TRIBOLOGICAL PROPERTIES INVESTIGATION FOR NANOPARTICLE ENHANCED NATURAL OIL-BASED LUBRICANT

NIK MUHAMMAD HAZWAN BIN MOHAMED ABDUL GHANI

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

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2017

DECLARATION

I declare that this project report entitled "Tribological properties investigation for nanoparticle enhanced natural oil-based lubricant" is the result of my own work except as cited in the references.

Signature :...

Name :...

Date :..

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

APPROVAL

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

Signature :. ....

Name of Supervisor : ....

Date : ....

اونيۏرسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DEDICATION

To my beloved mother, father and siblings

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

ABSTRACT

Friction and wear are one of the main factors that affect the efficiency, performance, quality and life span of machinery system. The purpose of this study is to determine tribological properties of nanoparticles enhanced natural oil-based lubricants which consist of Refined Glycerine and Oleic Methyl Ester. Four ball tester experiments are carried out based on ASTM standard to evaluate the tribology properties of lubricants. The flash point and viscosity are taken at the lubricants to obtain the characteristics of these lubricants. The measurements of Coefficient of Friction and Wear Scar Diameter are taken at bearing ball for different types of lubricants. The difference in coefficient of friction and wear scar diameter for lubricant without and with additive are being investigated. The results obtained for coefficient of friction and wear scar diameter of lubricants are then compared with difference concentration of additive. The average coefficient of friction obtained from analysis for refined glycerine without and with additive show lower reading than oleic methyl ester. Lubricant with Carbon Nano Tube as additive show more preferred results compared to lubricant without additive in term of coefficient of friction. With increase the concentration of additive, all lubricants which is refined glycerine and oleic methyl ester only up to 3%wt of additive to get better result. More than 3%wt of additive, they continue increase the coefficient of friction. It happens during the homogenizing process, the lubricant cannot dissolve sufficiently with higher amount of additive. For wear scar diameter, refined glycerine with additive show the smallest reading compare to other. Based on the result, recommendations and suggestions are made to improve the accuracy of tribology test and tribology properties of lubricants.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

ABSTRAK

Geseran dan haus adalah salah satu faktor utama yang memberi kesan kepada kecekapan, prestasi, kualiti dan jangka hayat sistem jentera. Tujuan kajian ini adalah untuk menentukan sifat tribological nanopartikel dipertingkatkan pelincir berasaskan minyak semula jadi yang terdiri daripada glyserol mentah dan oleik methyl ester. Empat uji kaji bola tester dijalankan berdasarkan standard ASTM untuk menilai sifat-sifat tribologi pelincir. Titik kilat dan kelikatan diambil pada pelincir untuk mendapatkan ciri-ciri pelincir ini. Ukuran pekali geseran dan diameter haus parut diambil pada bearing bola untuk pelbagai jenis pelincir. Perbezaan dalam pekali geseran dan haus diameter parut untuk pelincir tanpa dan dengan tambahan sedang disiasat. Keputusan yang diperolehi daripada ukuran fizikal dan analisis berbanding dengan pekali geseran dan memakai parut diameter pelincir dengan kepekatan perbezaan tambahan. Pekali geseran purata yang diperolehi daripada analisis untuk gliserol mentah tanpa dan dengan tambahan menunjukkan bacaan yang lebih rendah berbanding oleik methyl ester. Pelincir dengan Karbon Nano Tiub sebagai persembahan bahan tambahan keputusan lebih diutamakan berbanding pelincir tanpa bahan tambahan dari segi pekali geseran. Dengan meningkatkan kepekatan bahan tambahan, semua minyak pelincir yang ditapis gliserin dan oleik methyl ester hanya sehingga 3% berat bahan tambahan untuk mendapatkan hasil yang lebih baik. Lebih daripada 3% berat bahan tambahan, mereka terus meningkatkan pekali geseran. Ia berlaku disebabkan oleh semasa proses larutan minyak, minyak pelincir tidak boleh larut cukup dengan jumlah yang lebih tinggi bahan tambahan. Untuk diameter haus parut, gliserol mentah dengan bahan tambahan menunjukkan bacaan yang paling kecil berbanding dengan yang lain. Berdasarkan kepada keputusan, cadangan dan cadangan dibuat untuk meningkatkan ketepatan ujian tribologi dan sifat-sifat tribologi pelincir.

ACKNOWLEDGEMENT

I would like to express my deepest appreciation to my supervisor Dr. Tee Boon Tuan for giving me this opportunity to do final year project with him. He never hesitated to give me advice and guidance whenever I confronted problems. I am thankful for his patience and advice while leading me in this project.

Sincere thanks to Dr. Ernie binti Mat Tokit and Dr. Nazri bin Md Daud for evaluating my final year project. The ideas and suggestions given were valuable for me complete this project.

Besides that, I would also like to thank Faculty of Mechanical Engineering (FKM), Universiti Teknikal Malaysia Melaka (UTeM) for giving me this opportunity to complete this project and allowing me to utilize all necessary equipment and tools needed for this study.

Finally, I would like to acknowledge with much appreciations to my family and friends for their continuous support and encouragement throughout the project period.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Table of Contents

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

اونيۏرسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF FIGURES

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF TABLE

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

اونيؤرسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF ABBEREVATIONS

ASTM	American Society for Testing of Materials
CNT	Carbon Nanotube
TGA	Thermogravimetric analysis
N2	Nitrogen
COF	Coefficient Of Friction
POME	Palm oil methyl ester
CL	Commercial lubricant
WSD	Wear Scar Diameter
RBD	Refined Bleached Deodorised
FYP	Final Year Project
VI	Viscosity Index
ANSI	American National Standards Institute
PMO	Paraffinic Mineral Oil
PS	Palm Stearin
FTP	Flash Temperature Parameter
MWSD	Mean Wear Scar Diameter
CNF	Carbon Nano Fiber

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHAPTER 1

INTRODUCTION

1.1 Background Study

The tribology study of metal processing has been emphasized nowadays due to the trend towards machinery world. To increase the life span of machinery system, lubricant is needed. Global environmental awareness encouraged the replacement of mineral lubricant with renewable, sustainability, high biodegradability and eco-friendly lubricant. Palm oil based lubricant constitute as one of the natural oil-based lubricant and as alternative lubricant for industrial processes.

اونيۏرسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Pure natural oils have been known to be good lubricants since ancient times in lowering friction and preventing wear. The advent of petroleum of petroleum-based oils produced rapid advances in lubrication technology that quickly dominated other oils, such as natural oils in the lubricant industry. A thermogravimetric analysis and variable-temperature viscosity analysis were conducted to study the thermal response of the lubricants in a high temperature environment. (Reeves. 2014)

1.2 Problem Statement

Tribological properties such as wear, viscosity, flash temperature of resulting nanoparticle enhanced lubricant will be evaluated and compared with selected lubricants. But the uses of mineral oil lubricants can pollute the environment either during or after use. Hence, natural oil-based lubricant which has high biodegradability compared to mineral oil is applied to provide an alternative to replace the mineral oil as lubricant. In this project, we use natural oil from plant because they are non-toxic, biodegradable and renewable. Natural oil-based lubricants have a higher lubricity, lower volatility, higher shear stability, higher viscosity index, higher load carrying capacity and superior detergency when compared to mineral oils. (Syahrullail et al. 2011).

The tribology properties and effectiveness of the natural oil-based lubricant can be evaluated by using four-ball tester, seta flash series 2 and viscometer to determine the friction and wear of ball bearing which is carry out the properties of lubricant, flash temperature and viscosity for difference type of lubricants respectively. This project aimed to investigate the tribological properties of nanoparticles enhanced natural oil-based lubricant at difference concentration of additive and make comparison with selected lubricants. Measuring of tribological properties of lubricant can be done by using four-ball tester, seta flash series 3 and viscometer.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

1.3 Objective

The objectives of this project are as follows:

1. To investigate the tribological properties of nanoparticles enhanced natural oil-based lubricants which consist of Refined Glycerine and Oleic Methyl Ester.
2. To compare the properties between the selected lubricants.

1.4 Scope of Project

The scopes of this project are:

The project will conduct tribology tests on two types of natural oil-based lubricants which are Refined Glycerine and Oleic Methyl Ester. The lubricants will be mixed with carbon nanotubes at 0.5%wt, 1%wt, 2%wt, 3%wt, 4%wt and 5%wt.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

1.5 General Methodology

List of method that will be done to achieve the objectives of this project are as follows:

1. Literature Review

   Journal, the standard document or whatever type of reference that can provide as references.

2. Experiments Conducted

The experiment will be conducted according to the given guidelines by ASTM standard.

3. Measurement

Measured the mixing of lubricant with carbon nanotube (CNT). The mixture are measured by using digital mass measurement instrument.

4. Analysis

Analysis will be performed on different type of lubricants and parameters such as different composition and with and without addictive.

5. Writing report

The report on this project will be completed at the end of the study.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

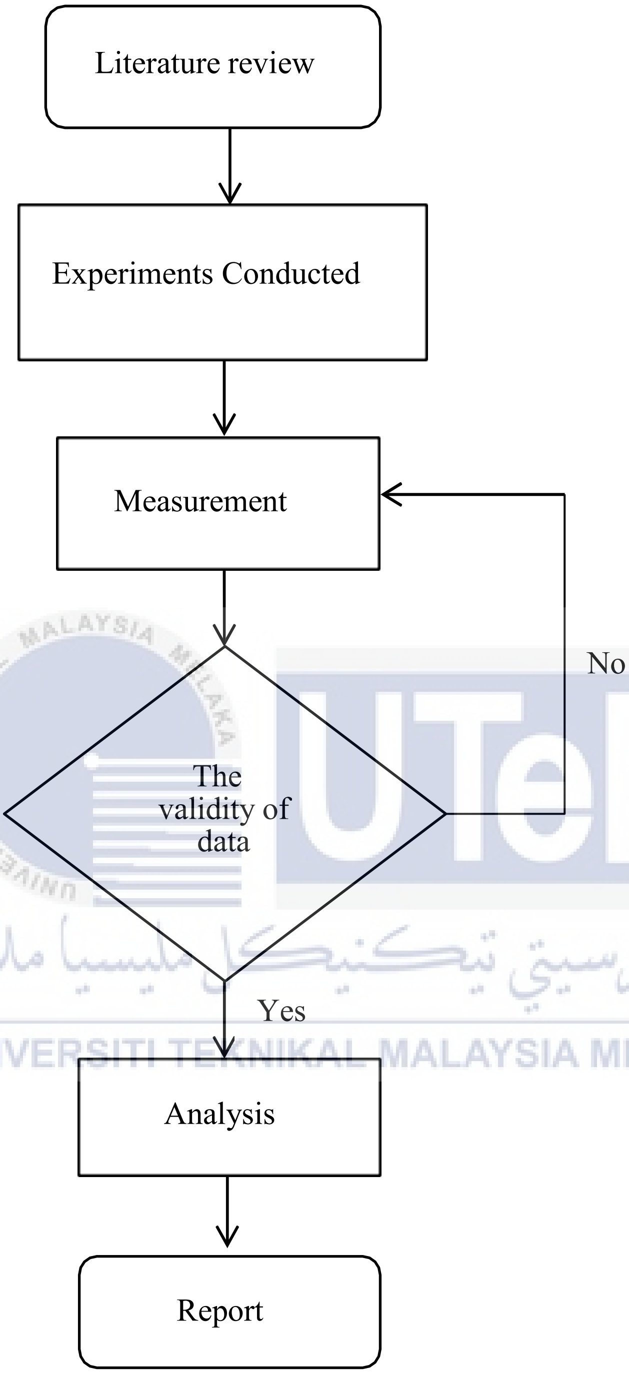


Figure 1. 1: Flow chart of the methodology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Literature review is focused on previous study in the field to obtain knowledge and information for the present study. This chapter will cover on the research finding about the performance of the tribological properties. There are many techniques or methods that can be used to conduct the experiment in order to study the performance of tribological properties. In this report, the method that has been chosen is four ball-testers. This method will be investigated the physical properties of ball bearing that been used in the experiment. Furthermore, theory about the natural oil-based performance also will be discussed in this chapter.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2.2 Background of Project

Various studies on lubricants properties have been carried out by many researchers in the past. This chapter reviews the previous published literatures, which lays foundation and basis for further work in this project. This helps give a better understanding about the topic and also acts as a guideline for the whole report structure. Main focus of the study is on lubricants properties and use of carbon nanotube (CNT).(Yong et al. 2016).

2.3 Fundamental of Tribology

Science and engineering of interacting surfaces in relative motion are the combination called Tribology. Study and application of principles of friction, lubrication and wear, these are the things that it discuss in tribology. Materials science and mechanical engineering, are the brunch that have in tribology that we can discuss.

Result in loss of materials from the surface will be obtained if the tribological interactions of solid surfaces exposed face with interfacing materials and environment. “Wear” is called the process leading to loss of materials. There are many types of major wear such as abrasive wear, friction (adhesive and cohesion), erosion, and corrosion. Modifying the surface properties of solids by one or more of “surface engineering” process (also called surface finishing) or by use of lubricant.(Mannekote & Kailas 2012)

2.4 Fundamental Theories of Lubricant

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Friction, wear, and lubrication are tribological phenomena that run the behaviour of interacting surfaces in a wide range of machine components. Understanding the physical and chemical nature of these phenomena is critical to achieving long component lifetime and economical operation. Research in the field of tribology is highly interdisciplinary, and encompasses the fields of physics, chemistry, engineering, and mathematical modeling. Lubricants calls contributions on new advances in all areas of tribology for publication as peer-reviewed research articles, reviews of current research, letters, and communications.

A lubricant is a substance introduced to reduce friction between surfaces in mutual contact, which eventually reduces the heat generated when the surfaces move. It may also have the function of transmitting forces, transporting foreign particles, or heating or cooling the surfaces. The property of reducing friction is known as lubricity.

2.4.1 Function of Lubricant

The main of lubricant is to minimize the friction between the interacting surfaces by prevent the direct contact between two metal surfaces. Besides that, lubricant also used to control wear, temperature, oxidation and corrosion of metal surfaces, form a seal and remove contaminants. All types of lubricant should be inert to the metal surface and should not under any chemical reaction toward the metal surface.(Cornelio et al. 2016)

2.5 Natural Oil-based Lubricant

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Lubricant must be more environmentally influenced, level of performance must be higher, and total life cycle cost must be lower than already lubricant present. For that lubricant to be formulated, we have to know very well the properties of those based fluid. The formulated lubricant that has been influenced by based fluid properties, have three different divided groups.

The three group as mentioned before are physical, chemical, and film formation properties. An investigation of the properties from all the group must be done to make sure that information about their influenced on based fluid overall performance.(Fox & Stachowiak 2007)

2.6 The influence of fatty acids on tribological and thermal properties of natural oils as sustainable biolubricants By (Reeves et al. 2015)

This is a study several natural oils were selected to represent a broad range of saturated and unsaturated fatty acid compositions within bio-based oils. These oils were investigated to understand the properties of fatty acid composition on friction and wear performance under ambient conditions using a pin-on-disk apparatus. The experiment was carried out based on American Society for Testing of Materials (ASTM) standard.

A thermogravimetric analysis was used to determine the correlations between the fatty acid composition, tribological performance, and the thermal response of the natural oils.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2.6.1 Methodology

2.6.1.1 Natural oils

Eight oils were selected to investigate the tribological performance of natural oils. These oils were chosen because they represent a variety of saturated, monounsaturated, and polyunsaturated fatty acid compositions within natural oils.

2.6.1.2 Tribological test & operating parameters

Pin-on-disk tests at ambient conditions were conducted to describe the tribological properties of the natural oils. Table 2.1 presents the testing conditions used throughout each experiment.

Table 2. 1 : Test parameters

Parameter	Selected value
Normal load (N)	10
Sliding velocity (mm/s)	36
Angular velocity (rpm)	21.5
Distance traveled (m)	3000
Duration (h)	23.2
Environment	Ambient conditions
Lubricants	Avocado, canola, corn, olive, peanut, safflower, sesame, and vegetable oil
Lubricant quantity (mL)	10

The pin and disk specimen were cleaned before and after each test using an ultrasonic cleaner with soap, acetone, and hexane solutions.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2.6.1.3 Viscosity analysis

The natural oils used in the tribology testing also go through open air viscometer testing using a digital paddle vibrational viscometer. These tests used a heating bath open to the ambient environment to increase the temperature of the fluid at a rate of approximately 1 1Cper minute from 21 1C (room temperature) to approximately 150 1Cwith each test duration lasting nearly 4 hour.

