CHAPTER 1
INTRODUCTION

1.1 BACKGROUND OF STUDY

Nowadays, the development of automotive engine lubricants has continued to keep pace with the engine design changes and engine performance expectations. Maintaining the fuel efficiency of engine lubricants during its change interval is crucial for good and impressive performance of modern powertrains. The automotive engine expectancy and efficiency can be increased by reducing the mechanical losses that are mostly caused by friction and wear. Therefore, advanced lubricants are now being formulated to reduce the wear and friction of the tribological component of the engine.

Continued growing environmental concerns are providing the impetus for increased demand and usage of vegetable oil utilization in lubricants for many applications. Out of 5-10 million tons of petroleum based oleochemicals entering the biosphere every year, about 40% comes from spills, industrial and municipal waste, urban runoff, refinery processes, and condensation from marine engine exhaust. Oleochemical pollutants are derived from the food industry, petroleum products, and by products such as lubricating hydraulic and cutting oils. Vegetable oil can offer significant environmental advantages as the lubricants with respect to resource renewability, biodegradability and adequate performance in a variety of applications [3].

Lubrication is required for sound operation of mechanical systems of engines, pumps, cams bearings, and cutting tools where without lubrication the pressure between the surfaces in close proximity would generate excessive heat for rapid surface damage which in a coarse condition literally welds the surfaces together, causing seizure.

Typically lubricants contain 90% base oil (most often petroleum fractions, called mineral oils) and less than 10% additives. Vegetable oils or synthetic liquids such as hydrogenated polyolefins, esters, silicone, fluorocarbons and many others are sometimes used as base oils. Additives deliver reduced friction and wear, increased viscosity, improved viscosity index, resistance to corrosion and oxidation, aging or contamination.

In this project, the palm oil will be used as the base oil and with little additional from mineral lubrication oil. Mineral oils will be used as the additives in this project.

1.2 PROBLEM STATEMENT

Responding to the recent government initiative to focus on Bio Technology Research Area and also the Petronas core business, the study on the automotive engine lubrication is established. With the increasing of vehicles on the road nowadays, air pollution has become a serious issue in this country. The increased in the air pollution was due to the emission of vehicles exhaust gas produced by the engine combustion and mineral based lubrication oil. Using the bio-based lubrication oil will lead to the cleaner exhaust gas and production of environmental friendly green oil.

The continuous increase in global crude oil price has triggered the idea of using vegetable oils for industrial application. Improvement of automotive fuel economy is a key element to prevent wasteful consumption of natural resources and preserve the environment. Since Malaysia has a large commodity of palm oil, therefore the study on the potentiality of using palm oil as base oil in the automotive engine lubricants is emerged. The performance of this newly developed lubricant could be compared to the performance of the existing mineral based lubricant. To perform the preliminary study on the lubrication using palm oil and the collection of test results obtained together with their analysis will be the scope of this study in order to achieve the project objective.

1.3 OBJECTIVES AND SCOPE OF STUDY

1.3.1 Objectives

The objectives of this research are to analyse bio-based lubrication behaviour using the tribological testing procedure, to evaluate the potential of its technical capability as a bio-based lubrication and to compare its properties to the existing commercial mineral lubrication and lastly conclude the findings of the study.

1.3.2 Scope of Work

The scopes of work for this project are to gather the standard information regarding Lubrication oil as classified in SAE and API, to study the essential properties of the lubrication oil and to understand perfectly the fundamental theory of lubrication such as fluid film lubrication and boundary lubrication and lubricant. Besides, it is also needs to study the basic raw material for lubrication oil and identify the suitable test procedure for the lubrication oil. On the other hand it should also study the chemical compound contained in the proposed bio based materials and search for the recent study conducted elsewhere in this field of study through relevant International Journal, Technical manual, Text Book, internet, etc.

1.4 SIGNIFICANCE OF STUDY

Upon completion of the research and test procedure/experiments, the final results obtained together with their analysis will conclude and recommend the suitability of the new lubrication oil (bio-based) for the automotive engine. The results and data will determine the performance/potential of the Bio-based candidates (palm oil) as the base oil for the automotive engine lubricant.

CHAPTER 2
LITERATURE REVIEW

2.1 FRICTION AND WEAR, LUBRICATION AND TRIBOLOGY

A lubricant is defined as a substance introduced between two mating surfaces in relative motion in order to reduce the effect of friction and prevent wear. The friction forces absorb power and give rise to wear, which ultimately will lead to a machine becoming unserviceable. If oil were put on a flat surface and a heavy block were pushed across the surface, the block would slide more easily than if it were pushed across a dry surface. The reason for this is that a wedge-shaped oil film is built up between the moving block and the surface [6]. The force required to push the block across a surface depends on the weight of the block and viscosity of the oil. Viscosity is the measure of how thick oil is and also the most important property for engine lube oil. It measures the oil's resistance to flow. The more resistant or "thick" the oil, the higher its viscosity it is. Oil with too low viscosity can shear and loose film strength at high temperatures. Oil with too high a viscosity may able to be pumped to the proper parts at low temperatures and the film may tear at high speed [7].

2.2 LUBRICATION

Lubrication is the process, or technique employed to reduce wear of one or both surfaces in close proximity, and moving relative to each another, by interposing a substance called lubricant between the surfaces to carry or to help carry the load (pressure generated) between the opposing surfaces. The interposed lubricant film can be a solid, (eg graphite, MoS_2) a solid/liquid dispersion, a liquid, a liquid-liquid dispersion (greases) or exceptionally a gas.

In the most common case the applied load is carried by pressure generated within the fluid due to the frictional viscous resistance to motion of the lubricating fluid between the surfaces. Lubrication can also describe the phenomenon when such reduction of wear occurs without human intervention (aquaplaning on a road). The science of friction, lubrication and wear is called tribology.

2.3 LUBRICANT

A lubricant is a substance (often a liquid) introduced between two moving surfaces to reduce the friction and wear between them. A lubricant provides a protective film which allows for two touching surfaces to be separated and "smoothed," thus lessening the friction between them. Lubricants chemically interact with all surfaces so that contact only occurs with the smooth and free lubricant. By this process, abrasive particles are dissolved into the lubricant, thus making them also very good solvents and cleaners.

The lubricant must be replaced when it has dissolved to saturation, because the inability to dissolve additional abrasive debris allows abrasive particles to scrape against or become lodge in the working surfaces, thus introducing a margin for physical contact between them.

Lubricants which dissolve working surfaces (like the petroleum products vasoline with rubber) defeat their purpose by corroding the smooth surfaces by their own dissolving power, thus compromising structural integrity, surface smoothness, and system-wide contamination.

Lubricants perform the following key functions, keep moving parts apart, carry away contaminants and debris, protect against wear, prevent corrosion, reduce friction, transmit power and transfer heat. Lubricants are generally composed of a majority of base oil and a minority of additives to impart desirable characteristics. Some types of lubricants are Liquid (lanolin, water, mineral oils, vegetables (natural oil), synthetic oils), Solid (Teflon/PTFE, minerals), Greases and Pastes.

2.4 THE REGIMES OF LUBRICATION

When progressively increasing the load between the contacting surfaces three distinct situations can be observed with respect to the mode of lubrication, which are called regimes of lubrication.

Fluid film lubrication is the lubrication regime in which through viscous forces the load is fully supported by the lubricant within the space or gap between the parts in motion relative to one another (the lubricated conjunction) and solid-solid contact is avoided.

2.4.1 Hydrostatic Lubrication

Hydrostatic lubrication is a special case of fluid film lubrication in which an external pressure is applied to keep the lubricant in the conjunction, enabling it to support the external load.

2.4.2 Hydrodynamic Lubrication

Hydrodynamic lubrication is also a special case of fluid film lubrication which occurs when the lubricant is able to support the load without external pressure, through hydrodynamic forces alone, which deform the shape of the interposing lubricant film into a wedge shape and drags the lubricant into the film, so that the externally applied load can be supported.

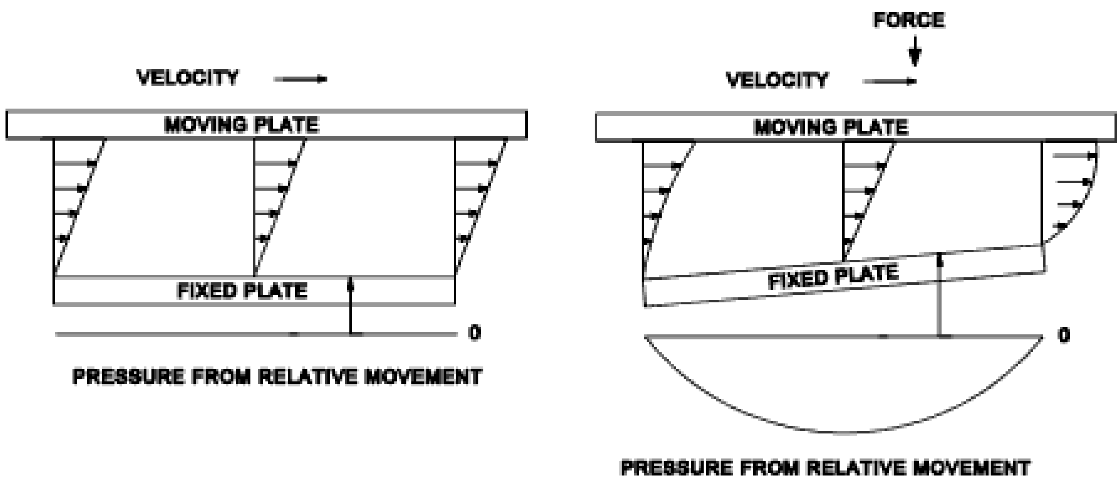

FIGURE 2.1: The picture illustrated the operation of the Hydrodynamic lubrication in opposed planes.

In hydrodynamic lubrication the fluid is assumed not to slip at the interface with the bearing surfaces i.e. the fluid in contact with the bearing surfaces moves at the same velocity as the surface. Over the thickness of the fluid there is a velocity gradient depending on the relative movement of the bearing surfaces. If the bearing surfaces are parallel (or concentric) the action motion of the lubricant will not result in a pressure which could support any bearing load.

However if the surfaces are at a slight angle the resulting lubrication fluid velocity gradients will be such that a pressure results from the wedging action of the bearing surfaces. Hydrodynamic lubrication depends upon this effect. Note; this principle is similar to the lift in water skiing / aqua planning.

