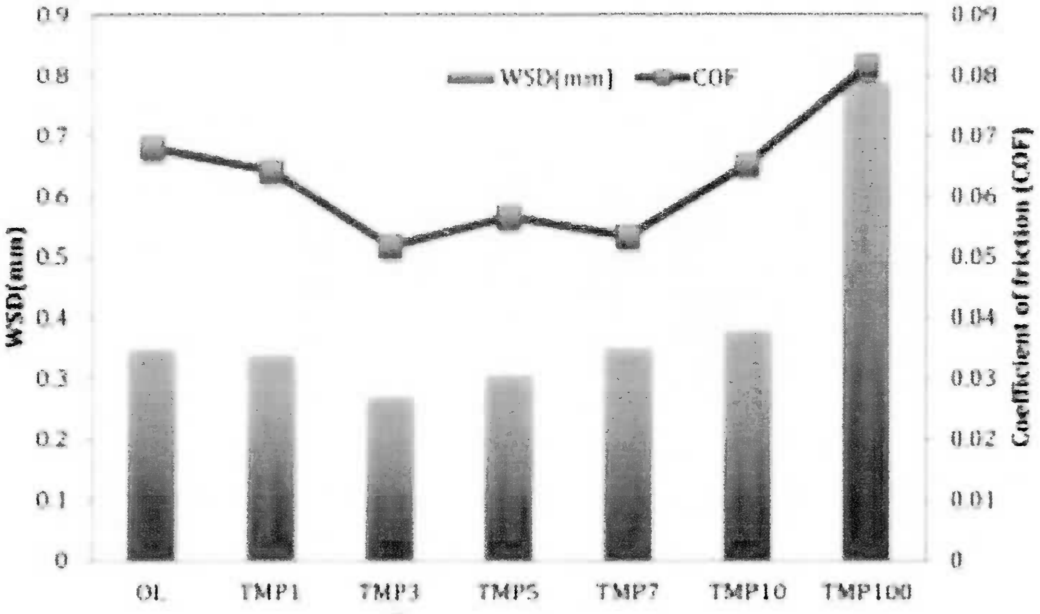

Fig. 4.11. Wear scar diameters (WSD) and coefficient of friction (COF) for different percentages of the palm oil-based TMP esters in OL (Zulkifli et al,. 2013)

4.3.4 WSD Castor Oil

The WSD contrast among the Castor oil blends, tidy rice oil, and commercial lubricant can be found in figure.4.12 below. Of the Castor oil blend, the WSDs of the clean Castor oil may be assumed to be higher than those of other oil samples. In comparison, the figure indicates that 20 percent and 40 percent of the beaver oil mixing fell to a lower wear. In contrast with the other ratios of fusion and compared with the 100% industrial lubricant, the higher WSD prevailed with Castor oil fusion. Therefore, the Castor oil is one of the anti-wear additives in 20 and 40% formulations and reduces the WSD. Castor oil's friction efficiency was tested with a typical 392.4 Newton and a bulk oil temperature of 75 ° C at a speed of 1h rotation of 1200 rpm.as stated by Husain et al.

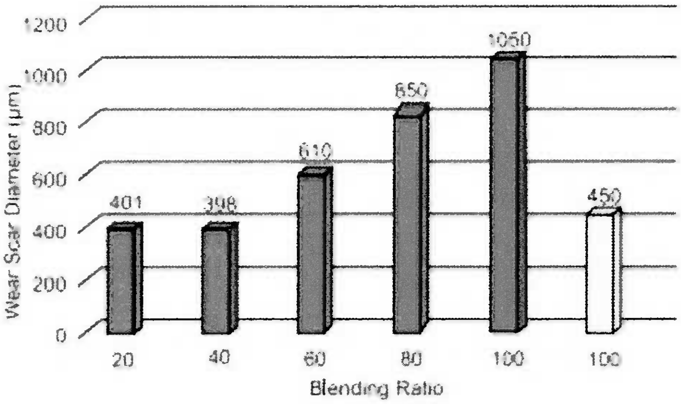

Figure 4.12: WSD (μm) vs blending ratio. (Husain et al., 2018)