2.6.2 Results and Discussion

2.6.2.1 Friction analysis

Fig. 2.1(a) depicts the variation of the coefficient of friction with sliding distance for various natural oils under ambient conditions. It can be seen that a general trend exists where there is a decrease of the coefficient of friction (COF) significantly at the start of each experiment. The COF of the natural oils reaches steady-state at a sliding distance of approximately 2000m. The experimental results show a clear distinction between the oils where the avocado, olive, canola, and peanut oils all have the lowest COF values (between 0.02 and 0.10), while sesame, vegetable, corn, and safflower oils all have the highest COF values (between 0.30 and 0.50). Fig. 2.1(b) shows the variation of the COF for various natural oils at the completion of the test. Here, it is clearly illustrated that avocado oil has the lowest COF value of the natural oils tested. Interestingly, safflower has the highest COF.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

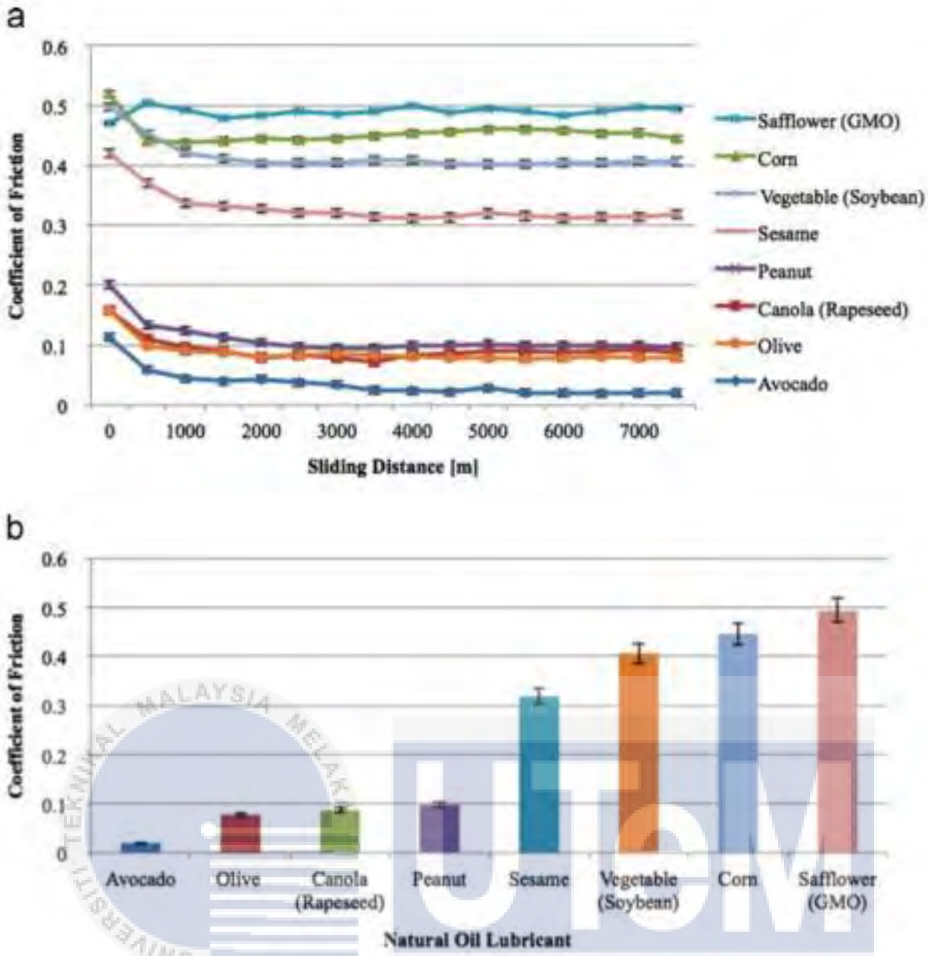
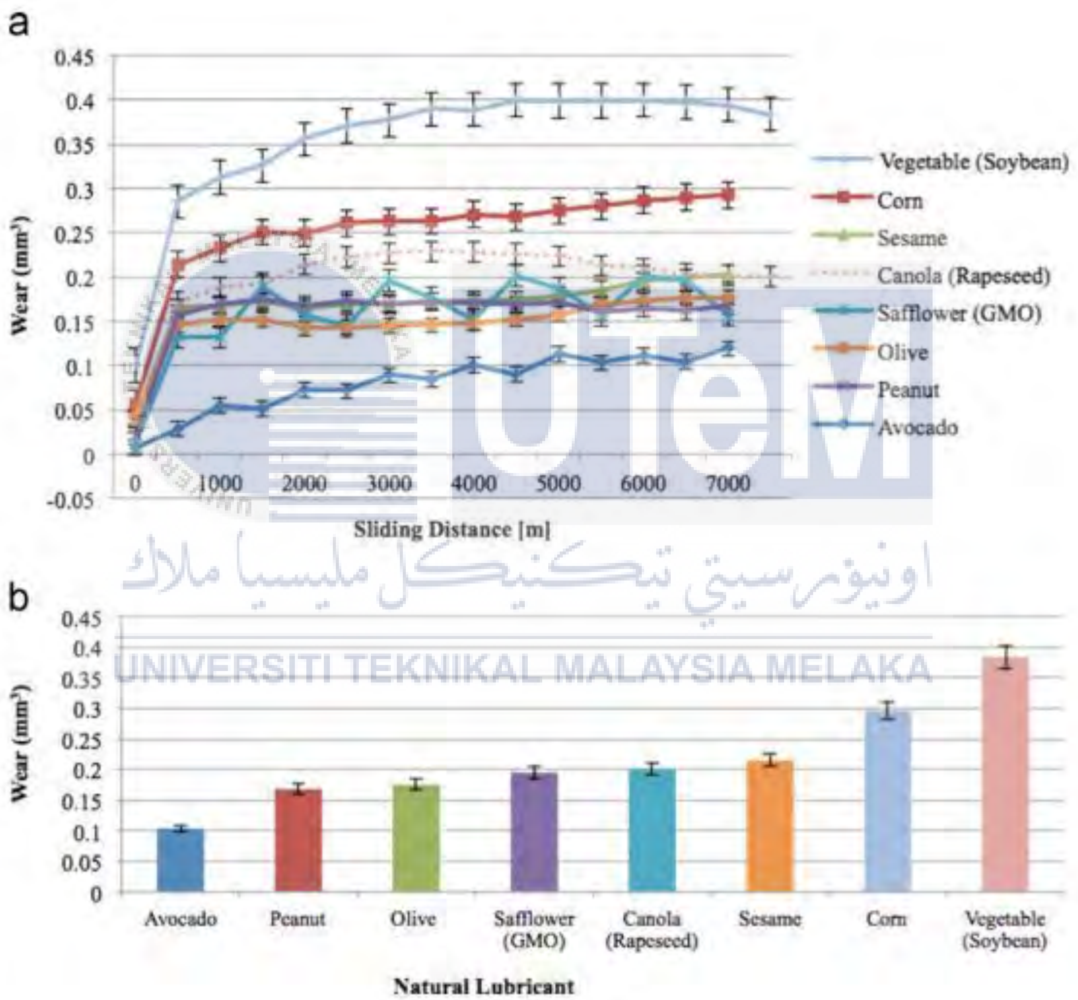


Figure 2. 1: Variation of coefficient of friction during ambient conditions (a) for natural oils with sliding distance (b) for natural oils at completion of tests.

2.6.2.2 Wear analysis

Fig. 2.2(a) depicts the variation of the pin wear volume with sliding distance for various natural oils. It can be seen that the wear volume increases significantly within the first 50 to 100m and continues to increase with sliding distance until approximately 1000 m. Afterwards the rate of change in wear volume decreases with sliding distance. This transition is due to the abrasive nature of the surfaces, which begin to conform the longer they are in sliding contact to each other. As a result of this contact, blunting of the surfaces leads to two body wear and clogging of the surfaces by abraded debris causing the worn surfaces to eventually enter into a steady wear state. Fig. 2.2(b) shows the variation of the wear volume for various natural oils at the completion of the tests, where the distinctions in wear volume for the different oils tested is illustrated. As shown in the figure, avocado oil has the lowest wear volume and vegetable and corn oil have the highest wear volume. Peanut, olive, safflower, canola, and sesame oil all have a moderate wear volume.



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Figure 2. 2: Variation of wear volume during ambient conditions (a) for natural oils with sliding distance (b) for natural oils at completion of tests

2.6.3 Conclusion

Based on the result get from experiments, the prevailing trend with the natural oils is that high oleic acid concentrations improve friction and wear performance by establishing densely occupied monolayers on the lubricating surface. Moreover, in an oxygen- free environment, the thermal stability of the natural oils is independent of the fatty acid composition and the degree of unsaturation.

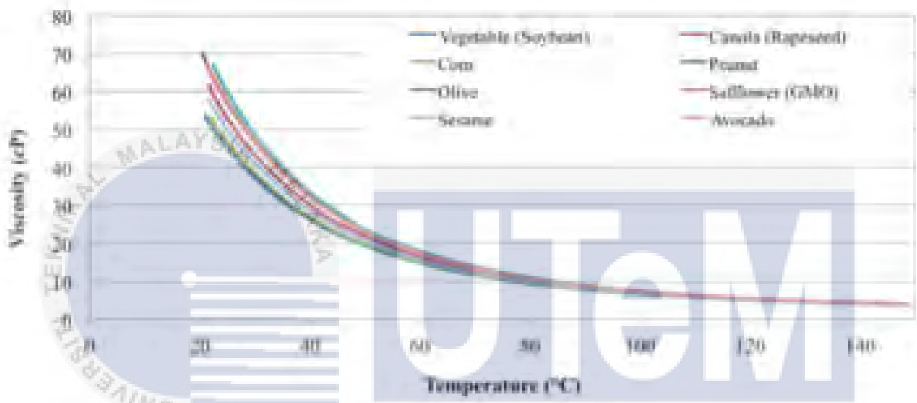


Figure 2. 3: Viscosity profiles with temperature for natural oils of varying chemical compositions

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Table 2. 2: Room temperature and high temperature viscosity measurements for the natural oils

Natural oil type	Unsaturation number (UN)	Room temperature viscosity (cP)	High temperature viscosity (cP)
Avocado	0.985	66.39	3.95
Canola (Rapeseed)	1.287	61.79	4.12
Corn	1.381	53.13	3.77
Olive	0.948	67.09	4.26
Peanut	1.102	70.24	4.17
Safflower (high oleic)	1.010	66.27	4.08
Sesame	1.232	57.97	3.67
Vegetable (soybean)	1.451	53.77	3.85
R-value		−0.884	−0.611
Difference		17.11	0.59
Percent difference		32%	16%

- Avocado oil was shown to have the best tribological properties with the lowest friction and wear when compared to other natural oils.
- Natural oils with high percentages of oleic acid maintain low COF values and low wear rates because the oleic acid establishes a denser fatty acid monolayer that minimizes the asperity contact and protects the metallic surfaces.
- Natural oils with high percentages of monounsaturated fatty acids such as oleic acid are optimal to ensure superior thermal-oxidative stability in ambient and high temperature environments.
- In an oxygen-free environment, the thermal stability of natural oils is dependent on individual fatty acid (stearic, oleic, and linoleic acids) percentages and independent of the degree of unsaturation of the natural oil.
- In an oxygen environment, the oxidative stability of natural oils is dependent on the fatty acid composition or unsaturation number of the natural oil and it becomes coupled with thermal stability.
- The fatty acid composition of natural oils affects the viscosity at room temperature but not affect the viscosity at higher temperatures due to the viscosity values converging at higher temperatures.
- The higher the unsaturation number the lower the viscosity at room temperature thus revealing how oils with higher amounts of monounsaturated acids have superior friction and wear properties.

2.7 Temperature effect on tribological properties of polyol ester-based environmentally adapted lubricant By (Aziz et al. 2016)

The aim of this study to evaluate the physical and chemical characteristics of pentaerythritol ester base oil and its formulated oil, neopentyl glycol ester base oil, and commercial lubricant. These studies contribute to information of lubricant regime valuation and wear properties of oils at elevated temperature condition. These studies contribute to information of lubricant regime estimation and wear properties of oils at elevated temperature condition.

2.7.1 Methodology

The running process of experiment begins with preparation of material that use such as Palm oil methyl ester (POME), pentaerythritol and sodium methoxide, neopentyl glycol, Commercial lubricant (CL), Klüberfood NH1 CH-2 Plus and additives such as Irgamet 39, Irgalube TPPT and Irgalube 349.

A pycnometer was used for density measurement at temperature 20 °C.

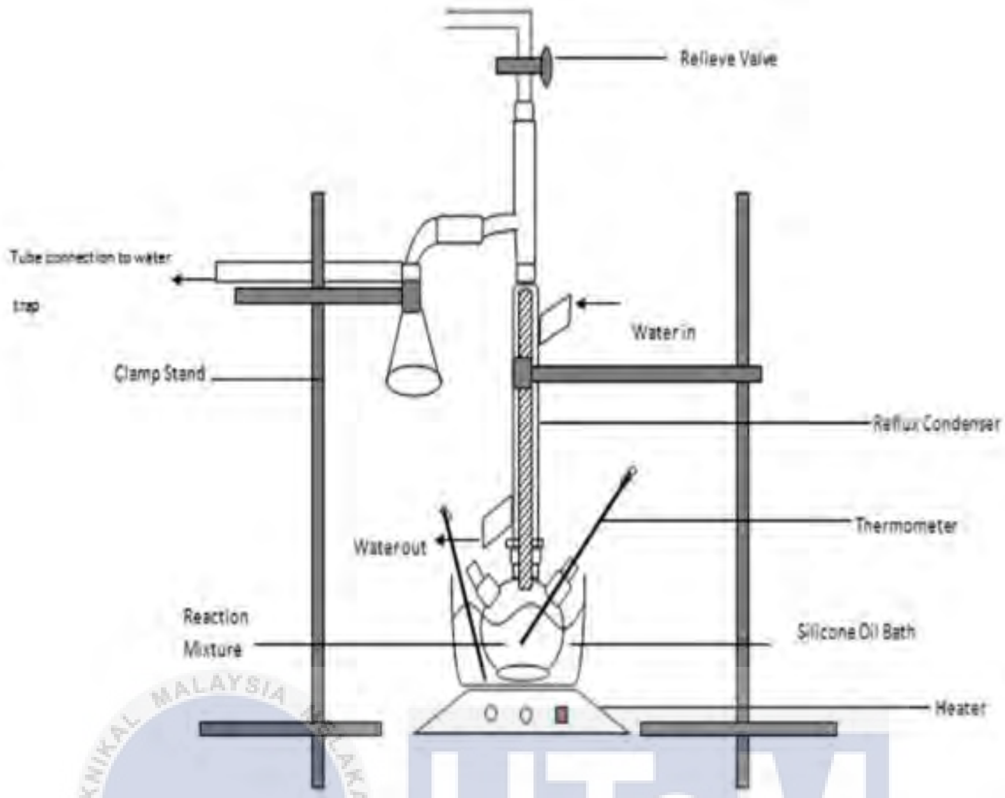


Figure 2. 4: Experiment setup for transesterification reaction

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2.7.1.1 Wear scar diameter

Four-ball testing was done by using IP 239 method. The test was conducted at varied temperatures which is 50, 60, 70, 80, 90 and 100 °C for 1800 s, loaded of 40 kg and rotation speed was kept 1200 rpm. About 10 ml of sample was used per test and the wear produced on the three stationary balls was denoted as wear scar diameter (WSD).

2.7.1.2 Friction evaluation

Frictional torque was measured using load cell beam which was put on the spindle. Ratio of the friction force between two bodies and the normal force that pressed them together was presented by dimensionless value known as coefficient of friction (COF). Small COF value indicated higher efficiency and this information was essential for transmission efficiency measurement. COF was calculated based on equation shown below:

$$\text{COF} = \frac{\sqrt{6} \times T}{3 \times R \times W}$$

W = weight (kg)

T = friction torque (kg.mm)

R = contact radius = 3.67

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2.7.2 Results and discussions

2.7.2.1 Chemical properties

Kinematic viscosity and viscosity index give information on lubricant resistance to flow in gravity and effect of raise temperature on flow. High viscosity index denotes stable lubricant viscosity with increasing temperature. The chemical properties of all lubricant oil are shown in Table 2.3.

Table 2. 3: Chemical properties of lubricant

Formulation	PE	NPGE	AWCI	CL
Density (g/cm^3)	0.93	0.90	0.93	0.99
Kinematic viscosity @40 C, cSt	72.78	27.92	75.37	131.76
Kinematic viscosity @100 C, cSt	13.08	6.60	13.16	17.08
Viscosity index (VI), cSt	183	206	178	142
Total acid no. (TAN) mg KOH/g	0.2	0.34	0.41	0.61
Flash point (°C)	232.5	228.5	228.5	246.5
Pour point (°C)	−21	−15	−19	−18
Cloud point (°C)	8	0	6	−1
NOACK volatility (%)	1.7	1.75	2.2	2
Copper strip corrosion test	3a	1b	1a	3a

2.7.2.2 Coefficient of friction (COF) and wear scar diameter (WSD)

The performances of PE, AWCI, NPG ester, ands CL under various temperatures were investigated to obtain a trend for their thermal stability. The four-ball tester was operated from 50 to 100 °C. In general, the COF increased with temperatures of the lubricants. Higher COF value is usually contributed by low viscosity oil.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

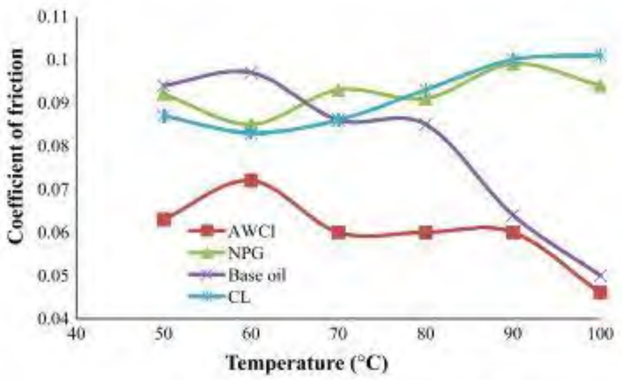


Fig. 2. Effect of temperature on coefficient of friction (COF).