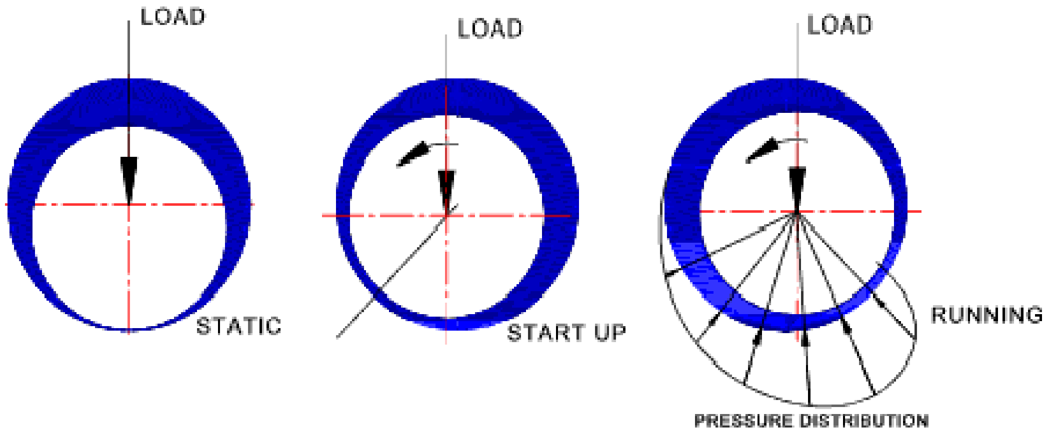

FIGURE 2.2: The picture illustrated the operation of the hydrodynamic lubrication in the journal bearing.

The operation of hydrodynamic lubrication in journal bearings is illustrated above. Before the rotation commences the shaft rests on the bearing surface. When the rotation commences the shaft moves up the bore until an equilibrium condition is reached when the shaft is supported on a wedge of lubricant. The moving surfaces are then held apart by the pressure generated within the fluid film. Journal bearings are designed such that at normal operating conditions the continuously generated fluid pressure supports the load with no contact between the bearing surfaces. This operating condition is known as thick film lubrication and results in a very low operating friction and extremely low bearing load.

2.4.3 Elastohydrodynamic Lubrication

Elastohydrodynamic lubrication: The opposing surfaces are separated but there occurs some interaction between the raised solid features called *asperities*, and there is an elastic deformation on the contacting surface enlarging the load bearing area whereby the viscous resistance of the lubricant becomes capable of supporting the load.

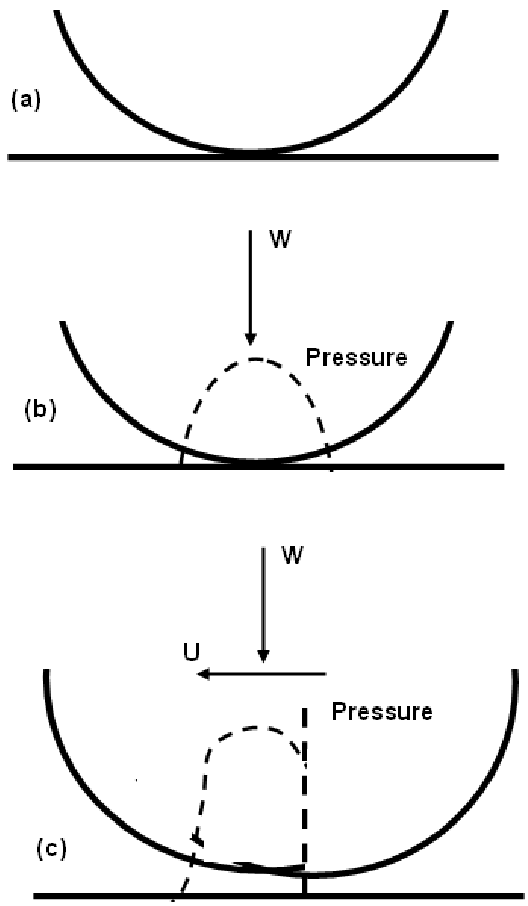

FIGURE 2.3: The picture illustrated the contact between a sphere and a plane under condition of elastohydrodynamic lubrication.

From FIGURE 2.3, when an elastic sphere is pressed against a rigid plane, initial contact occurs at a point (a). As the normal load is increased (b), the contact region expands and the contact area can be calculated from Hertz's theory. If a lubricant film is present and the sphere slides over the flat, the pressure distribution and surface deformations predicted by Hertz's equations must be modified [2].

The variation of lubricant viscosity with pressure allowing the elastic distortion of the bounding surfaces caused by the hydrodynamically generated pressure distribution. The film predicted by the theory has a thickness profile which is shown schematically in (c). It is nearly parallel for most of its length, and then develops a sharp constriction in the exit region, in which its thickness is reduced typically by about one quarter. Associated with this constriction is a local sharp spike in the pressure distribution.

2.4.4 Boundary Lubrication

Boundary lubrication (also called boundary film lubrication): The bodies come into closer contact at their asperities; the heat developed by the local pressures causes a condition which is called stick-slip and some asperities break off. At the elevated temperature and pressure conditions chemically reactive constituents of the lubricant react with the contact surface forming a highly resistant tenacious layer, or film on the moving solid surfaces (boundary film) which is capable of supporting the load and major wear or breakdown is avoided. Boundary lubrication is also defined as that regime in which *the load is carried by the surface asperities rather than by the lubricant*.

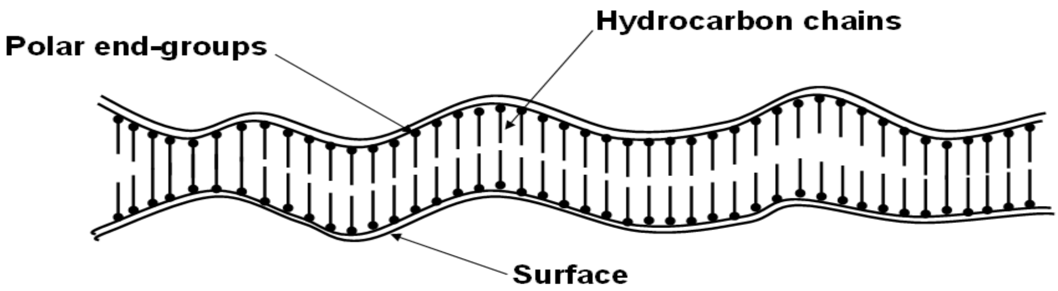

FIGURE 2.4: The mechanism of operation of a boundary lubricant. Polar end-groups on the Hydrocarbon chains bond to the surfaces, providing layers of lubricant molecules which reduce direct contact between the asperities.

FIGURE 2.4 illustrates the mechanism of operation of a typical boundary lubricant, a long-chain carboxylic acid, on metal surfaces. The lubricant molecules are adsorbed with the polar end-groups adhering strongly to the oxide layer present on the metal. The molecular chains tend to align perpendicularly to the surface, stabilized by their mutual repulsion, and form dense layers of hydrophobic chains typically 2 to 3 nm long [2].

When the two layers come together, most of the normal load is carried by the interaction of the hydrocarbon chains, and there are only small areas of naked asperity contact. The frictional force is lower than for unlubricated sliding, and although some wear does occur, it is substantially less severe than if the surfaces were unprotected [2].

Lubrication oil can last for a very long time in normal machine operation. By determining the properties of lubrication oil, many machine operators will be able to know whether the oil can still be used. Some of the important properties of the lubrication oil are viscosity, viscosity index, pour point, additives, oxidation resistance, flash point, fire point and also alkalinity.

2.5 PROPERTIES OF LUBRICANTS

2.5.1 Oil Viscosity

The parameter which plays a fundamental role in lubrication is oil viscosity. Different oils exhibit different viscosities. In addition, oil viscosity changes with temperature, shear rate and pressure and the thickness of the generated oil film is usually proportional to it. So, at first glance it appears that the more viscous oil would give better performance, since the generated films would be thicker and a better separation of the two surfaces in contact would be achieved [1].

This unfortunately is not always the case since more viscous oils require more power to be sheared. Consequently the power losses are higher and more heat is generated resulting in a substantial increase in the temperature of the contacting surfaces which may lead to the failure of the component. For engineering applications the oil viscosity is usually chosen to give optimum performance at the required temperature [1].

The viscosity of different oils varies at different rates with temperature. It can also be affected by the velocities of the operating surfaces (shear rates). The knowledge of the viscosity characteristics of a lubricant is therefore very important in the design and in the prediction of the behavior of a lubricated mechanical system [1].

2.5.2 Kinematic Viscosity

Kinematic viscosity is defined as the ratio of dynamic viscosity to fluid density [1]:

$$\nu = \eta / \rho$$

where:

ν = is the kinematic viscosity [m^2/s];
η = is the dynamic viscosity [Pas];
ρ = is the fluid density [kg/m^3].

The most commonly used kinematic viscosity unit is the Stoke [S]. This unit, however, is often too large for practical applications, thus a smaller unit, the centistokes [cS], is used. The SI unit for kinematic viscosity is [m^2/s], i.e.:

$$1 \text{ [S]} = 100 \text{ [cS]} = 0.0001 \text{ [m}^2\text{/s]}$$

The densities of lubricating oils are usually in the range between 700-1200 [kg/m^3] (0.7-1.2 [g/cm^3]). The typical density of mineral oil is 850 [kg/m^3] (0.85[g/cm^3]). To find the dynamic viscosity of any oil in [cP] the viscosity of this oil in [cS] is multiplied by its density in [g/cm^3], hence for a typical mineral oil [9]:

$$\text{Viscosity in [cP]} = \text{viscosity in [cS]} \times 0.85 \text{ [g/cm}^3\text{]}$$

2.5.3 Viscosity Temperature Relationship

The viscosity of lubricating oils is extremely sensitive to the operating temperature. With increasing temperature the viscosity of oils falls quite rapidly. In some cases the viscosity of oil can fall by about 80% with a temperature increase of 25°C. From the engineering viewpoint it is important to know the viscosity value at the operating temperature since it determines the lubricant film thickness separating two surfaces [1].

For a liquid, the kinematic viscosity will decrease with higher temperature. For a gas, the kinematic viscosity will increase with higher temperature. The oil viscosity at a specific temperature can be either calculated from the viscosity-temperature equation or obtained from the viscosity-temperature ASTM chart.

2.5.4 Viscosity Index

From the engineering viewpoint there was a need for a parameter which could accurately describe the viscosity-temperature characteristics of the oils. In 1929 a "Viscosity Index" was developed by Dean and Davis [1]. Viscosity Index (VI) highlights how a lubricants viscosity changes with variations in temperature. Many lubricant applications require the lubricant to perform across a wide range of conditions. The best oils (with the highest VI) will not vary much in viscosity over such a temperature range and therefore will perform well throughout.

The viscosity scale was set up by the Society of Automotive Engineers (SAE). Viscosity Index is quantified by comparing the behavior of the oil with that of two reference oils of known VI. The temperatures chosen arbitrarily for reference are 100 degree Fahrenheit (40°C) and 210°F (100°C). The original scale only stretched between VI=0 (worst oil) and VI = 100 (best oil) but since the conception of the scale better oils also have been produced, leading to VI greater than 100.