4.4 Comparison between the edible and inedible vegetable oil

Among the various experiment that were conducted on finding the tribology property of the vegetable oil. The data can be collect and compare with each other in order to know which type of vegetable oil is better to be used in automotive lubrication. With the same variable used in the experiments, the properties of the bio-lubricant can be compare with each other. From this comparison can also be known either the edible or inedible vegetable oil is more useful to be use as automotive lubrication substitute.

4.4.1 Data comparison CoF of vegetable oil based on past experiments.

Table 4.1 Coefficient of Friction of Jathropa Oil, Rubber Seed Oil, Palm Oil, and Castor Oil

Oil	JO	RSO	PO	CO
COF	0.05	0.058	0.08	0.06

The variable of the experiment conducted using the bio-lubricant are the same. Which is load applied was 40kg and with speed of 1200 rpm. The table above shows the difference of coefficient of friction between the four vegetable oils. This bio-lubricant COF value was taken from various studies that had been done before. The oil was tested without adding any additive into it. This means that the experiments was conducted by using 100% ratio. Even though all of it was a plant based oil, they produce different results. This is because each oil have different chemical structure hence producing different chemical reaction when undergo the experiments. JO shows the lowest coefficient of friction with 0.05 Nm between the others, while PO shows the largest COF with 0.08 Nm among the other four. The inedible oil which is JO and RSO produce almost the same COF, while the edible oil which is PO and CO produce a large difference of COF between each other. Inedible oil shows that they have lower COF than the edible oil.

4.4.2 Data comparison of WSD based on past experiments.

Table 4.2 shows the Wear Scar Diameter of Jathropa Oil, Rubber Seed Oil, Palm Oil, and Castor Oil

Oil	JO	RSO	PO	CO
WSD(mm)	0.05	0.5	0.8	0.4

Table above shows the WSD produce by a 1:1 ratio of bio-lubricant. JO produce the smallest WSD among the 4 other bio-lubricant. PO produce the highest value of WSD amongst the four. This is a result of the chemical attack of fatty acids on the ball surface that have been lubricated with rubber seed oil and the metallic soap coating have been stripped and scrubbed off during high load sliding motion contributing to the production of non-reactive detergents that improve wear. (Fattah et al . , 2017). Between the edible and inedible oil, the inedible oil produce the lowest WSD than the edible oil.

CHAPTER 5

CONCLUSION

Vegetable oil has been studied for years due to its properties. The vegetable oil has the potential in substituting the commercial mineral oil as a lubricant. The reason why there has been a lot of research on the use of the vegetable oil is due to the pollution that had occurred around the world due to the emission of toxic component that is released by mineral oil when they are released to the environment. The negative effect that were done by the mineral oil has increase the level of concern of the world in finding a substitute for the mineral oil that is more eco-friendly. From edible to inedible vegetable oil, all of it have a potential of becoming a substitute to the commercial mineral oil.

From the analysis that have been conducted it is known that Jathropa oil (JO) has the best tribology properties amongst the other three oils.with the lowest COF and WSD among the others that is 0.05 and 0.05 m-m. Palm oil shows the biggest value of COF and WSD with 0.08 and 0.8 mm. This shows that Palm oil produce highest friction and larger wear scar. Amongst the four vegetable oil JO shows the best tribology performance amongst the other three oil. This also shows that between the edible and inedible oil, the inedible oil shows better tribology performance than the edible oils. The difference of COF and WSD amongst the vegetable oil shows that each vegetable oil is different with each other due to their chemical components that exist within them. In the data taken from the past experiments, it also shows that the vegetable oil possess more lubricity than the mineral oil with their low COF and WSD hence shows that they possess the potential of replacing the fossils fuels that are declining through out the years in the future.

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