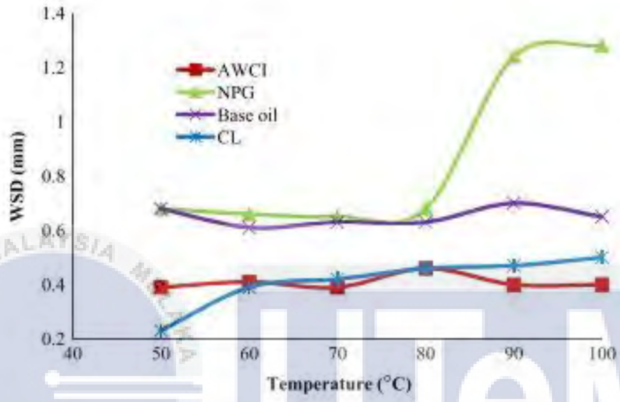


Figure 2. 5: Effect of temperature on wear scar diameter (WSD)

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2.7.3 Conclusion

This study shown that the formulated palm-based pentaerythritol ester, AWCI which was produced from the base oil (PE) synthesised from palm oil methyl ester demonstrated excellent physical and chemical properties. Further studies of their mechanism, energy of adsorption or energy of lateral interaction are required to discover in depth the issues affecting to these ester-based lubricants in the future. The kinematic viscosity of AWCI at 40 °C was 75.37 cSt and it was the only lubricant that passed the copper strip corrosion test with grade 1a. The performance of AWCI also surpassed the commercial lubricant, CL and its base oil (PE) when it showed the lowest COF and WSD compared to CL and PE.

2.8 Friction Characteristics of RBD Palm Olein using Four-Ball Tribotester By (Syahrullail et al. 2013)

This is a study to investigated the effect of load on the tribological performance of RBD (Refined Bleached Deodorised) palm olein and paraffinic mineral oil under different load by using four-ball wear tester according to the standard test of ASTM D4172. This experiment focused on the frictional torque, wear scar diameter, friction coefficient and the flash temperature for both type of lubricant oil.

2.8.1 Methodology

The four ball tester was used to determine the tribological properties of different type of lubricant. The test oil was heated to 75 °C within 3 degrees with the speed of 1200 RPM for one hour. The test ball is 12.7 mm in diameter and made from chrome alloy steel (AISI 52100) Grade 25 Extra Polished and have a Rockwell C hardness of 64 to 66. The Refined Bleached Deodorised (RBD) palm olein and paraffinic mineral oil will be the test lubricants. The wear scar diameter of each of the three bottom test balls was measured to determine the lubricity performance of the test lubricant. The wear scar was evaluated by a computer running CCD software and from the captured photomicrograph. During the experiment, the wear scar diameter was determined for each of the three fixed balls.

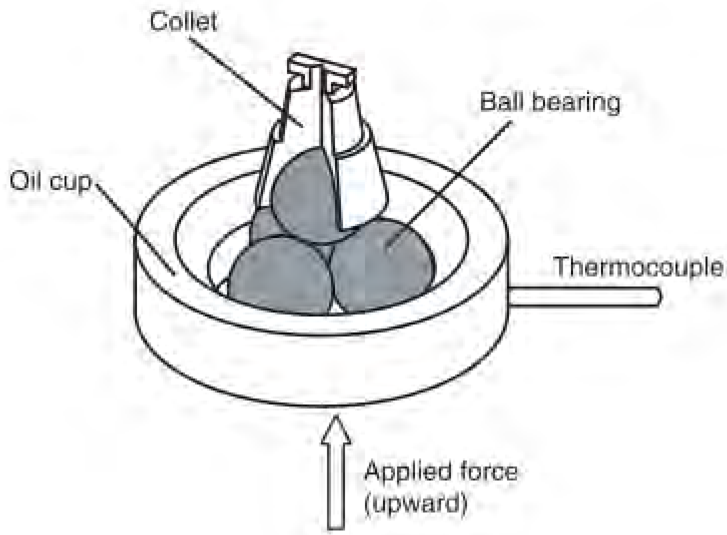


Figure 2. 6: Schematic diagram of four ball tester apparatus

2.8.2 Results and Discussion

2.8.2.1 Temperature

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

The temperature for both test lubricants increased with the incremental increases of the normal load. But for paraffin mineral oil, it result in higher temperature with increase in load, at where it start to increase gradually less than 80 kg experimental load condition. While for RBD palm olein, temperature start rise after reach 100 kg load for experiments. The maximum temperature was detected at 120 kg experimental conditions, and was recorded at 115 and 90 °C for paraffinic mineral oil and RBD palm olein, respectively.

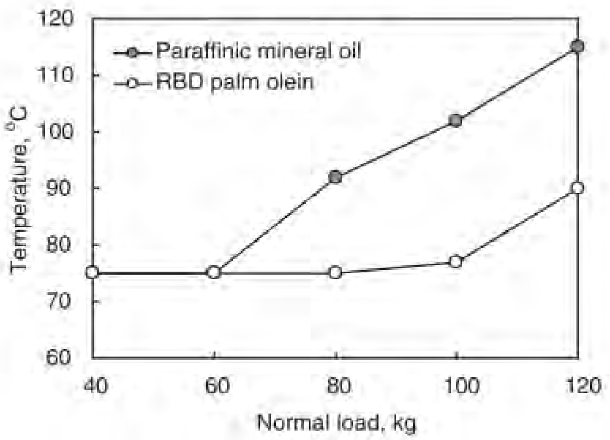


Figure 2. 7: Test lubricant temperatures for various normal loads

2.8.2.2 Wear Scar Diameter

For both lubricant, the figure shown the effect of load on the measured wear scar diameter. From this figure, it is very obvious that the wear scar diameter increases gradually with incremental increases in the normal load. The temperature increase contributed to a decrease in the test lubricant viscosity. Low viscosity lubricants tend to create only a thin film. Increasing temperature causes the lubrication film to become less stable and eventually to break down. Smaller wear scar diameter observed from steel ball which use RBD palm oil olein, the condition between the test balls falls in the mixed lubrication regime consisting of a thin lubricant film with adsorption of fatty acids from the palm oil playing the role of maintaining the thin lubricant.

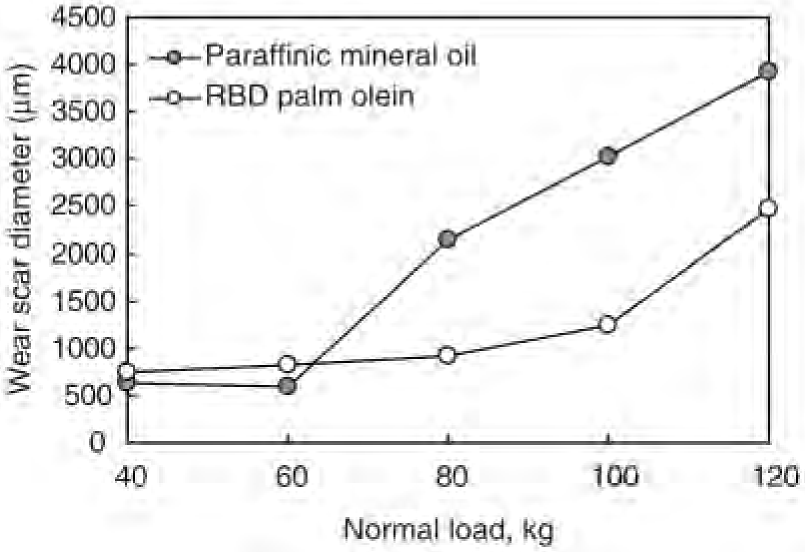


Figure 2. 8: Wear scar diameter for various normal loads

2.8.2.3 Coefficient of friction

Coefficient of friction for paraffinic mineral oil is higher than RBD palm oleic. This is due to the existing of fatty acid in RBD palm oleic can help in maintain the lubricant layer during sliding.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2.8.2.4 Flash temperature parameter

Paraffinic mineral oil have higher flash temperature compared to RBD palm oleic, this show that paraffinic mineral oil have good performance with reduced possibility of lubricant breakdown.

2.8.3 Conclusion

For conclusion, overall RBD palm oil show better performance than paraffinic mineral oil in friction reduction, wear resistance, lubricant film breakdown. At the same time, it shows weakness in term of thermal stability compare to paraffinic mineral oil.

2.9 The Effect of Temperature on the Tribological Behavior of RBD Palm Stearin By (Ing et al. 2012)

In this study, the influence of temperature on friction and wear performance for refined, bleached, and deodorized (RBD) palm stearin and additive-free paraffinic mineral oil is presented. The experiments were conducted using a four-ball tribotester with the standard of ASTM D-4172 and test temperatures of 55, 65, 75, and 85◦C were used. The results of RBD palm stearin were compared with those of paraffinic mineral oil.

2.9.1 Methodology

This experiment carried out by using chrome alloy steel and met AISI E-52100 specification with 12.7mm diameter of test balls. The lubricants used for this experiment were RBD palm stearin and paraffinic mineral oil with the volume 10mL for each test lubricant. The paraffinic mineral oil was used for comparison with the RBD palm stearin.

The density and viscosity of RBD palm stearin and paraffinic mineral oil were measured and are shown below.

Table 2. 4: Density of RBD palm stearin and paraffinic mineral oil

	Test Oil	
Properties	RBD Palm Stearin	Paraffinic Mineral Oil
Density (kg/m^3)	862.0	848.0
Viscosity at 40°C (mPa·s)	47.0	96.5
Viscosity at 75°C (mPa·s)	17.5	21.5

The test temperatures, which were expected to influence the friction and wear characteristics of lubricant, were evaluated. The experiment was carried out for 1 hour under a 392.4 N load and with a spindle speed (rotational speed) of 1,200 rpm. Four steel balls are cleaned by using acetone then three of them are placed into the ball port assembly. The volume of lubricant pour into the ball port assembly is 10 ml. The oil cup assembly components were installed into the frictionless disc in the four-ball machine and, to avoid shock, the test load was applied slowly. After that, the selected lubricant was heated up to the desired temperature. When the set temperature was reached, the drive motor, which was set to drive the top ball at the desired speed, was started. This process continues for 1 hour, and then the wear scar diameter of steel ball in ball port assembly was measured using microscope and the friction coefficient of lubricant is analyses based on the data get from experiment.

2.9.2 Results and Discussion

2.9.2.1 Coefficient of friction

The performance of RBD palm stearin as a lubricant was investigated using a four-ball tester under various bulk temperatures. From the result of experiment, its show the coefficient of friction obtained increased when the bulk oil temperature was increased. This effect was due to the decreased lubricant viscosity caused by the increased temperature. The coefficient of friction for the RBD palm stearin was lower compared to paraffinic mineral oil at 55, 65, and 75◦C. However, at 85◦C, the coefficient of friction for the RBD palm stearin was slightly higher compared to that for paraffinic mineral oil. For both types of lubricant, the coefficient of friction increase with the increase of load.

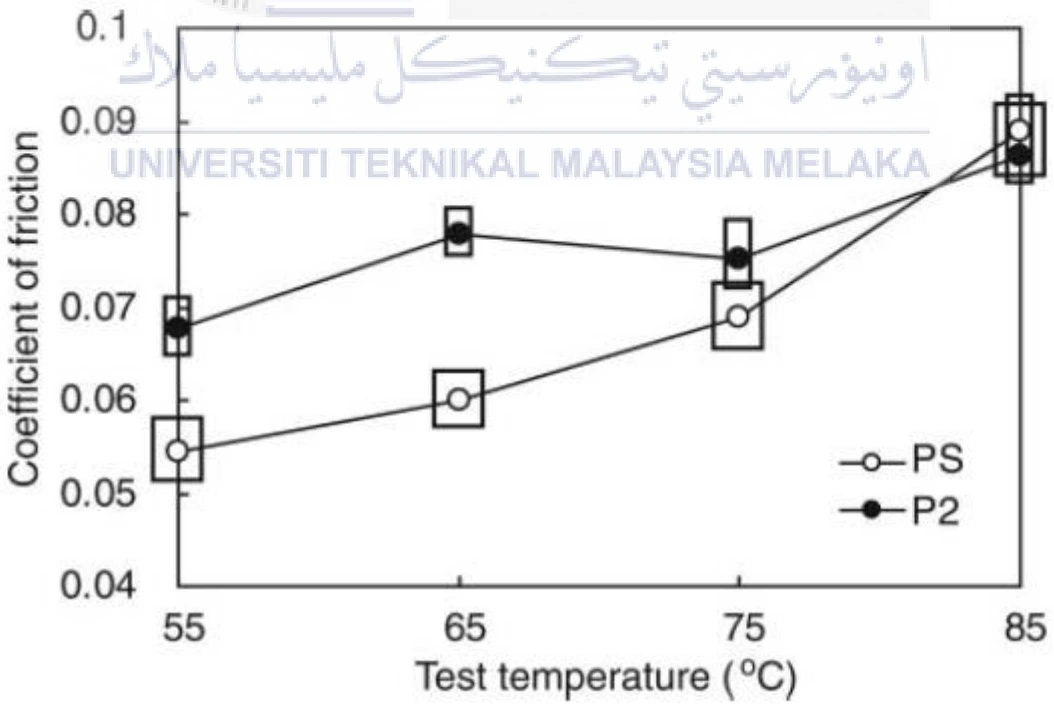
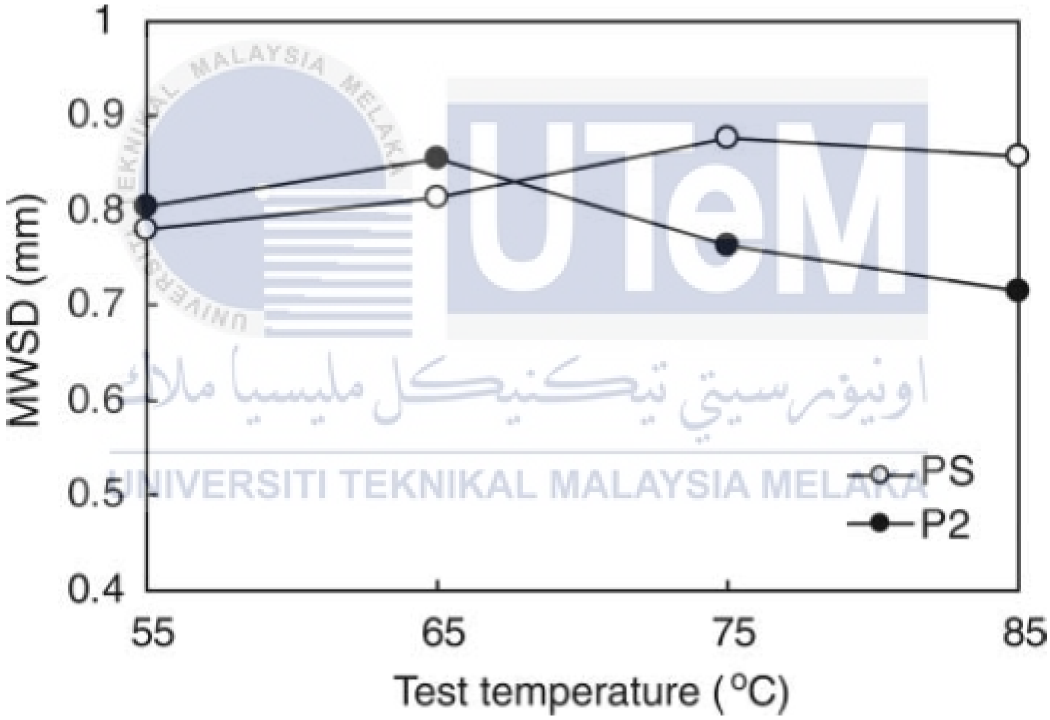


Figure 2. 9: Distribution of coefficient of friction

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2.9.2.2 Mean Wear Scar Diameter

At temperature of 55 and 65◦C the wear scar diameter on the ball bearings for both the RBD palm stearin and the paraffinic mineral oil increased with increasing temperature. The mean wear scar diameter for RBD stearin was smaller compared to that for the paraffinic mineral oil which show RBD palm stearin better lubricity in preventing metal to metal contact. However, at the temperatures (75 and 85◦C), the performance of the RBD palm stearin decreased at where the mean scar diameter increases.