Note that the Viscosity Index is an inverse measure of the decline in oil viscosity with temperature. High values indicate that the oil shows less relative decline in viscosity with temperature. The Viscosity Index of most of the refined mineral oils available on the market is about 100, whereas multigrade and synthetic oils have higher viscosity indices of about 150 [1].

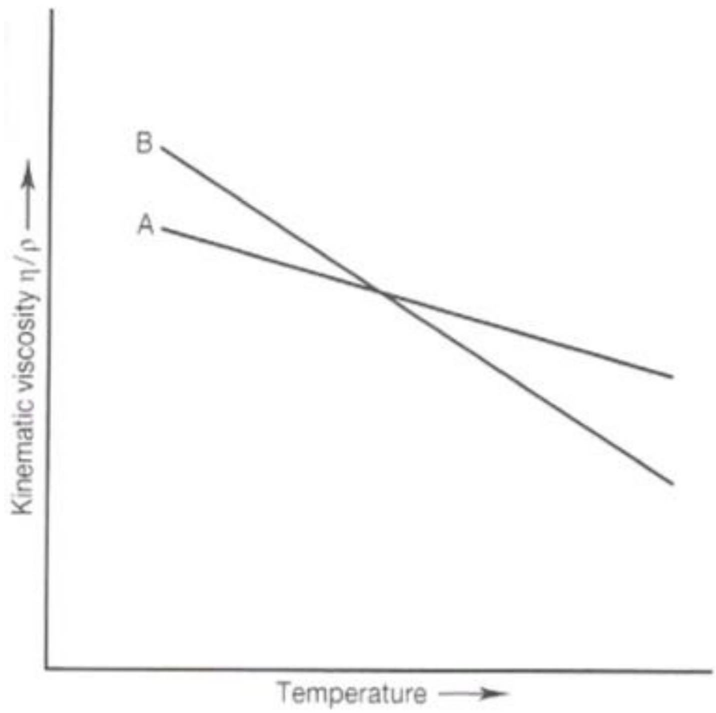

FIGURE 2.5: The graph shown the variation of kinematic viscosity with temperature for two mineral oils. Oil A has a higher viscosity index than oil B.

The behavior of two different oils is illustrated in FIGURE 2.6. Both oils have the same viscosity at room temperature, but the viscosity of oil A drops off less rapidly at higher temperatures than B. Oil A is said to have a higher viscosity index than B [2].

Viscosity Index improver additives and higher quality base oils are widely used nowadays which increases the VI's attainable beyond the value of 100 as shown in Figure 2.7. The viscosity index of synthetic oils ranges from 80 to over 400. Suitable polymer additives, such as polybutene or polyacrylics, increase the viscosity index of oil and are often used as viscosity index improvers in lubricating oils. Under conditions of high shear rate, however, these additives may lose their effectiveness, and the viscosity can then drop sharply [2].

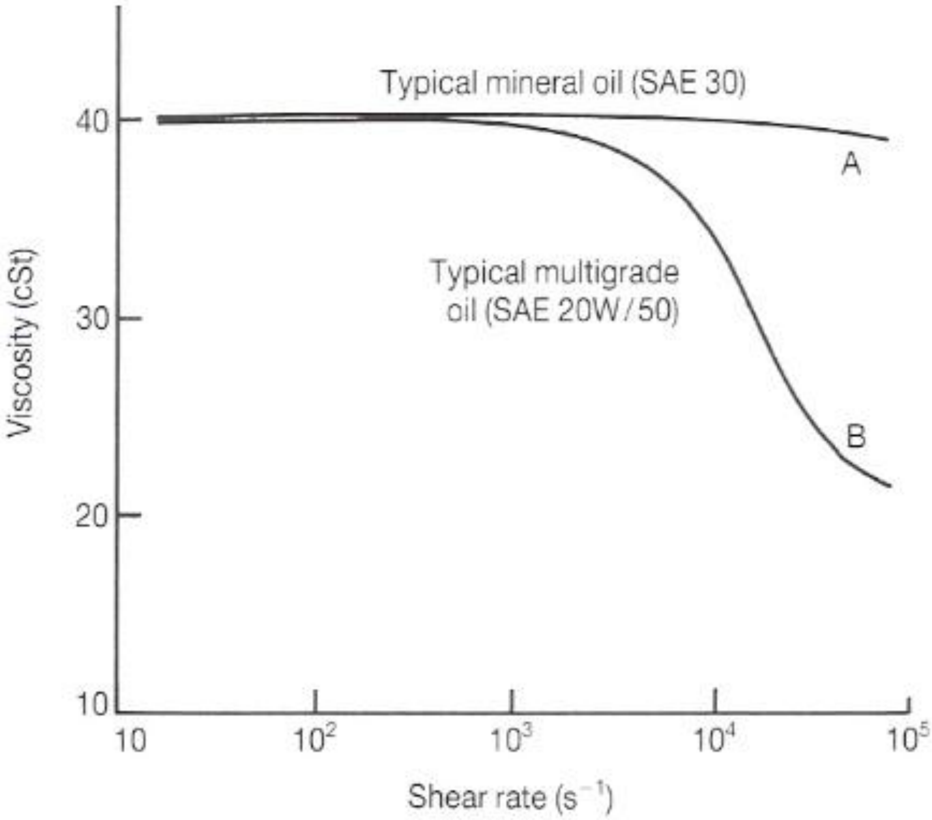

FIGURE 2.6: The variation of viscosity with shear rate for two mineral oils with the same viscosity at low shear rates. Oil A is a plain mineral oil, while oil B contains viscosity index improvers which lose their effectiveness at high shear rates.

2.6 TEMPERATURE CHARACTERISTICS OF LUBRICANTS

Temperature characteristics are crucial parameter in selecting the lubricant for specific application. At high temperature, oils decompose or degrade while at low temperatures oil may become near solid of even freeze. Oils tend to release the deposit or lacquer on the contacting surfaces, forming the emulsion with water or even might produce foam when vigorously churned.

2.6.1 Flash and Fire Points

The ‘flash point’ of the lubricant is the temperature at which its vapour will ignite. In order to determine the flash point the oil is heated at a standard pressure to a temperature which is just high enough to produce sufficient vapour to form an ignitable mixture with air. This is the flash point. The ‘fire point’ of oil is the temperature at which enough vapour is produced to sustain burning after ignition. Flash and fire points (ASTM D92, D93, D56, D1310) are very important from the safety view point since they constitute the only factors which define the fire hazard of a lubricant. In general, the flash point and the fire point of oils increase with increasing molecular weight. For a typical lubricating oil, the flash point is about 210°C whereas the fire point is about 230°C.

2.6.2 Pour and Cloud Points

The pour point of an oil (ASTM D97, D2500) is the lowest temperature at which the oil will just flow when it is cooled. This oil property is important in the lubrication of any system exposed to low temperature, such as automotive engines, construction machines, military and space applications. When oil ceases to flow this indicates that sufficient wax crystallization has occurred or that the oil has reached a highly viscous state. At this stage wax of high molecular weight paraffins precipitate from the oil. The waxes form the interlocking crystals which prevent the remaining oil from flowing. This is a critical point since the successful operation of a machine depends on the continuous supply of oil to the moving parts.

The cloud point is the temperature at which paraffin wax and the other materials begin to precipitate. The onset of wax precipitation causes a distinct cloudiness or haze visible in the bottom of the jar. This occurrence has some practical applications in capillary or wick fed system in which the forming wax may obstruct the oil flow. It is limited only to the transparent fluids since measurement is based purely on observation. If the cloud point of oil is observed at a temperature higher than the pour point, the oil is said to have a ‘Wax Pour Point’. If the pour point is reached without a cloud point the oil shows a simple ‘Viscosity Pour Point’.

2.7 PALM OIL (BASE OIL)

Palm oil is derived from the fruit of the oil palm tree, Elaesis guineensis, which has the appearance of a date palm with a large head of pinnate feathery fronds growing from a sturdy trunk. The fruit grows in bunches usually weighing in excess of 40 pounds, with 400 to 2000 individual fruits [8]. Palm oil is obtained from the flesh ("mesocarp") of the oil palm fruit. Like olive oil, palm oil is fruit oil. Palm oil should not be mistaken for palm kernel oil which is extracted from the kernel or seed of the palm fruit [9].

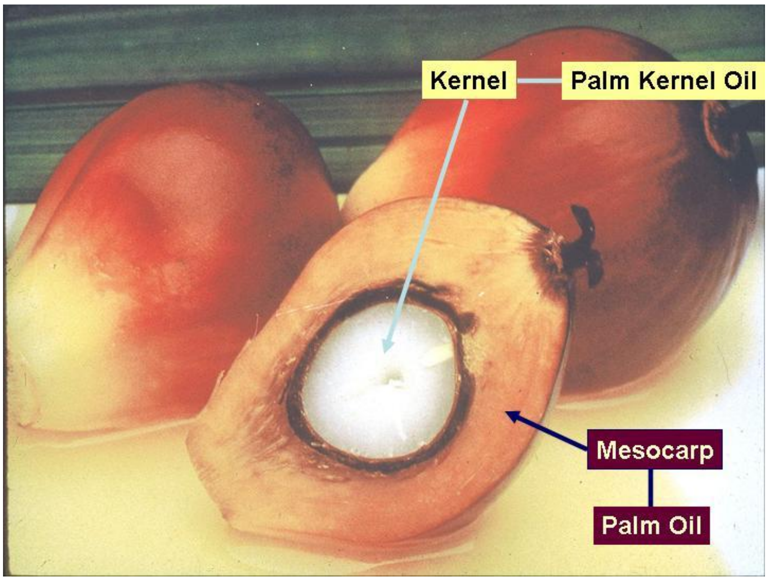

FIGURE 2.7: Picture of Palm fruit

Each palm fruit produces about 90% palm oil and 10% palm kernel oil. Palm oil contains an equal proportion of saturated and unsaturated fatty acids. It's particularly rich in the saturated palmitic acid (44%), with substantial amounts of the monounsaturated oleic acid (40%), and smaller amounts of polyunsaturated fatty acids (10%) [9].

Palm oil, being vegetable oils, is cholesterol-free. Having a naturally semi solid characteristic at room temperature with a specific origin melting point between 33ºC to 39ºC, it does not require hydrogenation for use as a food an ingredient [9].

The quality of the palm oil achieved at the mill and subsequent processing is dependent upon the fruit bunches delivered to the oil mill. Overripe fruit bruises easily, accelerating free fatty acid rise through enzymatic hydrolysis and adversely affecting bleachability of the extracted oil. After receipt at the oil mill, extraction of the oil from the fruit is accomplished in four stages [8]:

a) **Sterilization** – the fruit bunches are subjected to live steam under pressure to deactivate the enzymes responsible for hydrolysis and to loosen the fruit from the bunches. Improper deaeration or oversterilization has been found to create bleaching problems.
b) **Digestion** – the palm fruit is mashed at high temperatures to break up the cells to allow release of the oil particles.
c) **Pressing** – screw presses with gradual compression and live steam injection are used to extract the oil from the fruit.
d) **Clarification** – the oil settled out in a clarification tank is centrifuged to remove moisture and impurities followed by atmospheric or vacuum drying.