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Figure 2. 10: Wear scar diameter

2.9.2.3 Flash temperature parameter

The flash temperature for paraffinic mineral oil increased with increasing test temperature, but for RBD palm stearin lubricant, the flash temperature decrease with increase of temperature. The possibility of lubricant film breakdown is greater at low flash temperatures, which indicates poor lubricity. Therefore, it was concluded that the fatty acid thin film became less stable at higher temperatures in sliding contact. Therefore, at the higher temperatures (75◦C and above), paraffinic mineral oil showed better lubricating performance compared to RBD palm stearin. Pressure is the force (normal load) per unit area. In this study, the area was the contact area of the ball bearings, which was almost circular in shape. Because the value of the normal load was constant (40 kg), the pressure on the contact area depended on the wear scar diameter. The larger the wear scar diameter, the less pressure that was applied to the contact surface. At 85◦C the mean wear scar diameter of the ball bearings lubricated with RBD palm stearin was larger compared to those lubricated with paraffinic mineral oil, which means that the lubrication condition had collapsed and metal to metal contact happen.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

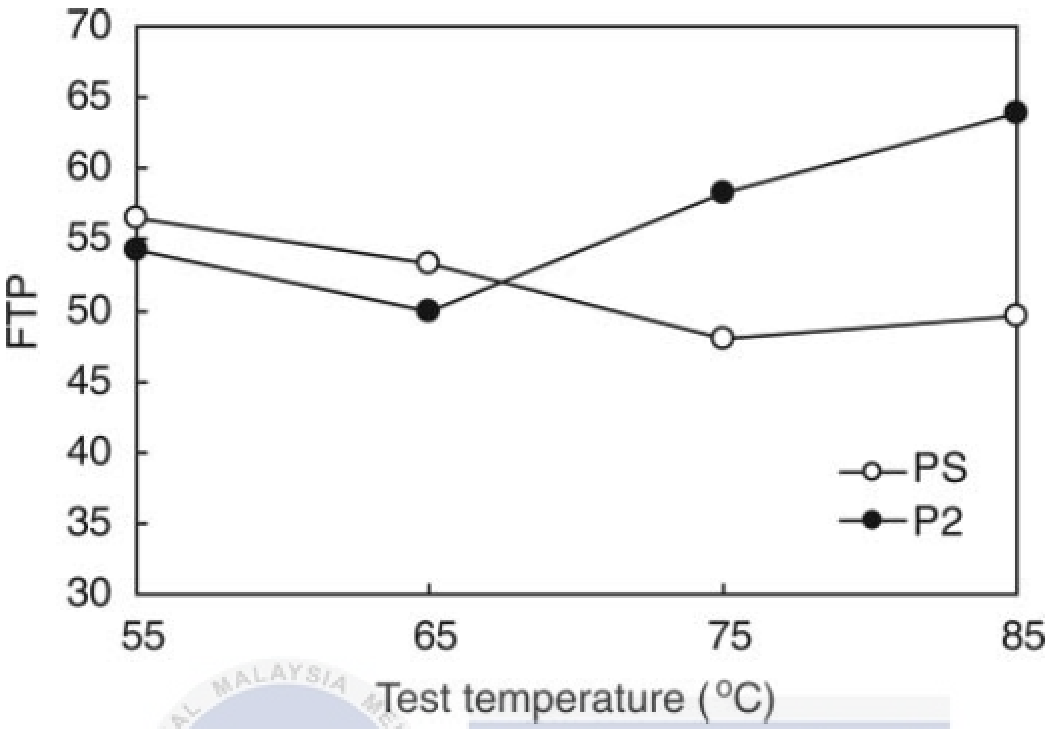


Figure 2. 11: Flash temperature parameter

2.9.3 Conclusion

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Based on the result obtained from experiments, RBD palm stearin lubricant show better lubricity at lower temperature which bring to low coefficient of friction, but when the temperature increase until certain level, the lubricity of paraffinic mineral oil lubricant show more stable and better performance. For wear scar diameter, RBD palm stearin lubricant show smaller wear scar diameter at lower temperature compare to paraffinic mineral oil, but at higher temperature, its shows larger wear scar diameter compares to paraffinic mineral oil.

2.10 Summary

From all of the literature review or previous study, natural oils is that high oleic acid concentrations improve friction and wear performance(Shahnazar et al. 2016). Besides that, RBD palm stearin lubricant also show better lubricity at lower temperature which bring to low coefficient of friction, but when the temperature increases until certain level, the lubricity of paraffinic mineral oil lubricant show more stable and better performance.

اونيۆرسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHAPTER 3

METHODOLOGY

3.1 Overview

This section will focus on the data collection through experimental method. The procedures to carry out physical measurement, steps for settings and equipment used for four ball tester, seta flash and viscometer are discussed in this chapter.

3.2 Introduction

This experiment to obtain the properties of nanoparticles enhanced natural oil-based lubricants at difference temperature are carry out by using four ball tester and wear oil. The sample (Steel balls) or results obtained from the four ball tester experiment will put under another process to determine the flash temperature and viscosity, besides that the characteristic of lubricant before four ball tester experiment conduct will also been determine under oil analysis process. The general methodology of this experiment is summarized in the flow chart as shown in Figure 3.1.

3.3 Flow chart

Flow chart in Figure 3.1 showed the flow of the methodology process of whole experiment in briefly by step by step.

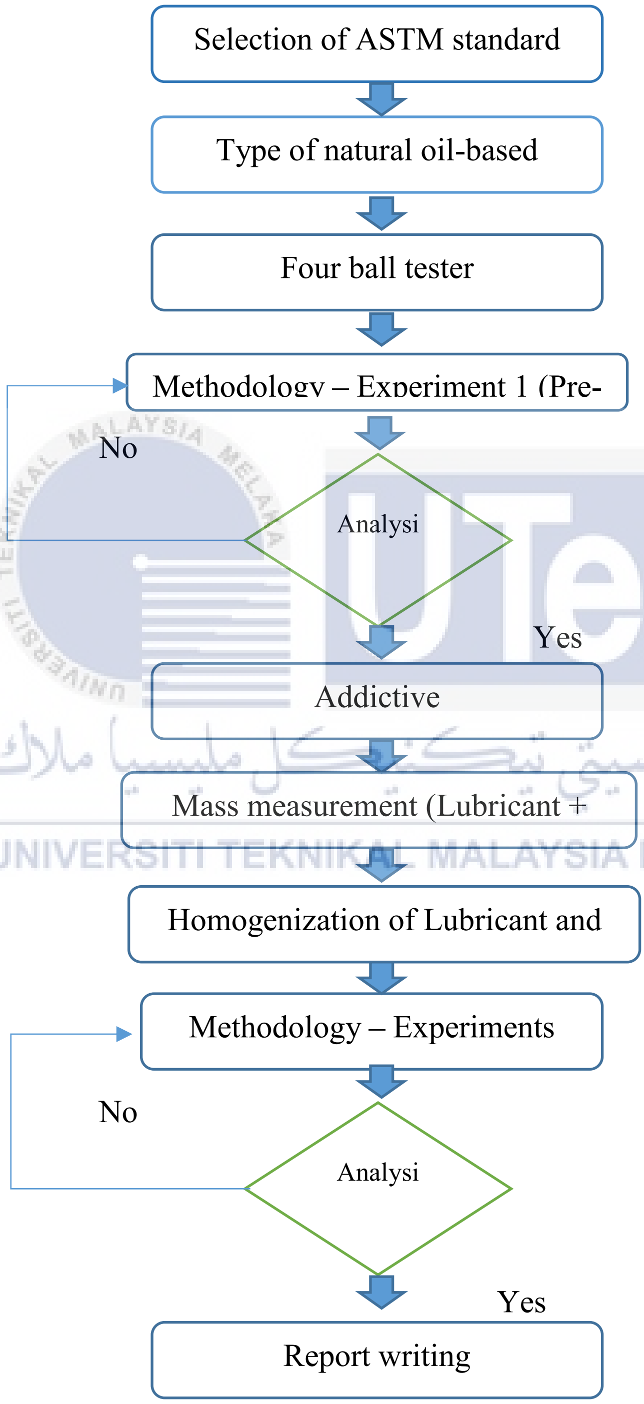


Figure 3. 1: Flow chart of the methodology

3.4 General Flow of Methodology

3.4.1 Apparatus and standard setting

a) Selection of ASTM standards

American Society for Testing and Material, ASTM is a set of global or international Standard for materials. From these entire standards, ASTM D-4172 is selected to run Experiment, which is purposely using the four ball tester.

Figure 3. 2: Summary of common ASTM Standard

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

b) Types of natural oil-based lubricant

The Natural Oil-Based lubricant used in this experiment is Palm Oil-Based lubricant which included:

1. refined glycerine
2. oleic methyl ester

Figure 3. 3: Palm oil based lubricant

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

c) Apparatus and materials

The experiment was conducted at the tribology lab by using four ball tester, seta flash series 3 and viscometer.

Figure 3. 4: Four Ball Tester

The materials used in experiment are listed as below:

a) Bearing balls

b) Lubricants (refined glycerine, oleic methyl ester)

c) Gloves

d) N-95 face mask

e) Tissue

f) Cleaning material (shampoo)

g) Zip beg

h) CNT – Nano carbon tube

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Figure 3. 5: Sartorius Stedim Homogenizer

UTeM
اونيورسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

3.4.2 Experiments Conditions

The experiment is conducted by running the experiment with different in temperature and mixed with carbon nanotubes at 0.5%wt, 1%wt, 2%wt, 3%wt, 4%wt and 5%wt to determine the tribological properties.

Table 3. 1: Types of experiment with its Standard and material

Experiment	Parameter
1	Lubricants- Refined glycerine and oleic methyl ester without additive. Standard use is ASTM D-4172-B, the load used is 40kg or 392N, which run for one hour with temperature of 75±2°C and speed of 1200±60 rpm

2	Lubricants- Refined glycerine and oleic methyl ester with addition of 0.5%wt CNT as additive. Standard use is ASTM D-4172-B, the load used is 40kg or 392N, which run for one hour with temperature of 75±2°C and speed of 1200±60 rpm
3	Lubricants- Refined glycerine and oleic methyl ester with addition of 1%wt CNT as additive. Standard use is ASTM D-4172-B, the load used is 40kg or 392N, which run for one hour with temperature of 75±2°C and speed of 1200±60 rpm
4	Lubricants- Refined glycerine and oleic methyl ester with addition of 2%wt CNT as additive. Standard use is ASTM D-4172-B, the load used is 40kg or 392N, which run for one hour with temperature of 75±2°C and speed of 1200±60 rpm
5	Lubricants- Refined glycerine and oleic methyl ester with addition of 3%wt CNT as additive. Standard use is ASTM D-4172-B, the load used is 40kg or 392N, which run for one hour with temperature of 75±2°C and speed of 1200±60 rpm
6	Lubricants- Refined glycerine and oleic methyl ester with addition of 4%wt CNT as additive. Standard use is ASTM D-4172-B, the load used is 40kg or 392N, which run for one hour with temperature of 75±2°C and speed of 1200±60 rpm
7	Lubricants- Refined glycerine and oleic methyl ester with addition of 5%wt CNT as additive. Standard use is ASTM D-4172-B, the load used is 40kg or 392N, which run for one hour with temperature of 75±2°C and speed of 1200±60 rpm

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

3.4.3 Result Analysis

Result analysis consist of performance comparison of properties between the selected lubricants and parameter such as:

i. With and without additive
ii. Different quantity of additive (0.5%wt, 1%wt, 2%wt, 3%wt, 4%wt and 5%wt)

3.5 ASTM D-4172

ASTM D-4172: Standard test method for wear preventive properties of lubricating greases using block on ring test machine in oscillating motion.

Table 3. 2: Types of ASTM 4172 and their parameter

ASTM Standard	Load (Kg)	Duration (Sec)	Temperature (°C)	Speed (Rpm)
A	15	3600	75±2°C	1200±60
B	40	3600	75±2°C	1200±60

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

3.6 Experimental Procedures

The experiments are divided into 2 categories: which are experiment 1 – without addictive, experiment 2 until experiment 7 with the addictive under temperature 75±2°C. Experiment 1 is conducted by using pure Palm oil based lubricant under temperature of 75±2°C, while experiment 2 until experiment 7 is conduct by using the lubricant with 0.5%wt, 1%wt, 2%wt, 3%wt, 4%wt and 5%wt amount of addictive under temperature 75±2°C. All experiment are carried out according to ASTM D-4172 B standard.

(a) Four Ball Tester Machine

(b) Internal component of ball cup   (c) Ball cup assembly with bearing ball

Figure 3. 6: Four ball tester apparatus

3.6.1 Experiment 1

UTeM
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

1) Clean four steel balls by using Acetone
2) One of the clean ball inserted into ball chuck. Ball chuck is inserted into the spindle of four ball tester machine and tightens according to the equipment direction.
3) Placed another three balls into ball cup, and fixed the ball in position by using the cup ring.
4) Coat the balls in ball cup completely by using lubricant selected and filled then ball cup with the lubricant and level off with the top surface of balls.
5) Placed ball cup assembly on the four ball tester machine, the temperature sensor are connected to ball cup assembly by lock it to the ball cup.
6) Load is added slowly to four ball tester machine. After reaching 392 N, the temperature is set to 75±2°C by adjust the temperature controller.

7) When reached the desired temperature, speed of the oscillation is set to 1200±60 rpm. Duration is set to 1 hour.

8) After four ball tester machine run for 1 hour, the drive motor is turn off and ball cup is removed from four ball tester.

9) The balls removed from ball cup and ball chuck, cleaned the ball using acetone.

10) Wear scar diameter of balls is measured by using microscope.

11) Average reading for 3600 reading of friction torque calculated by Microsoft Excel.

12) Repeat step 1 to 10 by using different lubricant.

3.6.2 Experiment 2

1) Additive of 0.5%wt of CNT and lubricants is measured by using digital mass measurement instrument

UTeM
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

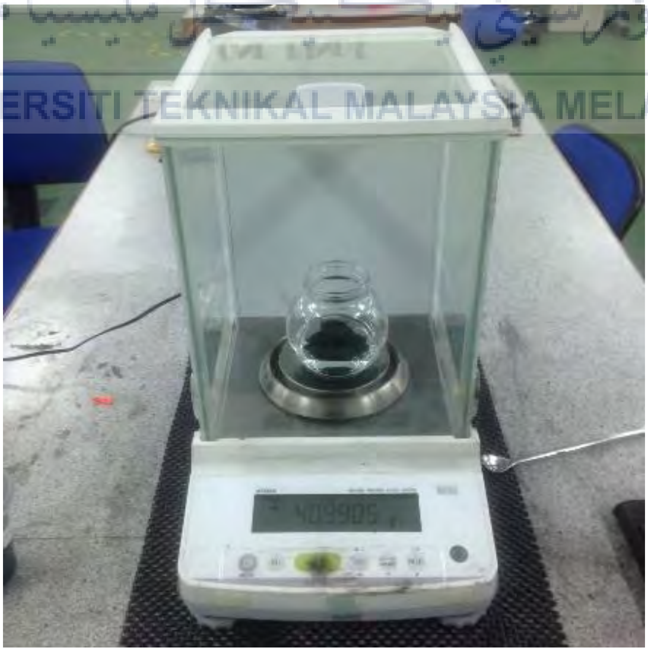


Figure 3. 7: Digital mass measurement

Precaution

a. For mass measurement process of additive, the digital mass measurement instrument is set to 0g as initial reading to prevent any misalignment and systematic error occur. Then the empty beaker is place on the digital mass measurement instrument, set the reading to 0 gram again with the empty beaker on the instrument. Then, fill the lubricant into empty beaker. Then the additive is poured into the beaker until the reading show 0.5%wt from amount of lubricant.

b. Step (a) is repeated for 1%wt, 2%wt, 3%wt, 4%wt, 5%wt of CNT and for each type of lubricant.

2) The mixture of additive and lubricant in beaker is placed on the plate in the homogenizer instrument and the position is adjusted to ensure that the tips used must merge half into the lubricant as shown in Figure 3.16.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

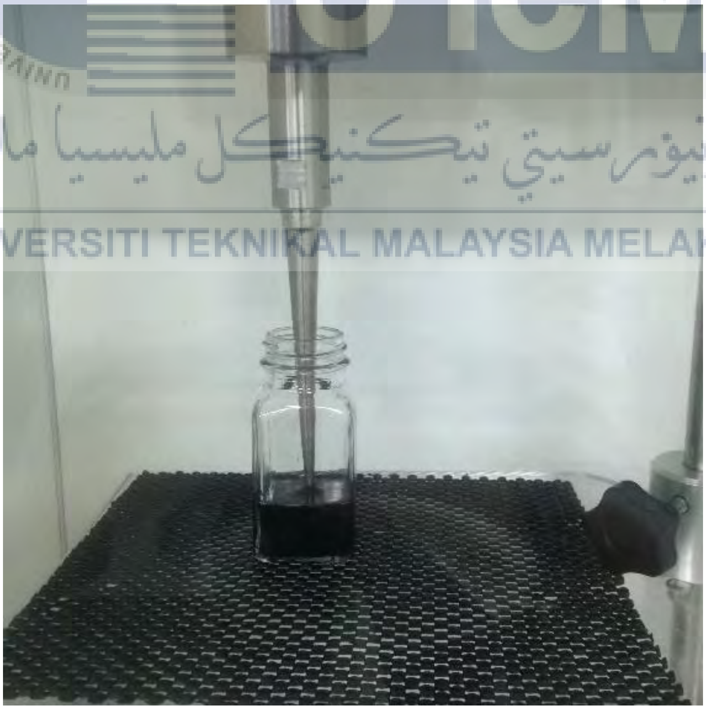


Figure 3. 8: The mixture of additive and lubricant in beaker in homogenizer

3) The homogenizer instrument is set to 50 rpm and run for 15 minute.

4) After 15 minute, the homogenizer instrument is turn off and the beaker are take out from homogenizer instrument and the lubricant are available for used in four ball tester experiment.

5) Repeat Step 1 to Step 12 in EXPERIMENT 1 by using the lubricant homogenized from Step 1 to Step 4 in EXPERIMENT 2.

3.6.3 Experiment 3

1) Set up the viscometer equipment.

Figure 3. 9: Viscometer equipment

2) Filled the lubricant completely into the cylinder steel.

3) Start clicked to run the viscometer until the process done and setting the rpm until reach higher percent viscosity that can achieve.

4) Collected data from the screen for viscosity of lubricant at 10C°, 20 C°, 30 C° and 40 C°.

5) Repeat step 1 to step 4 by using different lubricant.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHAPTER 4

RESULTS AND ANALYSIS

4.1 Overview

In this study, the data and results of friction and wear properties, flash temperature and viscosity of lubricants which is Refined Glycerine and Oleic Methyl Ester. Two conditions without and with additive for each type of lubricants is tabulated and analysed. The data and result obtained from the experiment are compared.

4.2 Experimental Results

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Experiment 1 was conducted by using Pure Palm Oil-based Lubricant which is Refined Glycerine and Oleic Methyl Ester under temperature 75°C. Experiment 2 followed after Experiment 1 where the additive added to the lubricants in certain concentration and tribology properties of these mixtures are determined.

Table 4. 1: Different types of experiment with different parameter

Experiment	Parameter
1	Refined Glycerine and Oleic Methyl Ester without additive
2	Refined Glycerine and Oleic Methyl Ester with additive which include 0.5%wt, 1%wt, 2%wt, 3%wt, 4%wt and 5%wt of carbon nanotubes (CNT)

The result from four ball tester measurement for Coefficient of Friction (COF) is obtained. The running time for each sample is 1 hour. Besides that, the Wear Scar Diameter was also measured by using microscope for ball bearing in each experiment.

4.2.1 Viscosity

The lubricant viscosity was determined with temperature of 40°C and 100°C as shown in Table 4.2. Based on Table 4.2, Refined Glycerine show the highest viscosity compared to Oleic Methyl Ester. Viscosity increment indicates that lubricant has deteriorated by oxidation, while a decrement usually indicates dilution by lower viscosity oil or by fuel.

UTeM
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

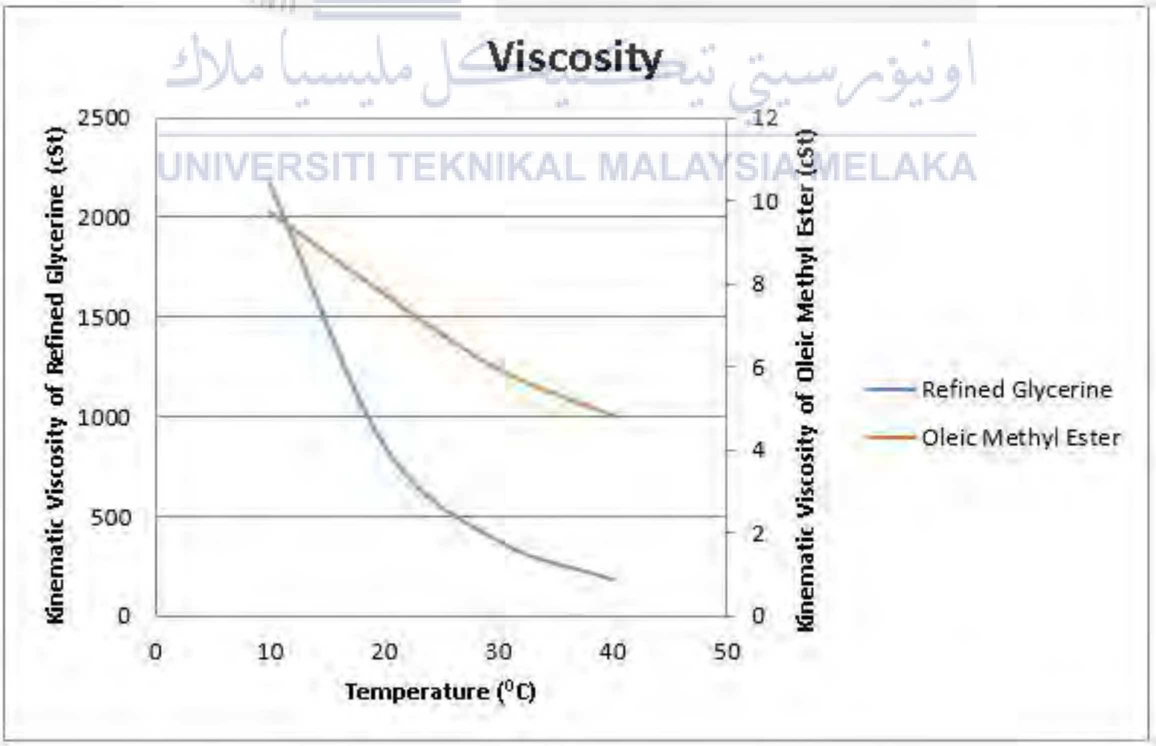


Figure 4. 1: Viscosity of lubricants

Table 4. 2: Kinematic viscosity of lubricant in unit of cSt

Type of lubricant	Kinematic viscosity of 40°C	Extrapolate kinematic viscosity at 100°C	Viscosity Index
Refined Glycerine	184.3	79.9	387.01
Oleic Methyl Ester	4.85	1.46	-

Figure 4.1 shown the pattern graph of 10°C, 20°C, 30°C and 40°C for each lubricants. The viscometer cannot take the reading of 100°C because it too hot for the hook at that equipment. So, we do extrapolate to find the kinematic viscosity at 100°C. Based on these data, we calculate the kinematic viscosity at 100°C by following the formula as shown below.

For Refined glycerine:

$$Y = 79.6515 + 5628.8366e^{-0.0988x}$$

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

For Oleic methyl ester:

$$Y = 0.5359 + 11.9135e^{-0.0256x}$$

As shown in Table 4.2, Refined Glycerine shows the higher viscosity while Oleic Methyl Ester shows the lowest viscosity. Its mean Refined Glycerine have higher performance of wear and friction prevention compare to Oleic Methyl Ester. This indicated that Refined Glycerine has very good performance in term of fluid internal resistance to shear and tensile stress. From this result, it’s also proved that Refined Glycerine has higher fluid friction, film strength, longer molecular chain, intermolecular friction and film thickness compare to Oleic Methyl Ester.

To find viscosity index (VI), we using calculator for viscosity index (VI) according to ASTM D2270. As shown in Table 4.2, we cannot find the viscosity index for oleic methyl ester because the kinematic viscosity at 100°C is below 2 cSt.

4.2.2 Flash point

According ASTM D3828 standard, the flash point was determined by using Seta Flash. The flash point was determined with starting temperature is 150°C for Refined Glycerine and 105°C for Oleic Methyl Ester. This experiment used the 4ml of each lubricant to carry out the actual flash point. Table 4.3 shows the actual flash point for each lubricant.

Figure 4. 2: Seta Flash

Table 4. 3: Flash point of lubricants

Sample	Refined Glycerine (RG)	Oleic Methyl Ester (OME)
Actual flash point	196.6°C	175.5°C

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

As shown in Table 4.3, Refined Glycerine shows the highest flash point while Oleic Methyl Ester shows the lowest flash point.

4.2.3 Coefficient of Friction, (COF)

The result from four ball tester measurement for Coefficient of Friction (COF) is recorded and data include Time, Load and Friction Torque for each second of the experiment within duration of 1 hour. Based on these data, we can calculate the Coefficient of Friction (COF) of the lubricant by following the step and applying the formula as shown below.

Step 1: Convert the load in unit of mass in kg by formula to get weight, W

$$\text{Mass in unit kg} = \frac{Load}{9.81}$$

Step 2: Convert the mass in kg into unit of Kg.mm to get friction torque, T

$$\text{Mass in unit of Kg.mm} = \frac{Mass\ in\ unit\ Kg}{0.00981}$$

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Step 3: Determine the Coefficient of Friction (COF) by using formula

$$\text{COF} = \frac{\sqrt{6} \times T}{3 \times R \times W}$$

W = weight (kg)

T = friction torque (kg.mm)

R = contact radius = 3.67

4.2.3.1 Coefficient of Friction, (COF) of lubricants

A. COF of bearing ball by using Refined Glycerine with and without additive.

Referring to Figure 4.3, COF of Refined Glycerine without additive has increased at the beginning of the experiment, and later achieve almost at steady state after 2000 second with average reading of 0.052555. For Refined Glycerine with additive 0.5%wt CNT, the COF has increased very high at 1790 second, however the COF started to drop after 1850 second with average reading of 0.065727. For Refined Glycerine with 1%wt and 2%wt of CNT, the COF has increased at the beginning of the experiment and later achieve almost steady state after 2500 second with average reading of 0.04858 and 0.052886 respectively. For Refined Glycerine with 3%wt CNT, its show very good lubricant because this lubricant achieve low COF reading compare to other lubricant. The average reading of Refined Glycerine with 3%wt CNT is 0.015551. Besides that, for 4%wt and 5%wt CNT get COF with average reading of 0.043057 and 0.062884 respectively.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

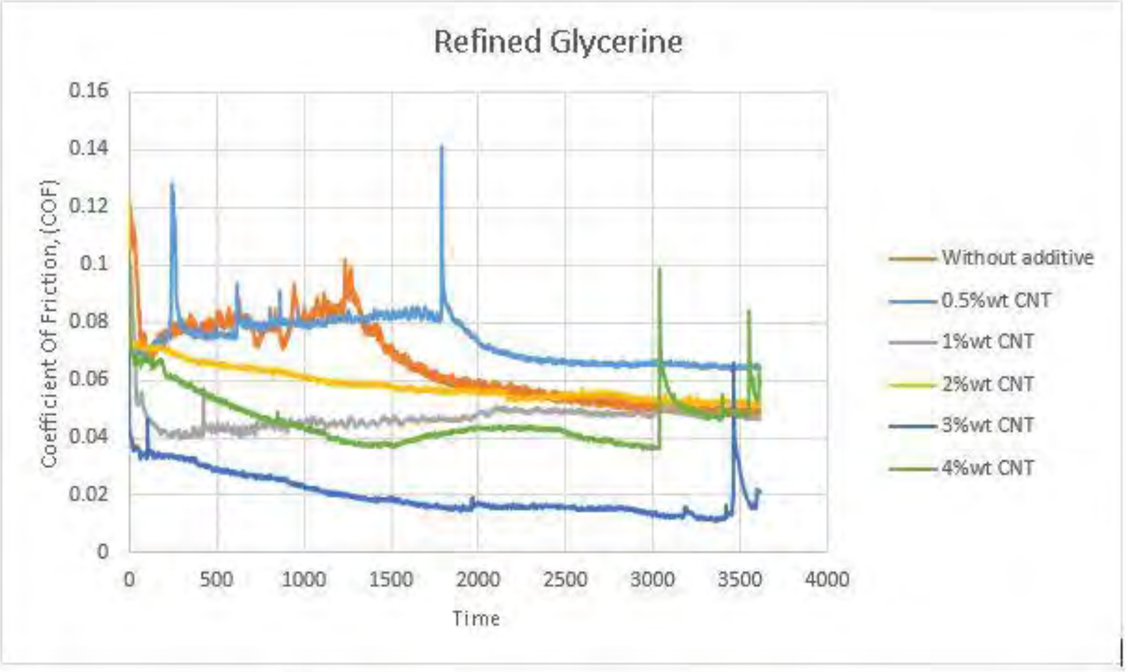


Figure 4. 3: COF against Time for Refined Glycerine without and with additive

The fluctuation occurs as shown in Figure 4.3 shows that there are several breakdowns of lubricant film during the experiment. The breakdown of lubricant is causing by the unstable of lubricant film which initiated by the properties of lubricant itself. When the COF of lubricant increase, it shows the temporary lost lubricant. For all these Refined Glycerine lubricants, Refined Glycerine with 3%wt CNT work better compare from others. This proved only to the extent of 3%wt CNT as lubricant additive successfully enhance the strength of lubricant as a film or oxide film between two metals to prevent direct contact occur. This indicates that it performs well than the others in reducing's the friction between two contact surfaces.

B. COF of bearing ball by using Oleic Methyl Ester without and with additive.

Based on Figure 4.4, COF of Oleic Methyl Ester without additive show steady state from beginning until reach at 3300 second. It has increased at 3300 second and continue

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

steady with total average reading of 0.130989. For COF of Oleic Methyl Ester with 0.5%wt additive, the COF increased at the beginning of the experiment, but the COF tend fluctuate along the experiment and finally end up with the average reading of 0.138478. COF of Oleic Methyl Ester with 1%wt and 2%wt additive has almost the same pattern graph. They are reach almost steady state from beginning until end of the experiment. The average COF of these lubricant are 0.087955 and 0.087542 respectively. For COF of Oleic Methyl Ester with 3% additive, the COF has fluctuated at the beginning of the experiment until 3300 second, but the COF start to steady state with average of reading of 0.084442. Besides that, for 4%wt and 5%wt CNT get COF with average reading of 0.141846 and 0.139718 respectively.

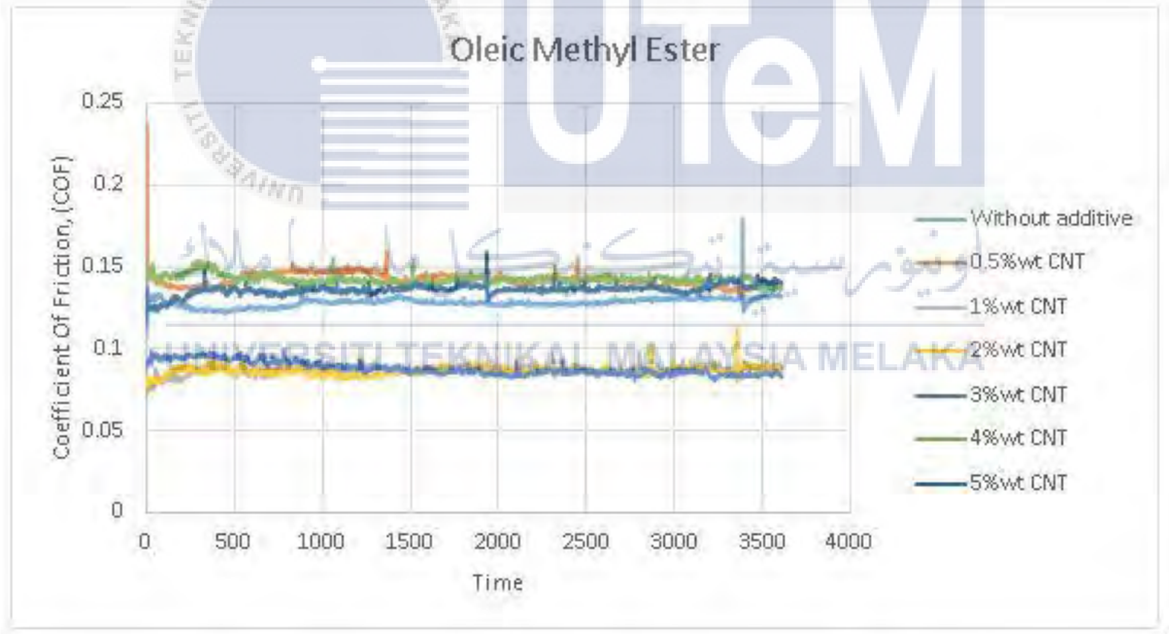


Figure 4. 4: COF against Time for Oleic Methyl Ester without and with additive

From Figure 4.4, it shows that all lubricant without and with additive experience several breakdown of lubricant film during which shows by the fluctuation of COF as shown in Figure 4.4. This proved that Oleic Methyl Ester with 3%wt CNT is very good lubricant enhance the strength of lubricant as a film or oxide film between two metal to prevent direct contact occur.

4.2.3.2 Overall comparison for COF between 2 types of lubricant

From Table 4.4, the COF for without and with additive show the lowest value at Refined Glycerine compare to Oleic Methyl Ester. This shown that Refined Glycerine work better in preventing friction occur between two contacting surface. For both of these lubricant shows the lowest average of reading of COF at lubricant with 3%wt additive. These lubricants only can mix until 3%wt concentration of additive to get the lowest COF. More than that, it will increase the friction of two contacting surface.