2.7.1 Chemistry of Palm Oil

Palm oil and palm kernel oil are composed of fatty acids, esterified with glycerol just like any ordinary fat. Both are high in saturated fatty acids, about 50% and 80%, respectively. The oil palm gives its name to the 16 carbon saturated fatty acid palmitic acid found in palm oil; monounsaturated oleic acid is also a constituent of palm oil while palm kernel oil contains mainly lauric acid. Palm oil is the largest natural source of tocotrienol, part of the vitamin E family. Palm oil is also high in vitamin K and dietary magnesium.

Napalm derives its name from naphthenic acid, palmitic acid and pyrotechnics or simply from a recipe using naphtha and palm oil. The approximate concentration of fatty acids (FAs) in palm oil is as follows:

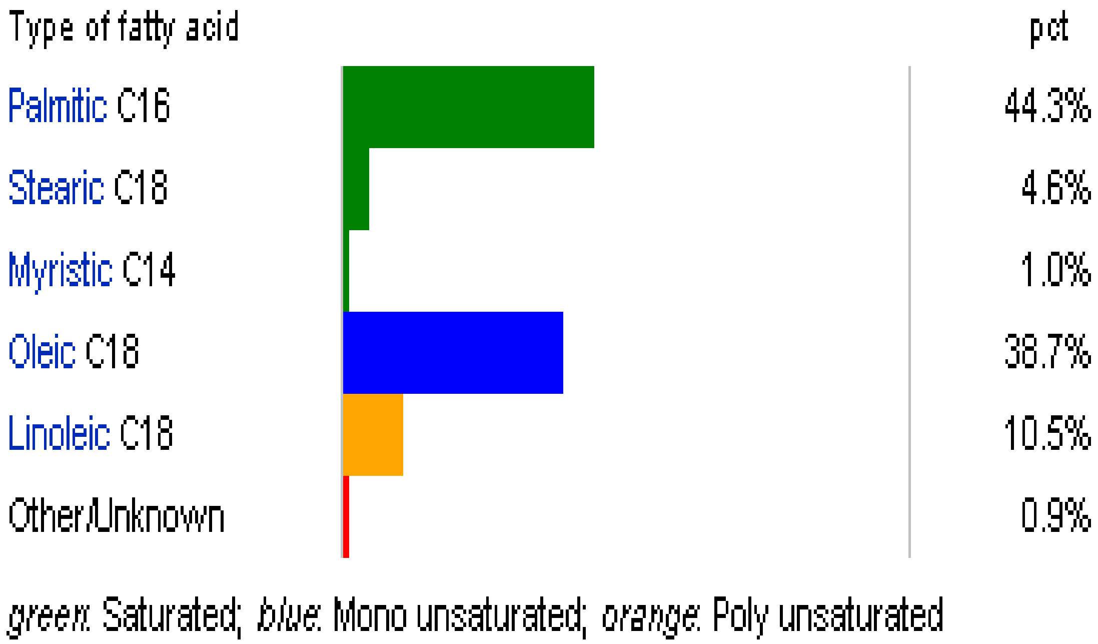

FIGURE 2.8: Statistical of fatty acid content of palm oil

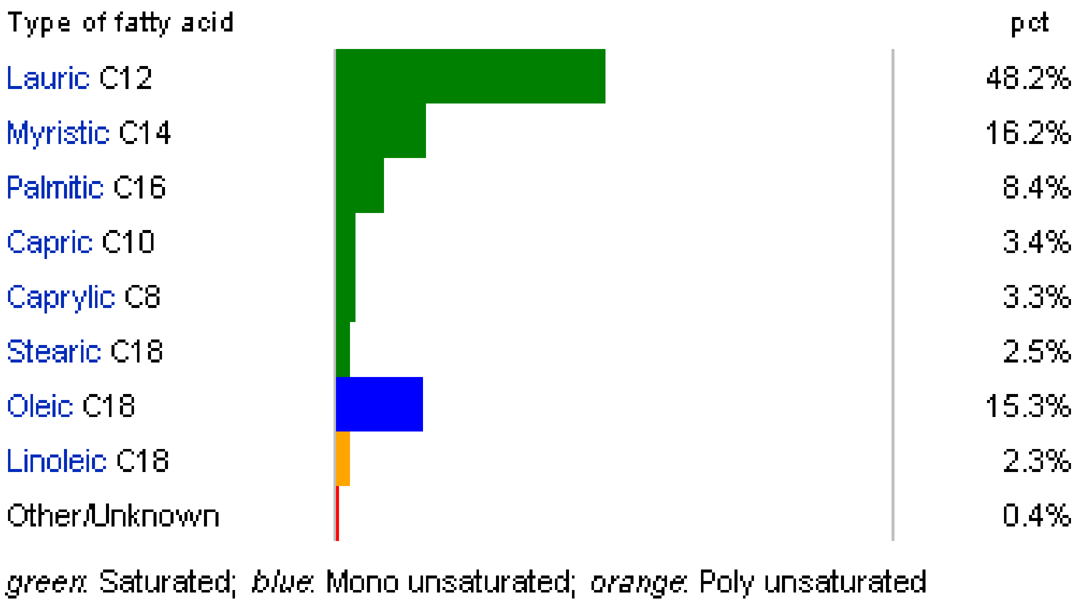

FIGURE 2.9: Statistical of fatty acid content of palm kernel oil

2.7.2 Palm Oil Composition & Physical Properties

Crude palm oil has a deep orange-red color contributed by high carotene content: 0.03% to 0.15%, of which consists of alpha and beta carotene. Caustic refining has little effect upon the color, but it can be heat bleached to low colors if the carotene has not been oxidized and fixed; abused crude palm oil may develop a brown color that is very difficult to remove [8].

Palm oil is distinguished from other oils by a very high level of palmitic fatty acid. This compares with a typical level of 21.6% for cottonseed oil, which is the vegetable oil with the next highest palmitic fatty acid level available in the United States. Hydrogenated hardstocks from both of these source oils, cottonseed and palm, are utilized to produce shortenings with beta-prime crystal habits. The TABLE 2.1 and 2.2 in Appendix A show the typical physical properties and characteristics for crude palm oil and kernel oil [8].

2.8 LUBRICATION OIL ADDITIVES

Different additives do different jobs. They can inhibit corrosion, foaming and oxidation, and act as dispersants. Special chemicals called additives are added to the base oil by the oil companies. Different combinations of these additives allow the oil to do different jobs in an engine. Extreme-pressure additives coat parts with a protective layer so that the oil resists being forced out under heavy load [10].

Additives are used in engine oils for different reasons [6]:

a) To replace some properties removed during refining.
b) To reinforce some of oil’s natural properties.
c) To provide the oil with new properties it did not originally have.
d) Control of corrosion.
e) Control of contamination by reaction products, wear particles and debris.
f) Reducing excessive decrease of lubricant viscosity at high temperatures.

Oxidation-inhibitors stop very hot oil combining with oxygen in air to produce a sticky material like tar, which clogs galleries. Corrosion-inhibitors help stop acids forming that cause corrosion, especially of bearing surfaces. Anti-foaming agents reduce the effect of oil churning in the crankcase and minimize foaming. Detergents reduce carbon deposits on parts like piston rings and valves. Dispersants collect particles that can block the system, separate them from each other and keep them moving. Then they will be removed when the oil is changed [10].

2.8.1 Properties of engine oil

Engine oils are sold with an SAE (Society of Automotive Engineers) grade number. It is indicates the viscosity range into which the oil fits. Oils tested at 212°F (100°C) have a number with no letter following. For example, SAE 30 indicates that the oil has only been checked at 212°F (100°C) [6]. This oil's viscosity falls within the SAE 30 grade number when the oil is hot. SAE 20W-30 indicates that the oil has been tested both 0°F (-18°C) and 212°F (100°C).

The letter ***W*** indicates *Winter*. Its viscosity falls into SAE 20W grade number range when the oil is cold and into the 20 grade number range when the oil is hot [6]. An SAE 5W-30 multigrade oil is one that meets the SAE 5W viscosity specification when cooled to 0°F (-18°C) and meets the SAE 30 viscosity specification when tested at 212°F (100°C). Multigrade oils must have a higher viscosity index than do straight-grade oils. Index viscosity is change in viscosity between the cold and hot extreme [6].

2.8.2 Synthetic Oils

This newly formulated lubrication oil will used the mineral oil as the additives and the palm oil as the base oil as mentioned before. Synthetic oils offer better protection against engine wear and can operate at higher temperatures. They have better low temperature viscosity, are chemically more stable and allow for closer tolerances in engine components without loss of lubrication. Synthetic lubricating oils are more costly to manufacture and to use but they have a number of advantages over conventional mineral oils.

They also last considerably longer, extending oil change intervals out to 15,000 Kms or 10,000 miles or more, which benefits the environment by reducing the used oil stream. True synthetic oils are based on man-made hydrocarbons, commonly polyalphaolefin or PAO, but very few of the synthetic oils on the market are full PAO oils. Many of the oils allowed to be labeled as synthetic are in fact blends of processed mineral oil and PAO, or even just heavily processed natural crude oil.

2.8.3 Multigrade Lubrication Oil

Term multigrade means an oil meeting the requirements of more than one SAE viscosity grade classification, and may therefore be suitable for use over a wider temperature range than a single-grade oil. The essence of the classification is to indicate viscosity at both low (engine-starting) temperatures and high (operating) temperatures [1]. The viscosities are indicated by two numbers, with higher values showing greater viscosity. The low-temperature viscosity is indicated with a **W** (for winter) and is given first. The correct way to indicate SAE viscosity is SAE xx**W**yy (e.g SAE 10W-30) [6].

2.8.4 Petronas Mach 5

The lubrication oil that will be selected as the additives for this newly formulated lubrication oil is the Petronas Mach 5 oil. PETRONAS Mach 5 is extra high performance multigrade engine oil specially designed and formulated to provide very high level of engine protection and superior performance in engines running under the most severe driving conditions. It is exclusively formulated with premium quality unconventional base oils and advanced additives technology to provide the outstanding thermal and oxidation stability that ensure minimum oil thickening at very high operating temperature, excellent deposits control and minimized engine wear and tear [11].

Engineered based on extensive field, racetrack, rally and testing experiences over many years, PETRONAS Mach 5 provides the outstanding performance lubricant that ensure complete engine protections especially for engines operating under the most severe operating conditions throughout today's long drain interval [11].

2.8.5 Applications and Benefits

Petronas Mach 5 is recommended for use in all types of passenger cars especially the latest model high performance cars fitted with fuel injections, multi-valves, turbochargers or superchargers operating under the most extreme conditions. This oil also suitable for engines requiring API SL, SJ, SH, SG or lower performance levels [11].