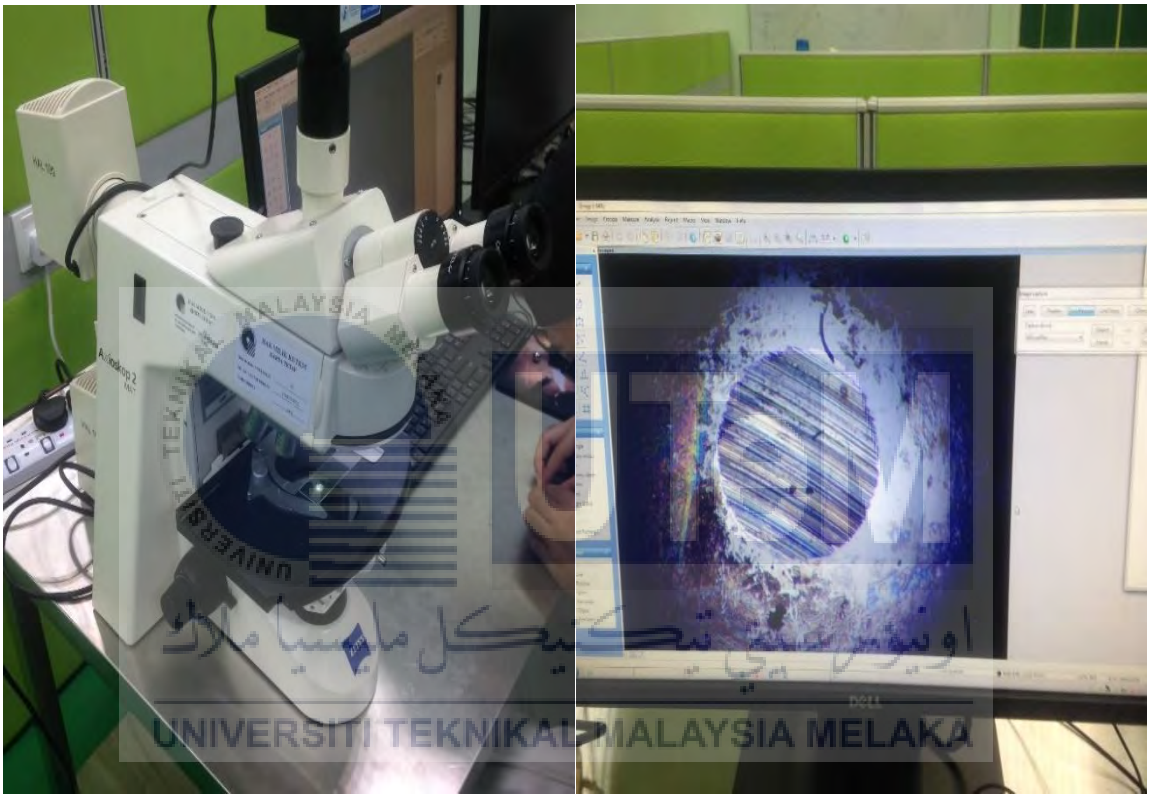
Table 4. 4: Average COF of all lubricant

Result	Refined Glycerine	Oleic Methyl Ester
Without additive	0.052555	0.130989
With 0.5%wt CNT	0.065727	0.138478
With 1%wt CNT	0.04858	0.087955
With 2%wt CNT	0.052886	0.087542
With 3%wt CNT	0.015551	0.084442
With 4%wt CNT	0.043057	0.141846
With 5%wt CNT	0.062884	0.139718

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

4.2.4 Wear Scar Diameter, (WSD)

The diameter of wear scar is measured by using microscope. This is done by drawing a circle which is adjustable in diameter and the wear scar should be in the area of circle.



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

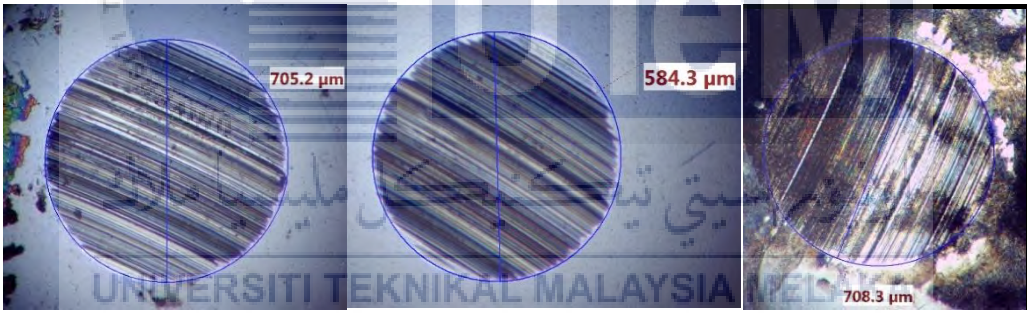
Figure 4. 5: Wear scar diameter method

4.2.4.1 Wear Scar Diameter (WSD) of Ball Bearing by using Refined Glycerine

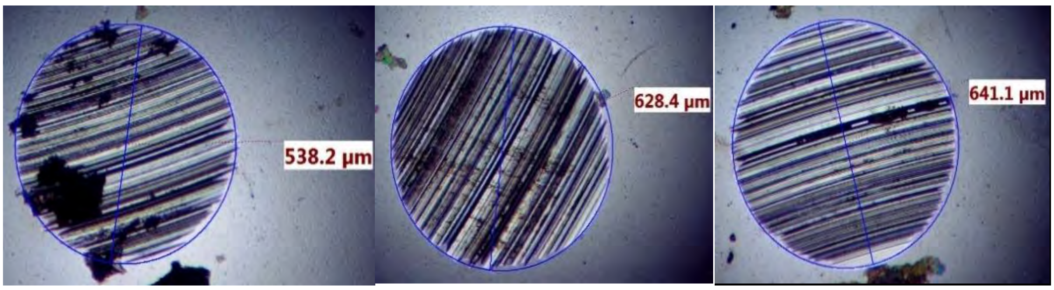
A. Wear scar diameter of ball bearing by using Refined Glycerine without and with additive as lubricant.

Table 4. 5: Wear scar diameter of Refined Glycerine without additive and with 0.5%wt additive

Result	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
	Without Additive			With additive 0.5%wt CNT		
Wear scar diameter (µm)	705.2 µm	584.3 µm	708.3 µm	538.2 µm	628.4 µm	641.1 µm
Average wear scar diameter (µm)	665.93 µm			602.56 µm		



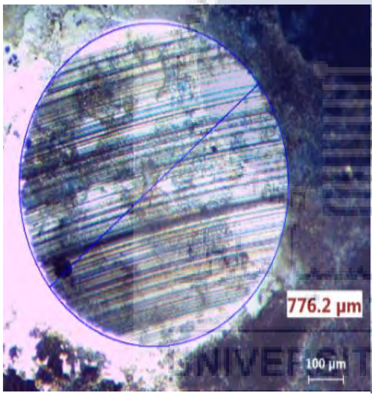
(a) Sample 1 (b) Sample 2 (c) Sample 3



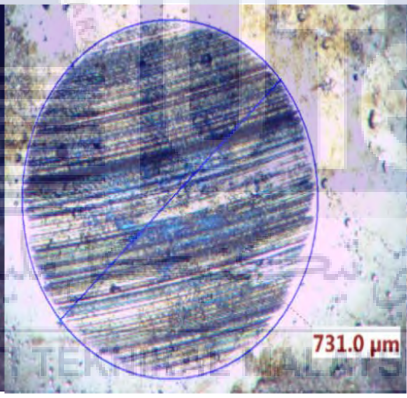
(d) Sample 4 (e) Sample 5 (f) Sample 6

Table 4. 6: Wear scar diameter of Refined Glycerine with 1%wt and 2%wt additive

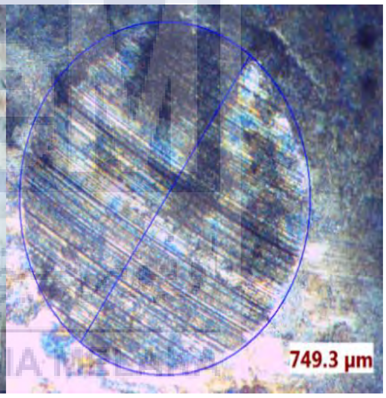
Result	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
	With additive 1%wt CNT			With additive 2%wt CNT		
Wear scar diameter (µm)	776.2 µm	731.0 µm	749.3 µm	602.9 µm	620.5 µm	595.1 µm
Average wear scar diameter (µm)	752.2 µm			606.2 µm		



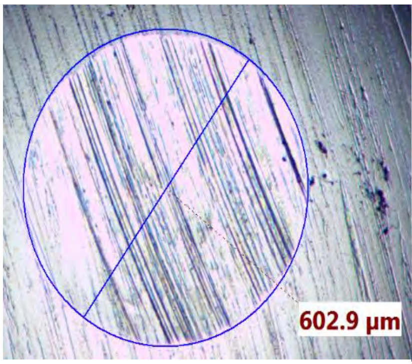
a) Sample 1



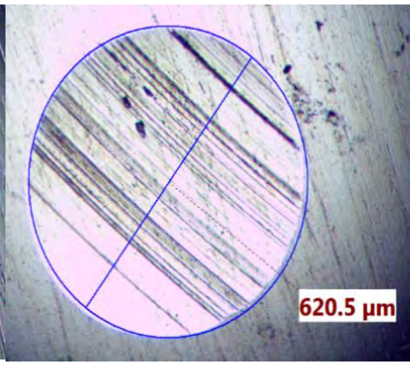
b) Sample 2



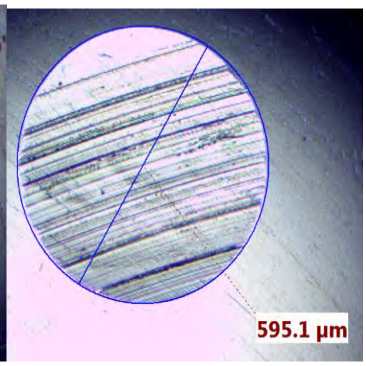
c) Sample 3



d) Sample 4



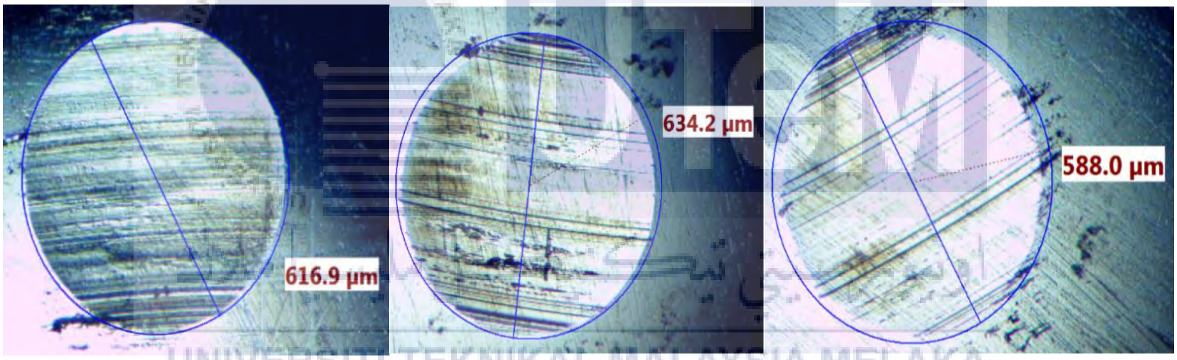
e) Sample 5



f) Sample 6

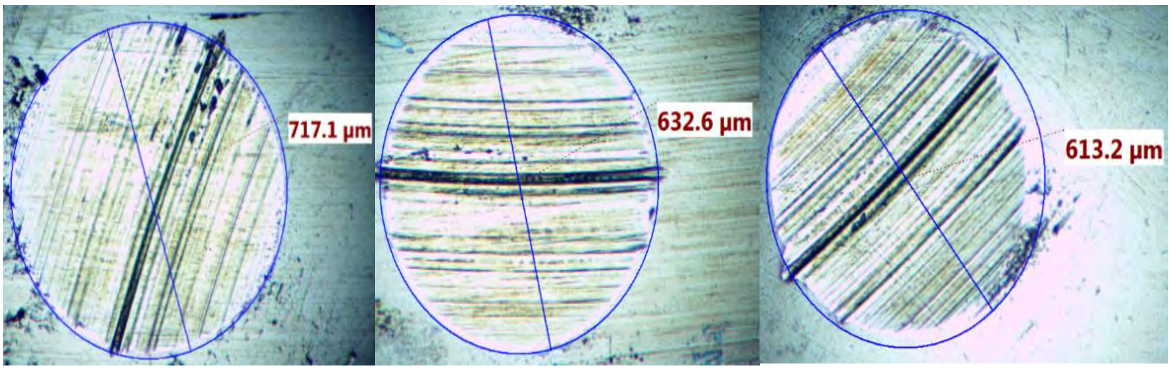
Table 4. 7: Wear scar diameter of Refined Glycerine with 3%wt and 4%wt additive

Result	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
	With additive 3%wt CNT			With additive 4%wt CNT		
Wear scar diameter (µm)	616.9 µm	634.2 µm	588.0 µm	717.1 µm	632.6 µm	613.2 µm
Average wear scar diameter (µm)	613.0 µm			654.3 µm		



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

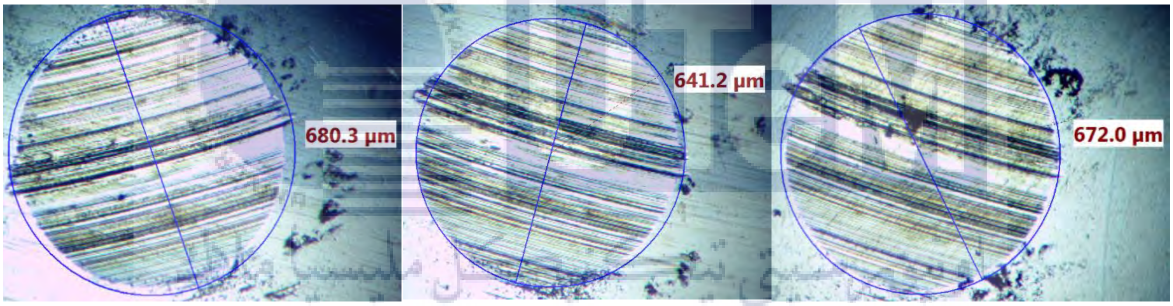
a) Sample 1 b) Sample 2 c) Sample 3



d) Sample 4 e) Sample 5 f) Sample 6

Table 4. 8: Wear scar diameter of ball bearing by using Refined Glycerine with 5%wt additive

Result	Sample 1	Sample 2	Sample 3
	With additive 5%wt CNT		
Wear scar diameter (µm)	680.3 µm	641.2 µm	672.0 µm
Average wear scar diameter (µm)	664.5 µm		



a) Sample 1 b) Sample 2 c) Sample 3

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

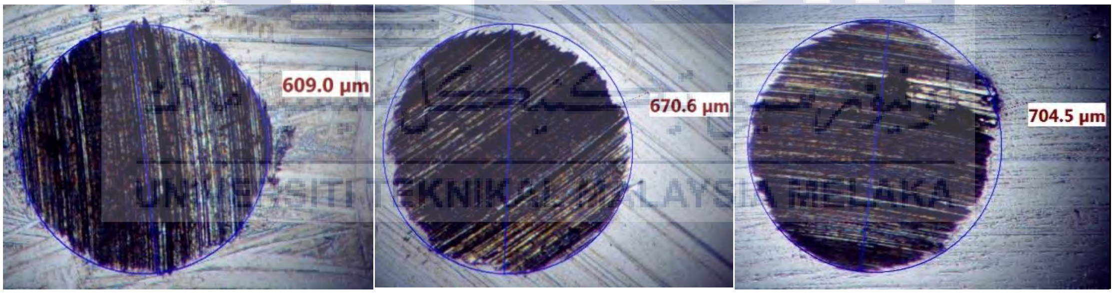
Referring to the result in Table 4.4, 4.5, 4.6, 4.7 above, it is clearly shown that the lubricant with additive perform better in reducing wear scar occur between two contacting metal surfaces. This prove that Refined Glycerine successfully utilize the high strength of CNT as additive to prevent the wear occur between two contacting metal and reduce the wear scar diameter in ball bearing.

B. Wear scar diameter of Oleic Methyl Ester without and with additive as lubricant.

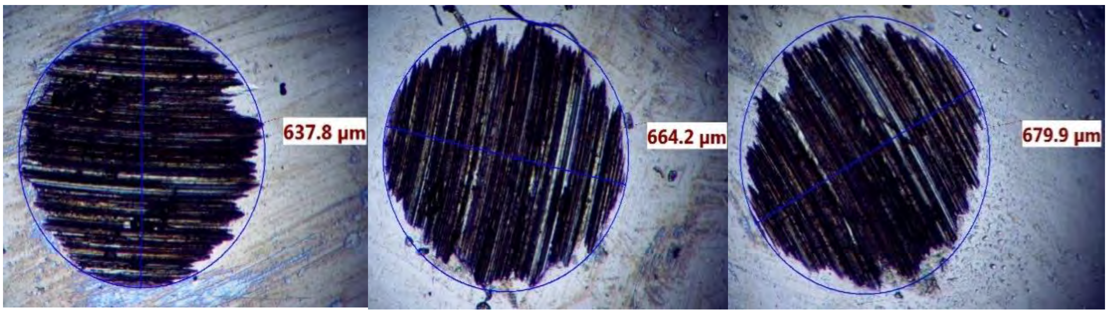
Table 4. 9: Wear scar diameter of Oleic Methyl Ester without and with additive as lubricant

Result	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
	Without Additive			With additive 0.5%wt CNT		
Wear scar diameter (µm)	609.0 µm	670.6 µm	704.5 µm	637.8 µm	664.2 µm	679.9 µm
Average wear scar diameter (µm)	661.36 µm			660.63 µm		

UNIVERSITI TEKNIKAL MALAYSIA MELAKA



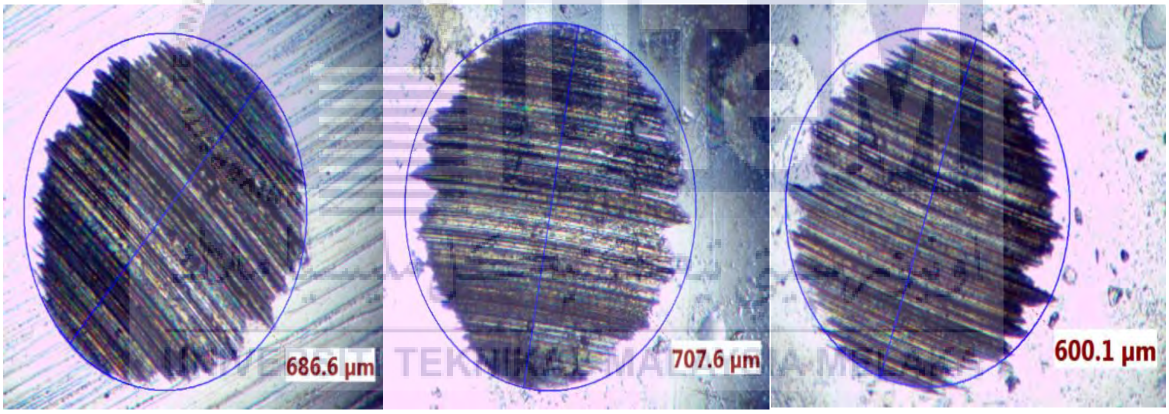
(a) Sample 1 (b) Sample 2 (c) Sample 3



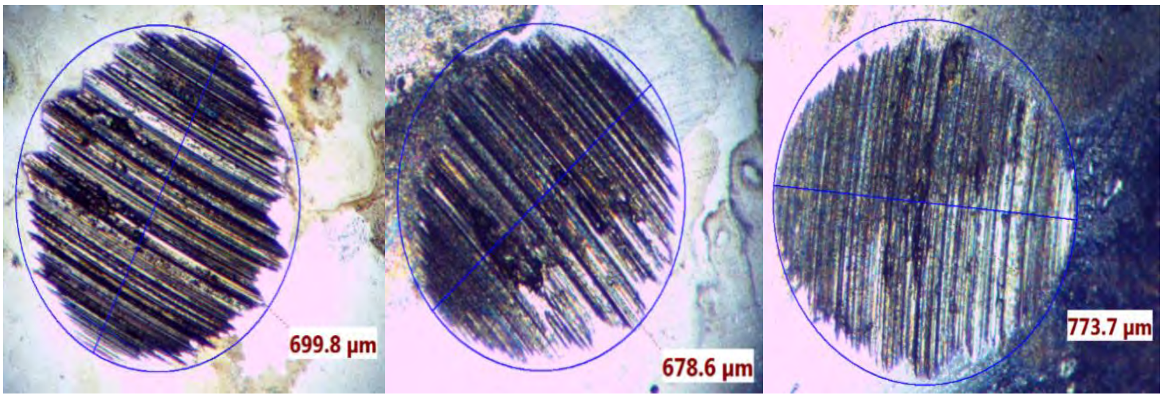
(d) Sample 4 (e) Sample 5 (f) Sample 6

Table 4. 10: Wear scar diameter of Oleic Methyl Ester with 1%wt and 2%wt additive

Result	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
	With additive 1%wt CNT			With additive 2%wt CNT		
Wear scar diameter (µm)	686.6 µm	707.6 µm	600.1 µm	699.8 µm	678.6 µm	773.7 µm
Average wear scar diameter (µm)	664.8 µm			717.4 µm		



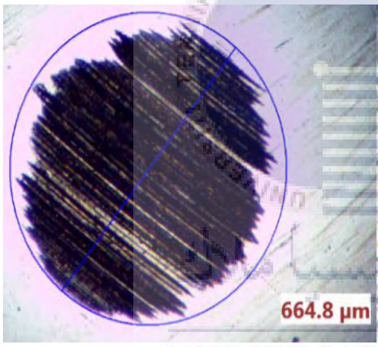
a) Sample 1 b) Sample 2 c) Sample 3

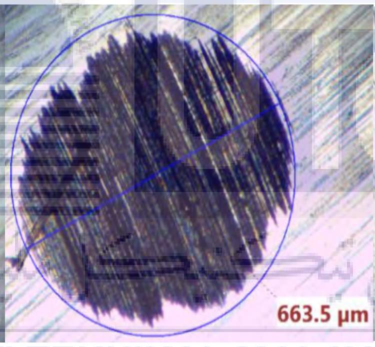


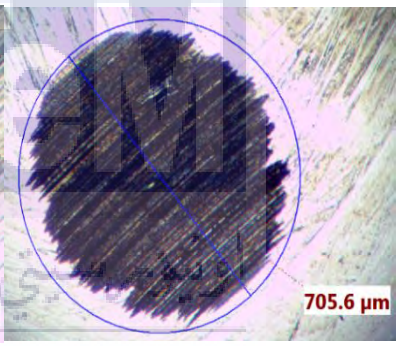
d) Sample 4 e) Sample 5 f) Sample 6

Table 4. 11: Wear scar diameter of Oleic Methyl Ester with 3%wt and 4%wt additive

Result	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
	With additive 3%wt CNT			With additive 4%wt CNT		
Wear scar diameter (µm)	664.8 µm	663.5 µm	705.6 µm	762.3 µm	669.7 µm	722.2 µm
Average wear scar diameter (µm)	677.9 µm			718.1 µm		

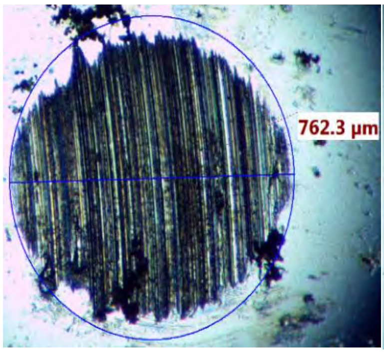


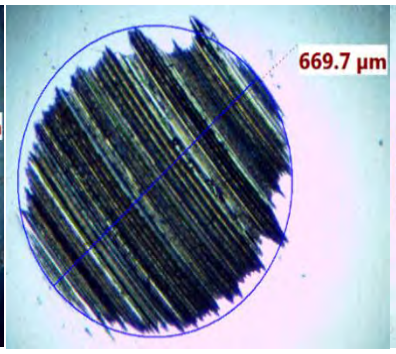


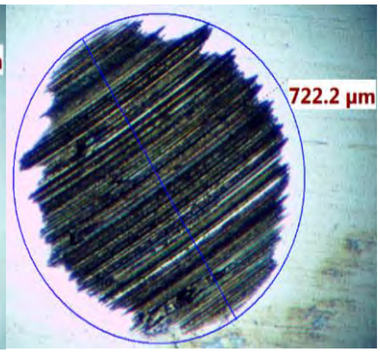


UNIVERSITI TEKNIKAL MALAYSIA MELAKA

a) Sample 1 b) Sample 2 c) Sample 3



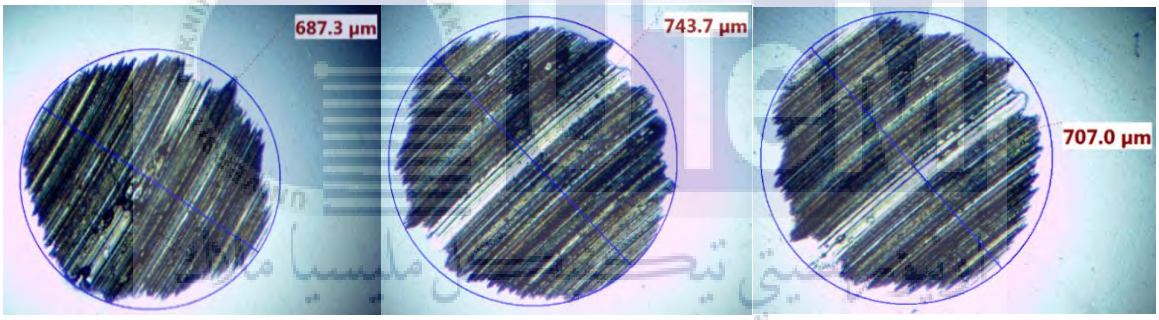




d) Sample 4 e) Sample 5 f) Sample 6

Table 4. 12: Wear scar diameter of ball bearing by using Oleic Methyl Ester with 5%wt additive

Result	Sample 1	Sample 2	Sample 3
	With additive 5%wt CNT		
Wear scar diameter (µm)	687.3 µm	743.7 µm	707.0 µm
Average wear scar diameter (µm)	712.7 µm		



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

a) Sample 1 b) Sample 2 c) Sample 3

Based on Table 4.8, 4.9, 4.10, 4.11, similar occur at Oleic Methyl Ester as Refined Glycerine, WSD for lubricant with CNT additive smaller than without additive, this show that the lubricant with additive prevent better compare to without additive in reducing the direct contact between two direct contacting or sliding surface.

4.2.4.2 Overall comparison for Wear Scar Diameter between 2 types of lubricant

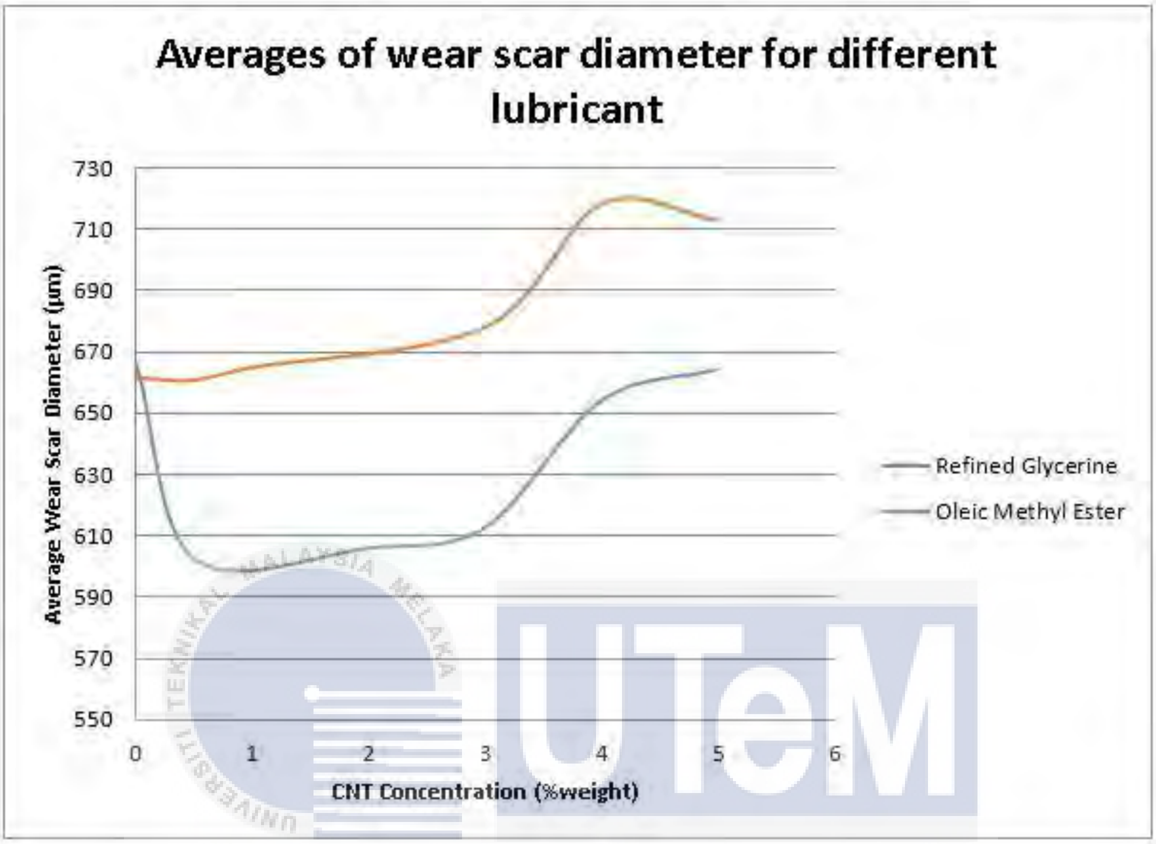


Figure 4. 6: Averages of wear scar diameter for different lubricant

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Table 4. 13: Comparison of averages of wear scar diameter between lubricant without and with additive

Result	Refined Glycerine	Oleic Methyl Ester
Without additive	665.9	661.4
With additive 0.5% CNT	602.6	660.6
With additive 1% CNT	752.2	664.8
With additive 2% CNT	606.2	717.4

With additive 3% CNT	613.0	677.9
With additive 4% CNT	654.3	718.1
With additive 5% CNT	664.5	712.7

Based on overall result as show in Figure 4.3, both lubricant showed the good result with added additive but Refined glycerine more preferable result and very good lubricant compare to Oleic methyl ester. Smaller size of wear scar diameter, less friction will be occur. That's mean the lubricant which is Refined Glycerine work better in prevent the direct contact between two metal surface and successfully preventing wear to occur high volume and area in contacting surface. This showed Refined Glycerine is a good lubricant compare to Oleic Methyl Ester. There is error when taking measurement of wear scar diameter which is for Refined Glycerine with 1%wt additive and Oleic Methyl Ester with 2%wt additive. Figure 4.3 show the pattern without the error to get the smooth pattern.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHAPTER 5

CONCLUSION

The analysis of friction and wear characteristic of lubricant and grease should be emphasized as the application of machines is greatly increased nowadays. High performance and efficiency lubrication is the main characteristic or parameter to control the life and efficiency of those machines consist of metal to metal direct contact in proses.

The friction and wear characteristic of natural lubricant which consist Refined Glycerine and Oleic Methyl Ester has been determined by using four ball tester experiment. From the experiment, the result of friction and wear of natural oil-based lubricant have being compared to each other. Based on the comparison for both lubricant without and with additive, Refined Glycerine lubricant show the positive result and can be consider as the suitable lubricant performance.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

For additive added experiment, the result shows that for some natural oil-based lubricant, its show preferred result for COF compares to without additive and different concentration of additive. With additive show better result in COF. Based on that result, we can conclude that CNT has a strong molecular structure which can successfully reduce the friction between two contacting surfaces, but at the same time it only successfully reduce friction at concentration of 3%wt additive. More than 3%wt, the friction will increase. This is due to the composition and chemical reaction between CNT and lubricant was not completed during the homogenizer process because of it too thick which makes the bonding for lubricant layer easy to break when load applied.

For comparison between the friction and wear properties it is shown that Refined Glycerine perform better COF compared to Oleic Methyl Ester. For Wear scar diameter of Refined Glycerine also show better result compared to Oleic Methyl Ester. The friction and wear characteristic of lubricant is not only depend on a single parameter but other factor which include load, time, standard, temperature and additive concentration. Load apply decided the suitable range of lubricant should be apply. Besides that, factor like time and standard apply also decided the sustainability of lubricants itself. Meanwhile, temperature different such as high and low temperature applied will result in different result which will show the range of temperature at where the lubricant can work with maximum performance. To enhance the strength properties of lubricant, additive is needed, but not too much additive suitable for lubricant due to different concentration of lubricant and additive.

Overall, the result from this work indicates that Refined Glycerine of natural oil-based lubricant show positive result compare to Oleic Methyl Ester for COF. For wear scar diameter also Refined Glycerine of natural oil-based lubricant show better performance compare to Oleic Methyl Ester.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

REFERENCES

Aziz, N.A.M. et al., 2016. Temperature effect on tribological properties of polyol ester-based environmentally adapted lubricant. *Tribology International*, 93, pp.43–49.

Cornelio, J.A.C. et al., 2016. Tribological properties of carbon nanotubes as lubricant additive in oil and water for a wheel–rail system. *Journal of Materials Research and Technology*, 5(1), pp.68–76. Available at: http://dx.doi.org/10.1016/j.jmrt.2015.10.006.

Fox, N.J. & Stachowiak, G.W., 2007. Vegetable oil-based lubricants-A review of oxidation. *Tribology International*, 40(7), pp.1035–1046.

Ing, T.C. et al., 2012. The Effect of Temperature on the Tribological Behavior of RBD Palm Stearin. *Tribology Transactions*, 55(5), pp.539–548.

Mannekote, J.K. & Kailas, S. V., 2012. The effect of oxidation on the tribological performance of few vegetable oils. *Journal of Materials Research and Technology*, 1(2), pp.91–95. Available at: http://dx.doi.org/10.1016/S2238-7854(12)70017-0.

Reeves, C.J. et al., 2015. The influence of fatty acids on tribological and thermal properties of natural oils as sustainable biolubricants. *Tribology International*, 90, pp.123–134. Available at: http://dx.doi.org/10.1016/j.triboint.2015.04.021.