Some of the benefits of the Petronas Mach 5 oil are it produces outstanding engine protection at all driving conditions, prolong engine life, outstanding engine cleanliness- protect against sludge and vanish deposits, resits viscosity and thermal breakdown even under the most severe service, very high shear stability (stay in grade) and also easier cold engine starting (minimize friction and wear during start-up). The TABLE 2.3 in Appendix A show the product typical of Petronas Mach 5 SL [11].

The following are the standards abide by PETRONAS Mach 5 SL according to the American Petroleum Institute (API), International Lubricants Standardization and Approval Committee (ILSAC) and the Association of Constructors of European Automobiles (ACEA).

TABLE 2.4: PETRONAS Mach 5 SL Standards

Standards	**SAE 10W-30**
API	SL/CF
ILSAC	GF-3
ACEA	A3-98

CHAPTER 3

METHODOLOGY

3.1 PROJECT METHODOLOGY

Basically, the project had been divided into three main parts which are research/study, perform testing procedure and data analysis. For FYP I, the project covered the research and study part where it focused on studying the standard information regarding lubrication oil as classified in SAE and API and gathering other information and recent study conducted elsewhere about the field. By the end of the first part, the author is expected to be able to understand perfectly the fundamental of lubrication and scope of the project and perform preliminary test procedure of the newly formulated lubrication oil.

While for the implementation parts had been covered during FYP II. For the second parts, the project focused on performing the test procedure for the newly formulated lubrication oil and analysed the data obtained. The test procedures that involved were Lubrication Raw Oil Materials Mixing and Blending Technique, Viscosity Testing and Four (4) Ball Wear Test. For the data analyzing, the procedure had been performed by Optical Microscopy Analysis and SEM Analysis.

The collection of the test results obtained together with their analysis had been compared to the existing mineral lubrication oil. The results concluded the performance and potentiality of using this newly formulated lubrication oil to the end user. By the end of this part it is expected to have a completed research and findings on development of Bio-based automotive engine lubrication oil.

3.2 MULTIMIXER (MUD MIXER)

Multimixer or also known as the mud mixer is the equipment for the Lubrication Raw Oil Materials Mixing and Blending Technique. In order to mix the palm oil with the additive (Petronas Mach 5), the author used this equipment so that the oils can be mixed well/better. The author used the multimixer to produce 3 samples of the lubricants. First sample contains 95% palm oil + 5% mach 5, second sample contain 90% palm oil + 10% mach 5 and the last one is 85% palm oil + 15% mach 5. These samples will be used for the viscosity testing and also 4 ball testing method (FIGURE 3.1 in Appendix A).

TABLE 3.1: Bio-based Lubrication Oil composition.

Specimen	**Composition**
Specimen 1	100% Petronas Mach 5
Specimen 2	100% Palm Oil
Specimen 3	95% Palm Oil + 5% Petronas mach 5
Specimen 4	90% Palm Oil + 10% Petronas Mach 5
Specimen 5	85% Palm Oil + 15% Petronas Mach 5

The author prepared each samples around 200ml and the time taken to mix the samples is around 10-15 minutes. Actually, there is no specific time to mix the oils, but in order to make sure that the oils mix well, longer time is better. The standard operating procedure for the multimixer/mud mixer is quite simple and easy to use.

3.3 VISCOMETER

The author used the Tamson Viscometer Unit model of Armfield (TVB445) to perform the viscosity testing on the prepared samples of lubricants. The TVB445 bath is designed to perform a variety of accurate temperature control required for general laboratory use or as a constant temperature bath. The bath is intended for temperature control of applications requiring an extremely high degree of stability over a broad temperature range. The robust construction and advanced safety features give the bath a wide application range (FIGURE 3.2 in Appendix A).

The heat input is controlled by a microprocessor system. A special optimized electronic temperature measurement circuit ensures high accuracy and reproducibility of operation conditions. The bath features standard a RS232C interface for connection to a computer, data logger or terminal. The baths have a cooling coil built-in as standard, for rapidly bringing the bath temperature down, or for working at or below ambient temperature.

When used the Tamson Viscometer Unit, there is certain thing that the author need to take care of like the temperature control and setting of the machine. The author needs to adjust the required temperature setting manually although there is a digital setting that displays the temperature already. Both the values should be equal in order to get better results.

3.4 FOUR BALL WEAR TESTER

The Four-Ball geometry was developed in 1933 and has become one of the most widely used wear test procedures. It's self-aligning nature and ready availability inexpensive high quality test specimens make it ideally suited to being and accurate and repeatable screening test. The most widely used the test methods for this apparatus are ASTM D 2266 for greases and ASTM D 4172 for lubricants.

The ASTM D-4172 Four-Ball Wear Test is the standard test used to determine a lubricant's ability to minimize wear in metal-to-metal contact situations. Three steel balls are secured and placed in a triangular pattern within a bath of the test lubricant. With load, speed and temperature kept constant, a fourth ball sits atop the other balls and is rotated and forced into them for one hour. Following the test, the lower three balls are inspected for wear scars at the point of contact. The diameters of the wear scars are measured and the results are reported as an average of the three scars. The lower the average wear scar diameter, the better the wear protection properties of the oil.

TABLE 3.2: Typical test condition for ASTM D 4172 Wear Test.

Temperature	75 +/- 2°C (167°F)
Speed	1200 +/- 60 rpm
Duration	60 +/- 1 minute
Load	392 +/- 2N (40kgf)

In this test, three 12.7 mm diameter steel balls are clamped and fixed in a cup together and immersed in the test oil to be evaluated. A fourth 12.7 mm diameter steel ball, referred to as the top ball, turned on the other three under specific conditions of temperature, speed, load and time. The top ball is pressed with a force of 147 or 392 N (15 or 40 kgf) into the cavity formed by the three clamped balls for three-point contact. The temperature of the test oil is regulated at 75°C while the top ball is rotated at 1200 rpm for 60 minutes. After the test, the wear scar diameters on the three lower balls are measured in two perpendicular directions and the balls are replaced. The results of wear tests are in the form of a wear scar diameter for a given load applied for a given time (FIGURE 3.3 in Appendix A).

3.5 OPTICAL MICROSCOPE

The optical microscope is a type of microscope which uses visible light and a system of lenses to magnify images of small samples. It consists of a small, single convex lens mounted on the objective turret to magnifying the wear scar on the specimen. The ball is placed on the table (holder) and make sure that it receives visible light. Adjust the knob to magnify the image until the scar clearly can be observed before the reading taken. Rotate the ball and take another reading at different place on the ball and then take the average reading of the wear scar diameter of the ball. Lubricants are compared by using the average size of the measured scars. However, the further details can be obtained by using Scanning Electron Microscopy (SEM) analysis (FIGURE 3.4 in Appendix A).

3.6 SCANNING ELECTRON MICROSCOPE (SEM)

Scanning electron microscopy (SEM) is widely used to qualitatively examine surface texture of tribological specimens where the images are characterized by high resolution three-dimensional appearance and are useful for judging the surface structure of the sample. The surface images used in the analysis are obtained either by tilting the specimen in the SEM by known angle (high magnification images) or by translating the specimen by a known distance, low magnification images (FIGURE 3.5 in Appendix A).

CHAPTER 4
RESULTS AND DISCUSSION

4.1 LABORATORY VISCOSITY TEST RESULT

4.1.1 Viscosity Test (Petronas Mach 5)

TABLE 4.1: Results for Petronas Mach 5 Viscosity Test

Test	Temperature (°C)	Size Ubbelohde Viscometer	Efflux Time obtained (s)	Kinematic Viscosity
1	40	2 [20-100 mm²/s, cSt]	714 seconds	71.4 mm²/s, cSt
2	100	1C [6-30 mm²/s, cSt]	394 seconds	11.82 mm²/s, cSt

TABLE 4.1 shows the viscosity test results for Petronas Mach 5 obtained from the viscosity measurement using the Tamson Viscometer Unit. From the table, the kinematic viscosity obtained for temperature 40°C is 71.4 mm²/s and for the temperature 100°C the result is 11.82 mm²/s. The value of the kinematic viscosity decreased as the temperature increased from 40°C to 100°C. The results proved that the viscosity of lubricants is extremely sensitive to the operating temperature as stated in the theory. With the increasing in temperature, the viscosity of oils falls quite rapidly. These results are almost the same as the kinematic viscosity claimed by the manufacturers which stated that for temperature 40°C, the kinematic viscosity for the Petronas Mach 5 is 72.9 mm²/s and for temperature 100°C, the value is 11.2 mm²/s.

Calculation for kinematic viscosity:

To obtain kinematic viscosity in mm^2/s, cSt, multiply the efflux time in seconds by the viscometer constant. The viscometers constant are ranges based on the size of the Ubbelohde Viscometer use.

Test 1

The viscometer constant for size 2 is 0.1 mm^2/s^2, cSt/s.

Kinematic viscosity = (0.1 mm^2/s^2) x (714 s)

= 71.4 mm^2/s

Test 2

The viscometer constant for size 1C is 0.03 mm^2/s^2, cSt/s.

Kinematic viscosity = (0.03 mm^2/s^2) x (394 s)

= 11.82 mm^2/s

4.1.2 Viscosity Test (Palm Oil)

TABLE 4.2: Results for Palm Oil Viscosity Test.

Test	Temperature (°C)	Size Ubbelohde Viscometer	Efflux Time Obtained (s)	Kinematic Viscosity
1	40	1B [10-50 mm^2/s, cSt]	687 seconds	34.35 mm^2/s, cSt
2	100	1 [2-10 mm^2/s, cSt]	850 seconds	8.5 mm^2/s, cSt

From the TABLE 4.2 above, the kinematic viscosity for the palm oil viscosity test obtained for test 1 (40°C) is 34.35 mm^2/s and for test 2 (100°C), the result is 8.5 mm^2/s. Based on the theory and research done, the manufacturers claimed that the viscosity for palm oil at temperature 40°C is 41.66 mm^2/s 40°C and 8.47 mm^2/s at temperature 100°C. The results obtained from the experiment are almost the same as claimed by the manufacturers. The kinematic viscosity of the palm oil also decreased as the temperature increased from 34.35 mm^2/s at 40°C to 8.5 mm^2/s at temperature 100°C.

4.1.3 Viscosity Test (95% Palm Oil + 5% Mach 5)

<u>FOR 40°C</u>

TABLE 4.3: Results for (95% Palm Oil + 5% Mach 5) at 40°C Viscosity Test

Test	Size Ubbelohde Viscometer	Efflux Time Obtained (s)	Kinematic Viscosity
1	1B [10-50 mm^2/s, cSt]	714 seconds	35.7 mm^2/s, cSt
2	1B [10-50 mm^2/s, cSt]	715 seconds	35.75 mm^2/s, cSt
3	1B [10-50 mm^2/s, cSt]	714 seconds	35.7 mm^2/s, cSt

Average = 714.33 s   Average =35.72

TABLE 4.3 shows the results of kinematic viscosity at temperature 40°C for 95% Palm Oil + 5% Mach 5 sample. Since the author does not have the kinematic viscosity test claimed by the manufacturers for this newly developed sample, the author performed the viscosity test three times for the same sample and takes the average of the results obtained. The significance for this action is in order to get more accurate and precise results of the sample. The average result obtained for the sample at temperature 40°C is 35.72 mm^2/s. Compared to the result obtained for the palm oil sample before, the kinematic viscosity has increased from 34.35 mm^2/s to 35.72 mm^2/s. The increased in the result is due to the additive that has been added to the palm oil sample.

<u>FOR 100°C</u>

TABLE 4.4: Results for (95% Palm Oil + 5% Mach 5) at 100°C Viscosity Test

Test	Size Ubbelohde Viscometer	Efflux Time Obtained (s)	Kinematic Viscosity
1	1 [2-10 mm^2/s, cSt]	914 seconds	9.14 mm^2/s, cSt
2	1 [2-10 mm^2/s, cSt]	911 seconds	9.11 mm^2/s, cSt
3	1 [2-10 mm^2/s, cSt]	912 seconds	9.12 mm^2/s, cSt

Average = 912.33 s   Average = 9.12

TABLE 4.4 shows the result of viscosity test at temperature 100°C for 95% Palm Oil + 5% Mach 5 sample. From the table, the kinematic viscosity result for the sample is 9.1233 mm²/s. The result obtained is the average value from three tests that has been conducted on the sample. The kinematic viscosity for this sample decreased from 35.72 mm²/s to 9.1233 mm²/s as the temperature increased to 100°C. This result is higher compared to the result for palm oil at temperature 100°C.

4.1.4 Viscosity Test (90% Palm Oil + 10% Mach 5)

FOR 40°C

TABLE 4.5: Results for (90% Palm Oil + 10% Mach 5) at 40°C Viscosity Test

Test	Size Ubbelohde Viscometer	Efflux Time Obtained (s)	Kinematic Viscosity
1	1B [10-50 mm²/s, cSt]	696 seconds	34.8 mm²/s, cSt
2	1B [10-50 mm²/s, cSt]	701 seconds	35.05 mm²/s, cSt
3	1B [10-50 mm²/s, cSt]	698 seconds	34.9 mm²/s, cSt

Average = 698.33 s   Average =34.9167

TABLE 4.5 shows the result of viscosity test for 90% Palm Oil + 10% Mach 5 sample at 40°C. From the table, the kinematic viscosity for the sample at 40°C is 34.9165 mm²/s. Compared to the kinematic viscosity of 95% Palm Oil + 5% Mach 5 sample at 40°C, the value decreased from 35.72 mm²/s to 34.9165 mm²/s. Based on the theory, the value of the kinematic viscosity should increase once the additive added to the sample.

FOR 100°C

TABLE 4.6: Results for (90% Palm Oil + 10% Mach 5) at 100°C Viscosity Test

Test	Size Ubbelohde Viscometer	Efflux Time Obtained (s)	Kinematic Viscosity
1	1 [2-10 mm²/s, cSt]	838 seconds	8.38 mm²/s, cSt
2	1 [2-10 mm²/s, cSt]	844 seconds	8.44 mm²/s, cSt
3	1 [2-10 mm²/s, cSt]	848 seconds	8.48 mm²/s, cSt

Average = 843.33 s   Average = 8.433

TABLE 4.6 shows the result of kinematic viscosity for 90% Palm Oil + 10% Mach 5 at temperature 100°C. From the table, the kinematic viscosity for the sample at 100°C is 8.433 mm²/s. Compared to the kinematic viscosity of 95% Palm Oil + 5% Mach 5 sample at 100°C, the value decreased from 9.1233 mm²/s to 8.433 mm²/s. The sample 90% Palm Oil + 10% Mach 5 drops off less rapidly at higher temperatures than sample 95% Palm Oil + 5% Mach 5. So it has higher viscosity index.

4.1.5 Viscosity Test (85% Palm Oil + 15% Mach 5)

FOR 40°C

TABLE 4.7: Results for (85% Palm Oil + 15% Mach 5) at 40°C Viscosity Test

Test	Size Ubbelohde Viscometer	Efflux Time Obtained (s)	Kinematic Viscosity
1	1B [10-50 mm²/s, cSt]	694 seconds	34.7 mm²/s, cSt
2	1B [10-50 mm²/s, cSt]	695seconds	34.75 mm²/s, cSt
3	1B [10-50 mm²/s, cSt]	701 seconds	35.05 mm²/s, cSt

Average = 696.67 s   Average = 34.833

TABLE 4.7 shows the result of viscosity test for 85% Palm Oil + 15% Mach 5 sample at 40°C. From the table, the kinematic viscosity for the sample at 40°C is 34.8335 mm²/s. Compared to the kinematic viscosity of 90% Palm Oil + 10% Mach 5 sample at 40°C, the value decreased from 34.9165 mm²/s to 34.8335 mm²/s. Based on the theory, the properties of the sample should increase once the additive added to the sample.

FOR 100°C

TABLE 4.8: Results for (85% Palm Oil + 15% Mach 5) at 100°C Viscosity Test

Test	Size Ubbelohde Viscometer	Efflux Time Obtained (s)	Kinematic Viscosity
1	1 [2-10 mm^2/s, cSt]	857 seconds	8.57 mm^2/s, cSt
2	1 [2-10 mm^2/s, cSt]	856 seconds	8.56 mm^2/s, cSt
3	1 [2-10 mm^2/s, cSt]	858 seconds	8.58 mm^2/s, cSt

Average = 857 s Average = 8.57

TABLE 4.8 shows the result of kinematic viscosity for 85% Palm Oil + 15% Mach 5 at temperature 100°C. From the table, the kinematic viscosity for the sample at 100°C is 8.57 mm^2/s. Compared to the kinematic viscosity of 95% Palm Oil + 5% Mach 5 sample at 100°C, the value decreased from 9.1233 mm^2/s to 8.57 mm^2/s. The sample 85% Palm Oil + 15% Mach 5 drops off less rapidly at higher temperatures than sample 95% Palm Oil + 5% Mach 5. So the sample 85% Palm Oil + 15% Mach 5 has higher viscosity index than 95% Palm Oil + 5% Mach 5.

NOTE: The S.I. unit of kinematic viscosity is 1 meter squared per second, and is equal to 10^4 stokes. The S.I. unit of viscosity is 1 pascal second, and is equal to 10 poises. One centistokes is equal to one millimeter squared per second.

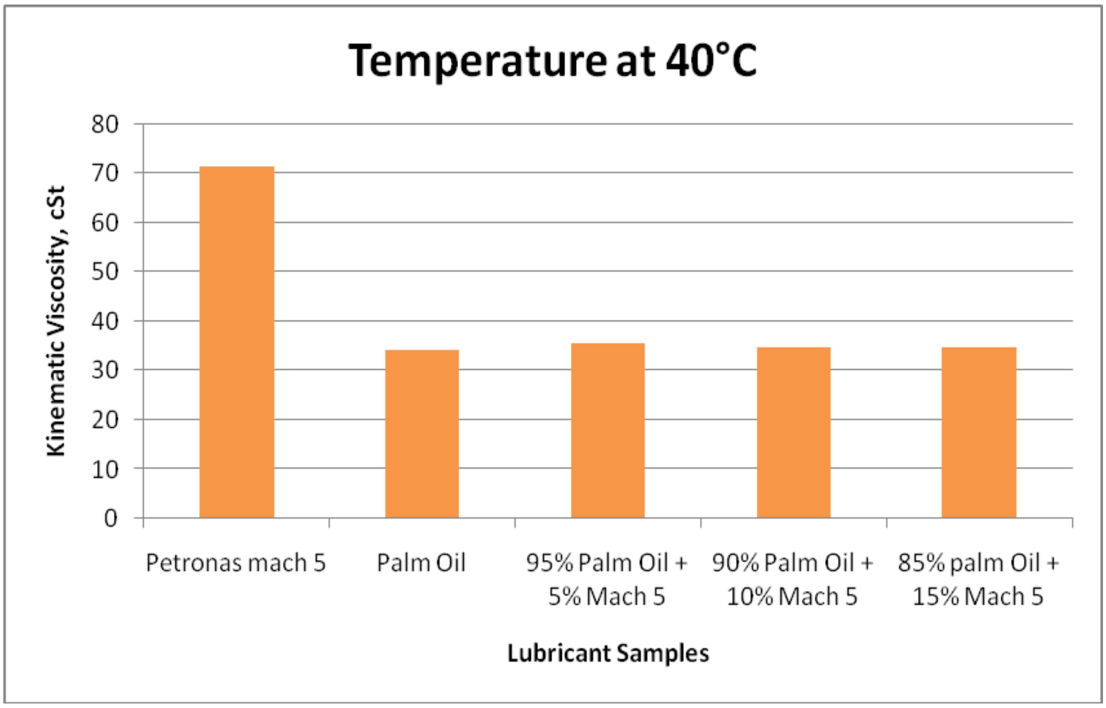

FIGURE 4.1: Experiment result at temperature 40°C

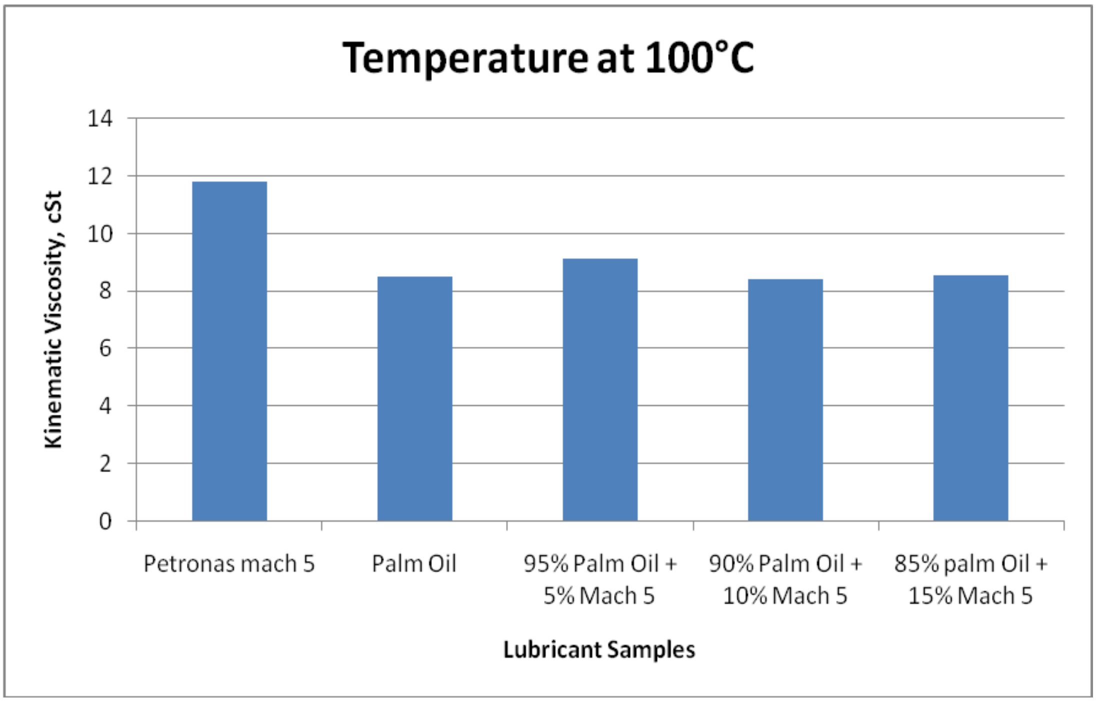

FIGURE 4.2: Experiment result at temperature 100°C

Refer on the above figures (FIGURE 4.1 and 4.2), the kinematic viscosity for Petronas Mach 5 obtained for temperature 40°C is 71.4 mm^2/s and for the temperature 100°C the result is 11.82 mm^2/s. While for the palm oil viscosity test, the kinematic viscosity obtained for test 1 (40°C) is 34.35 mm^2/s and for test 2 (100°C) the result is 8.5 mm^2/s. For the other three samples, the results for their kinematic viscosity are almost the same, not too many changes in value. From the Figure 4.1 and 4.2, its clearly show that the level of the graphs are almost same high which means that the differences in the value are small.