Shahnazar, S., Bagheri, S. & Abd Hamid, S.B., 2016. Enhancing lubricant properties by nanoparticle additives. *International Journal of Hydrogen Energy*, 41(4), pp.3153–3170. Available at: http://dx.doi.org/10.1016/j.ijhydene.2015.12.040.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

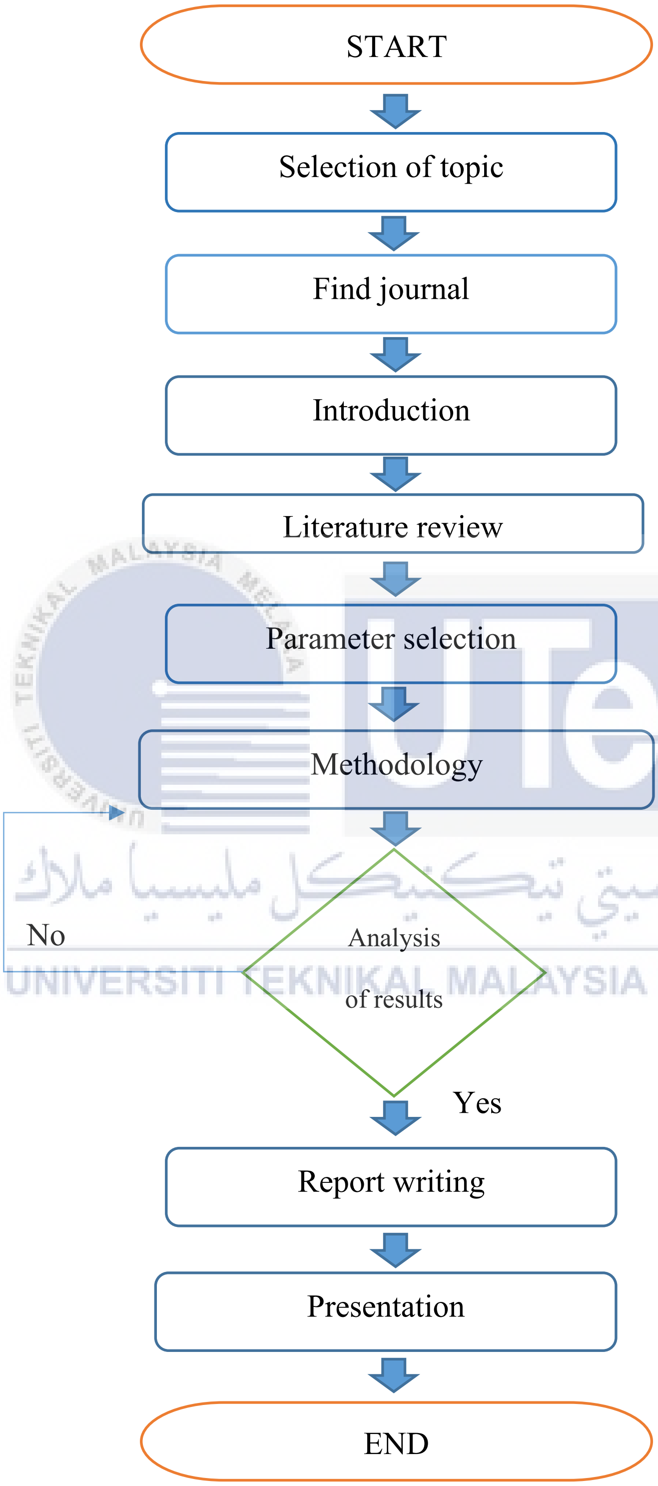
Syahrullail, S. et al., 2011. Experimental evaluation of palm oil as lubricant in cold forward extrusion process. *International Journal of Mechanical Sciences*, 53(7), pp.549–555. Available at: http://dx.doi.org/10.1016/j.ijmecsci.2011.05.002.

Syahrullail, S. et al., 2013. Friction Characteristics of RBD Palm Olein using Four-Ball Tribotester. , 315, pp.936–940.

Yong, K., Tee, B. & Abdollah, M., 2016. Friction and wear characteristic of different natural oil-based lubricants with carbon nanotubes as additive. *Research Day 2016*, (March), pp.169–170.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

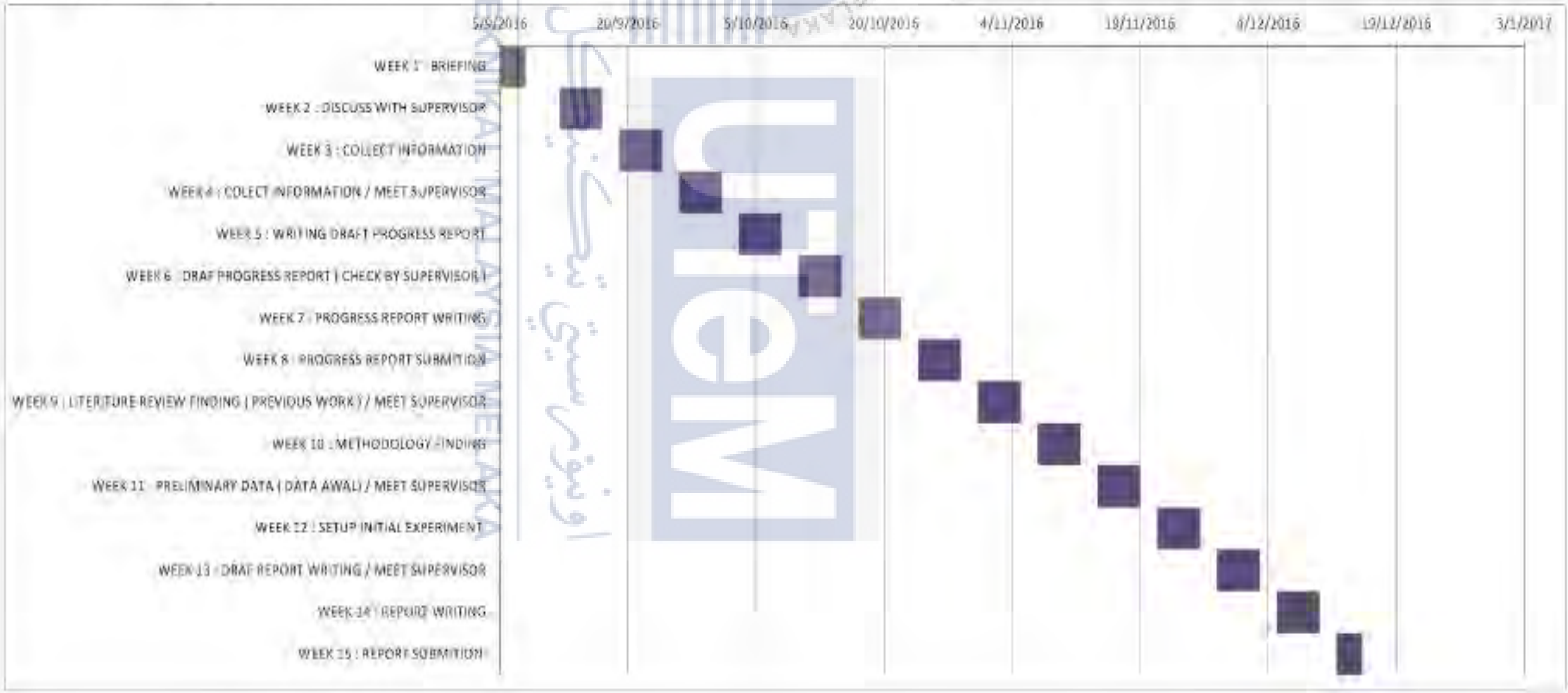
APPENDIX



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

PSM SCHEDULE : TRIBOLOGICAL PROPERTIES INVESTIGATION FOR NANOPARTICLE ENHANCED NATURAL OIL-BASED LUBRICANTS

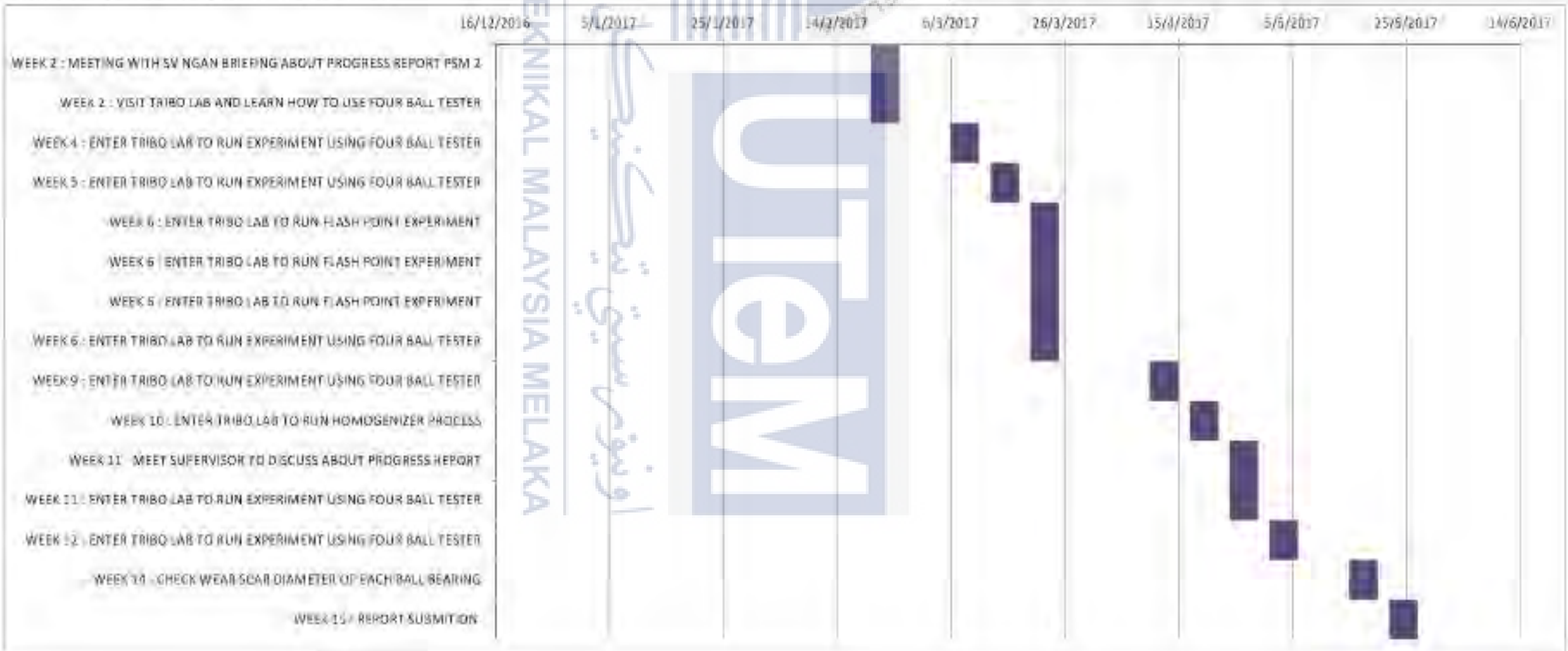
START DATE	END DATE	DESCRIPTION	DURATION
5/9/2016	9/9/2016	WEEK 1 : BRIEFING	3
12/9/2016	16/9/2016	WEEK 2 : DISCUSS WITH SUPERVISOR	5
19/9/2016	23/9/2016	WEEK 3 : COLLECT INFORMATION	5
26/9/2016	30/9/2016	WEEK 4 : COLECT INFORMATION / MEET SUPERVISOR	5
3/10/2016	7/10/2016	WEEK 5 : WRITING DRAFT PROGRESS REPORT	5
10/10/2016	14/10/2016	WEEK 6 : DRAF PROGRESS REPORT (CHECK BY SUPERVISOR)	5
17/10/2016	21/10/2016	WEEK 7 : PROGRESS REPORT WRITING	5
24/10/2016	28/10/2016	WEEK 8 : PROGRESS REPORT SUBMITION	5
31/10/2016	4/11/2016	WEEK 9 : LITERITURE REVIEW FINDING (PREVIOUS WORK) / MEET SUPERVISOR	5
7/11/2016	11/11/2016	WEEK 10 : METHODOLOGY FINDING	5
14/11/2016	18/11/2016	WEEK 11 : PRELIMINARY DATA (DATA AWAL) / MEET SUPERVISOR	5
21/11/2016	25/11/2016	WEEK 12 : SETUP INITIAL EXPERIMENT	5
28/11/2016	2/12/2016	WEEK 13 : DRAF REPORT WRITING / MEET SUPERVISOR	5
5/12/2016	9/12/2016	WEEK 14 : REPORT WRITING	5
12/12/2016	16/12/2016	WEEK 15 : REPORT SUBMITION	3



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

PSM SCHEDULE : TRIBOLOGICAL PROPERTIES INVESTIGATION FOR NANOPARTICLE ENHANCED NATURAL OIL-BASED LUBRICANTS

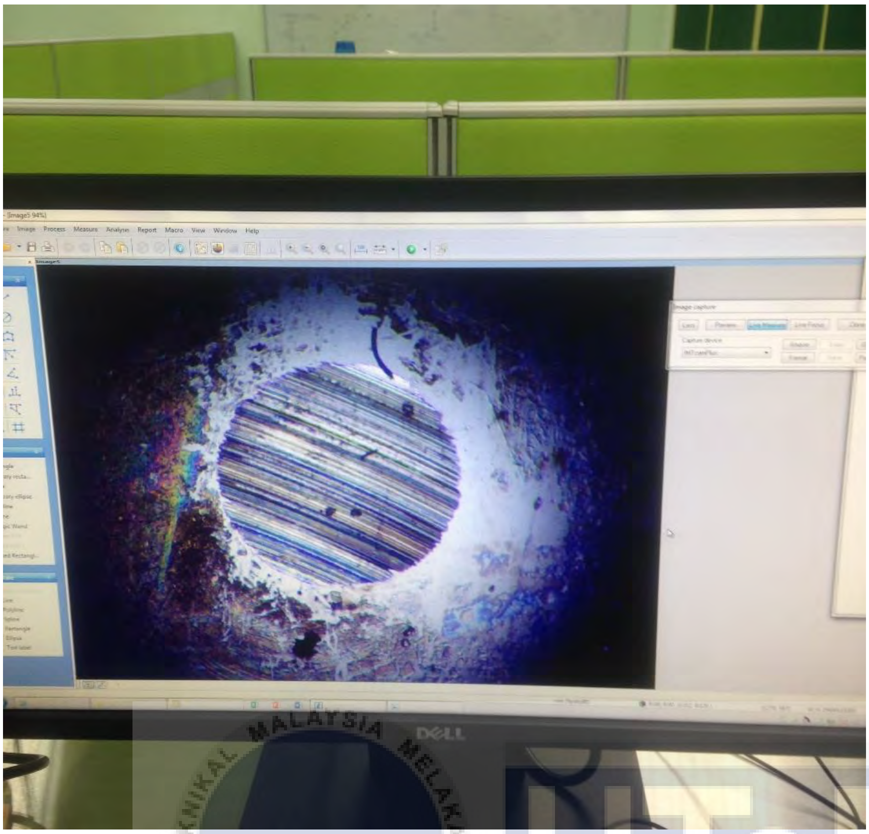
START DATE	END DATE	DESCRIPTION	DURATION
20/2/2017	24/2/2017	WEEK 2 : MEETING WITH SV NGAN BRIEFING ABOUT PROGRESS REPORT PSM 2	5
20/2/2017	24/2/2017	WEEK 2 : VISIT TRIBO LAB AND LEARN HOW TO USE FOUR BALL TESTER	5
6/3/2017	10/3/2017	WEEK 4 : ENTER TRIBO LAB TO RUN EXPERIMENT USING FOUR BALL TESTER	5
13/3/2017	17/3/2017	WEEK 5 : ENTER TRIBO LAB TO RUN EXPERIMENT USING FOUR BALL TESTER	5
20/3/2017	24/3/2017	WEEK 6 : ENTER TRIBO LAB TO RUN FLASH POINT EXPERIMENT	5
20/3/2017	24/3/2017	WEEK 6 : ENTER TRIBO LAB TO RUN FLASH POINT EXPERIMENT	5
20/3/2017	24/3/2017	WEEK 6 : ENTER TRIBO LAB TO RUN FLASH POINT EXPERIMENT	5
20/3/2017	24/3/2017	WEEK 6 : ENTER TRIBO LAB TO RUN EXPERIMENT USING FOUR BALL TESTER	5
10/4/2017	14/4/2017	WEEK 9 : ENTER TRIBO LAB TO RUN EXPERIMENT USING FOUR BALL TESTER	5
17/4/2017	21/4/2017	WEEK 10 : ENTER TRIBO LAB TO RUN HOMOGENIZER PROCESS	5
24/4/2017	28/4/2017	WEEK 11 : MEET SUPERVISOR TO DISCUSS ABOUT PROGRESS REPORT	5
24/4/2017	28/4/2017	WEEK 11 : ENTER TRIBO LAB TO RUN EXPERIMENT USING FOUR BALL TESTER	5
1/5/2017	5/5/2017	WEEK 12 : ENTER TRIBO LAB TO RUN EXPERIMENT USING FOUR BALL TESTER	5
15/5/2017	19/5/2017	WEEK 14 : CHECK WEAR SCAR DIAMETER OF EACH BALL BEARING	5
22/5/2017	26/5/2017	WEEK 15 : REPORT SUBMITION	5



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UTeM
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

UTeM
اونيورسيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA



UNIVERSITI TEKNIKAL MALAYSIA MELAKA