Based on the results (FIGURE 4.1 and 4.2), the results for the kinematic viscosity at temperature 40°C for lubrication samples that contain palm oil as the base oil is between 34.35 mm^2/s – 35.72 mm^2/s. Based on the theory and research done earlier, the guidelines for properties of vegetables oil (palm oil) designed for lubrication base oils stated that the value for the kinematic viscosity at temperature 40°C should be in range 30-35 mm^2/s. This result shows that the palm oil already fulfil that requirement. Besides, the results also show that the lubrication sample base palm oil has greater viscosity index compare to the Petronas Mach 5 (mineral lubrication oil). Based on the theory, viscosity index for the Petronas Mach 5 is 146 while the Palm Oil has viscosity index value around 188.

The patterns of the figures above show that the results are correct. From the figures, the kinematic viscosity of the Petronas Mach 5 decreased from 71.4 mm^2/s at temperature 40°C to11.82 mm^2/s at temperature 100°C. The decrement is around 59.58 mm^2/s. While for palm oil base lubrication samples, the kinematic viscosity decrement is between 25.82 mm^2/s to 26.6 mm^2/s. This situation proves that the palm oil base lubrication oil samples has higher viscosity index compare to the mineral lubrication oil (Petronas Mach 5). The theory stated that the viscosity of lubricating oils is extremely sensitive to the operating temperature. With increasing temperature the viscosity of oils falls quite rapidly. Besides, the Viscosity Index is an inverse measure of the decline in oil viscosity with temperature. High values indicate that the oil shows less relative decline in viscosity with temperature (FIGURE 2.6).

From the results obtained above, the author found that some of the results are accurate and precise and vice versa. This is due to the some errors that take place during the testing procedure/process. Some of the errors that involves are the existences of the bubbles in the Ubbelohde tube during the testing and also the temperature setting of the machine. In order to get precise and accurate results, the temperature of the bath and tube should be same (equilibrium). Besides, the other error is the starting and stopping of the time for the process of each samples. This is due to the human error in control the stop watch during the testing procedure.

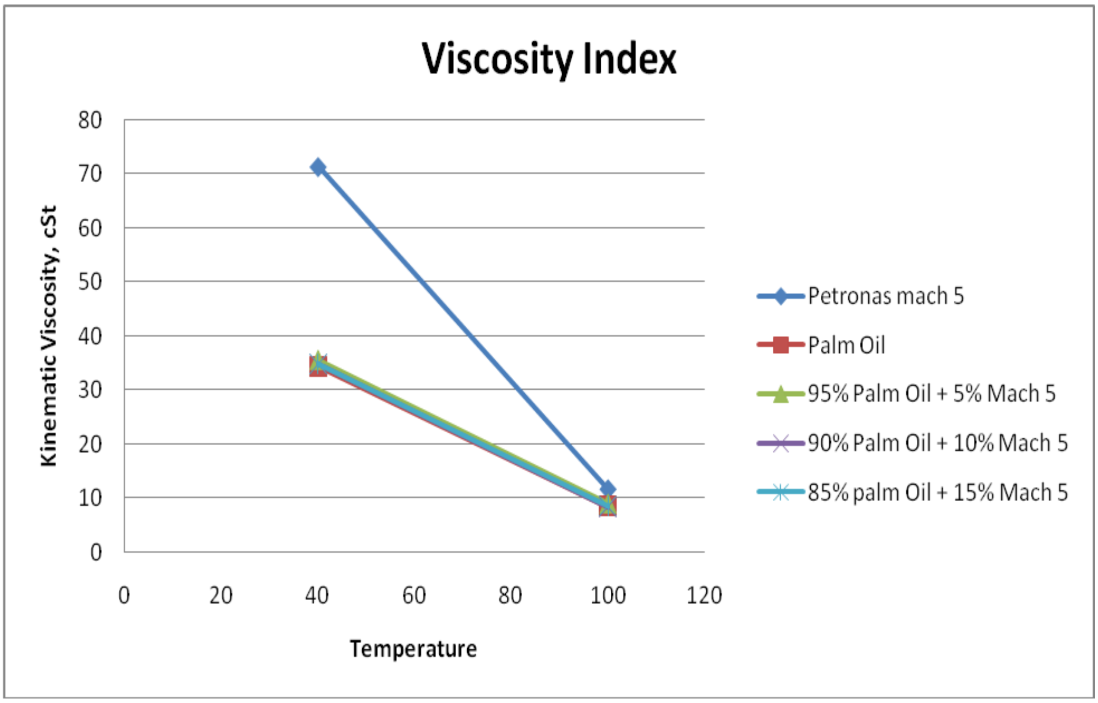

FIGURE 4.3: Viscosity index of lubricant samples

Based on the FIGURE 4.3 above, the results show that the lubricant samples that contain palm oil as the base oil drop off less rapidly at higher temperatures than the Petronas Mach 5 sample. The results concluded that the lubricant samples that contain palm oil as the base oil has higher viscosity index than the Petronas Mach 5 sample.

4.2 WEAR SCAR ANALYSIS RESULTS

The following results are the average of the wear scar diameter of the lubricants sample tested at Four-Ball wear machine which were measured using optical microscope.

TABLE 4.9: Wear Scar Analysis Results

a) 100% Petronas Mach 5

Test	Average Ball 1 (scar diameter, mm)	Average Ball 2 (scar diameter, mm)	Average Ball 3 (scar diameter, mm)	Total Average
1	0.21	0.17	0.14	0.173

b) 100% Palm Oil

Test	Average Ball 1 (scar diameter, mm)	Average Ball 2 (scar diameter, mm)	Average Ball 3 (scar diameter, mm)	Total Average
1	0.17	0.27	0.345	0.262

c) 95% Palm Oil + 5% Petronas Mach 5

Test	Average Ball 1 (scar diameter, mm)	Average Ball 2 (scar diameter, mm)	Average Ball 3 (scar diameter, mm)	Total Average
1	0.185	0.22	0.35	0.252

d) 90% Palm Oil + 10% Petronas Mach 5

Test	Average Ball 1 (scar diameter, mm)	Average Ball 2 (scar diameter, mm)	Average Ball 3 (scar diameter, mm)	Total Average
1	0.15	0.265	0.275	0.23

e) 85% Palm Oil + 15% Petronas Mach 5

Test	Average Ball 1 (scar diameter, mm)	Average Ball 2 (scar diameter, mm)	Average Ball 3 (scar diameter, mm)	Total Average
1	0.145	0.255	0.26	0.22

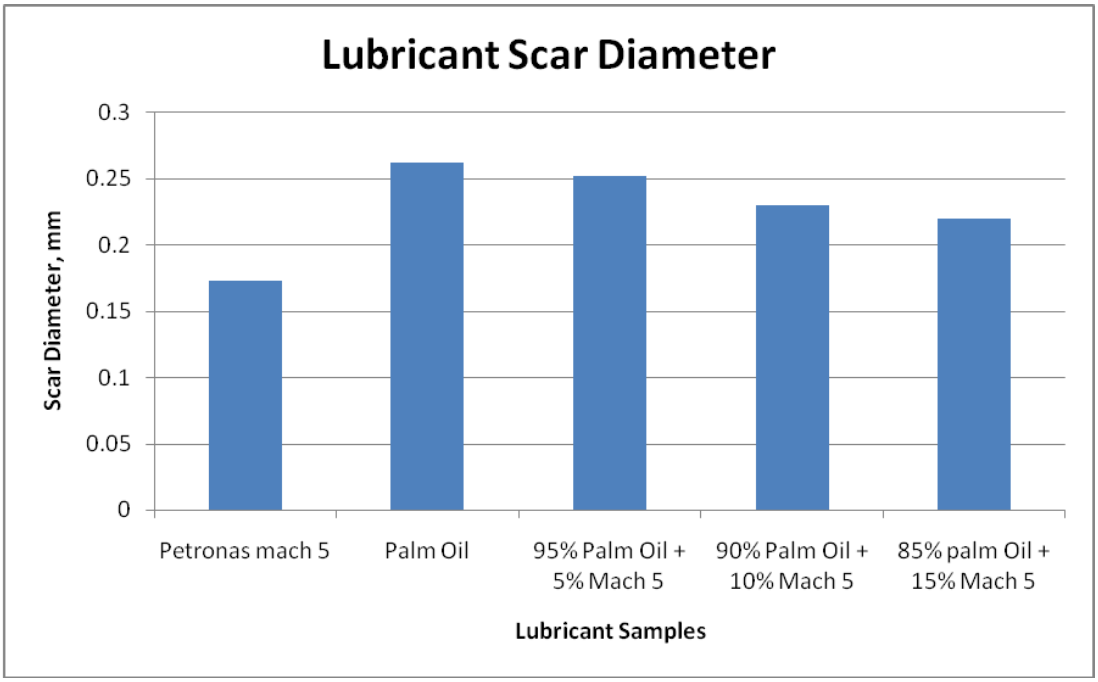

FIGURE 4.4: Lubricants scar diameter

Based on the results showed in the TABLE 4.9 and FIGURE 4.4 above, the average scars measurement on balls indicated that the lubricants viscosity influenced the wear properties, performance and characteristics of the engine and other moving parts. Inabilities of any lubricants to maintain the viscosity generating more powered to be sheared and this phenomena consequently will result in the increase of engine temperature and failure to the components. From the results in the table, it showed that the samples (b) which contain 100% Palm Oil has larger wear scar diameter compared to the sample (a), 100% Petronas Mach 5. But, the results getting better once the palm oil mixed with the additive (Petronas Mach 5). The average wear scar diameter of the palm oil decreased from 0.262 mm till 0.22 mm.

The theory stated that the lubricants are compared by using the average size of the measured wear scar diameter. The lower the wear scar diameter, the better the wear protection properties of the lubrication oil. Based on the results, the palm oil has the potential to be used as the base oil for the lubricant although not fully proven yet. This is because the palm oil base lubrication samples able to compete with the existing mineral oil (Petronas Mach 5) in terms of the average wear scar diameter.

4.3 SCANNING ELECTRON MICROSCOPE (SEM) RESULTS

Following images are the Scanning Electron magnification on wear surface texture for the lubricants.

4.3.1 100% Petronas Mach 5

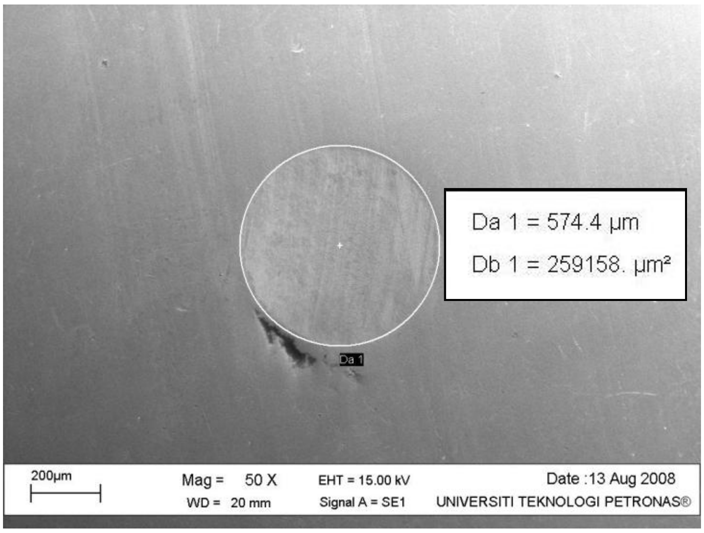

FIGURE 4.5: 100% Petronas Mach 5 wear scar diameter

4.3.2 100% Palm Oil

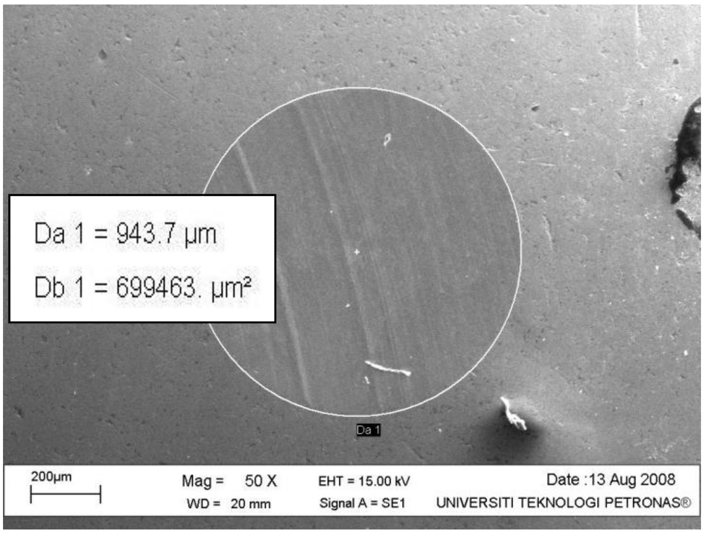

FIGURE 4.6: 100% Palm Oil wear scar diameter

4.3.3 95% Palm Oil + 5% Petronas Mach 5

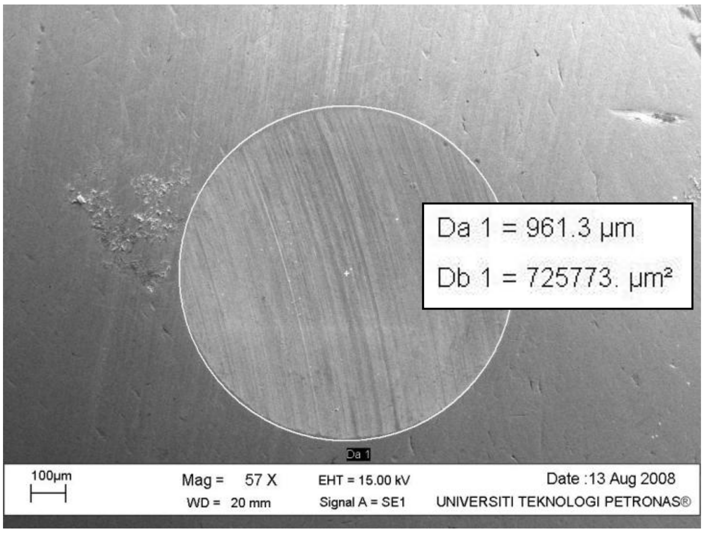

FIGURE 4.7: 95% Palm Oil + 5% Petronas Mach 5 wear scar diameter

4.3.4 90% Palm Oil + 10% Petronas Mach 5

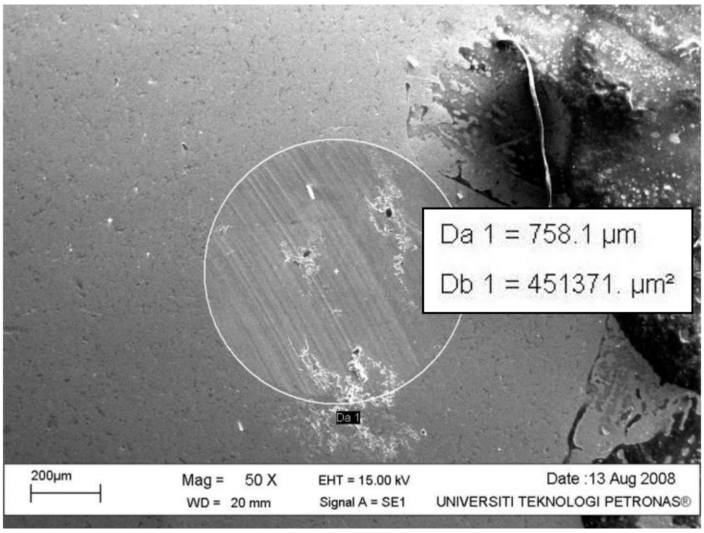

FIGURE 4.8: 90% Palm Oil + 10% Petronas Mach 5 wear scar diameter

4.3.5 85% Palm Oil + 15% Petronas Mach 5

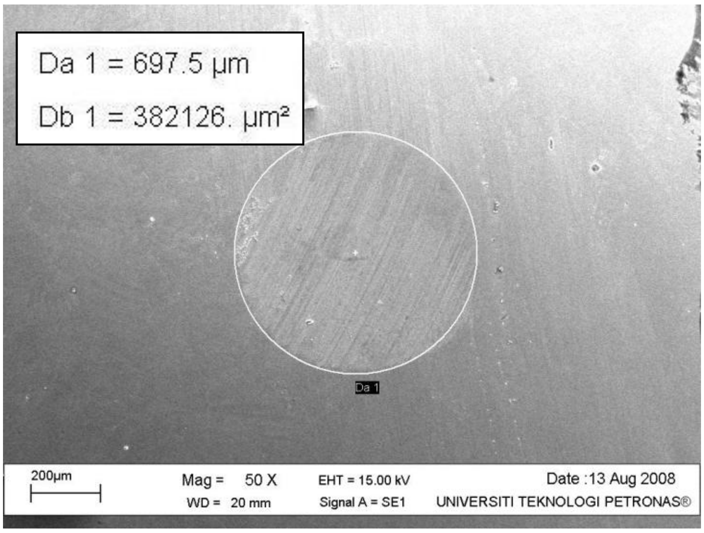

FIGURE 4.9: 85% Palm Oil + 15% Petronas Mach 5 wear scar diameter

The figures above show the results of the scanning electron magnification on wear surface texture for the five lubricant samples as stated above. The purpose of the scanning electron magnification testing is to qualitatively examine the surface texture on the specimens from the four-ball wear test. The results of wear scar diameter of the specimens sample tested at Four-ball wear machine measured using optical microscope can be compared to the results from the scanning electron microscope test in order to prove that the wear scars diameter obtained are correct and accurate. From Table 4.9, the average wear scar diameter of sample (a) which contains 100% Petronas mach 5 has smaller average wear scar diameter compared to the sample (b), 100% Palm Oil. The results are getting better (average wear scar diameter decreased) since the palm oil mixed with the additive (Petronas Mach 5).

Based on the results showed in the figures above, it clearly showed that the wear surface texture diameter of the samples getting smaller from one sample to another as the quantity of the additive contains in the palm oil increase. The images of the wear scar diameter surface texture proved that the results obtained from the optical microscope are correct.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The study in this project draws the following conclusion:

a) The palm oil has good potential and capability to be designed as new alternative lubrication oil in the automotive engine industry based on its performance during the project work.
b) The palm oil shown good results and performance in the viscosity and wears characteristic testing. Its performance can be compared to the properties and characteristic of the existing commercial mineral lubrication oil in the market.
c) The results on this experiment have enhanced the understanding about the tribology of the moving components, fundamental and formulation of the lubrication film formation concept and its application in the automotive industry.
d) The investigation into the potential of bio-based automotive engine lubrication oil using the tribological test method have provided valuable exposure and useful experience in conducting laboratory testing on lubricant using Four Ball Wear Test, Optical Microscope and SEM study on wear scar diameter and Viscometer for viscosity study.

The study concludes that the vegetable oils and their double bonds influence low temperature behaviour of the lubricant. Most of the vegetable oils that are readily available and inexpensive in market are not suitable for use as base oil for lubricant due to high saturates or polyunsaturates fatty acid content. Monounsaturated fatty acid content in vegetable oils present optimum oxidative stability and low temperature properties. Therefore, in order for the vegetable oils to be used as a base oil for the lubricant, it has to be converted to a monounsaturated fatty acid. Thus, the base fluids for lubricants must have a balance of fatty acids, preferably a high level of monounsaturated, minimal polyunsaturates and with no saturates at all for cold climates.

5.2 RECOMMENDATIONS

The study in this project draws the following recommendation that could be implemented for future study:

a) For future work, it is recommended to focus on further study on the potential of the palm oil as the new alternative lubrication base oil that can maintain the viscosity and minimize the wear even after being used in the engine for a period of time.
b) For the additives, make it more variety with the used of other existing mineral lubrication oil such as Pennzoil, Caltex Havoline Formula and SHELL Helix.
c) Add more experiments and laboratory works like the Pour Point and Flash Point experiment in order to get better result on the properties and potential of the bio-based automotive engine lubrication oil.

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