FRICTIONAL BEHAVIOR OF SK11 IN ENGINE OIL AND NANOPARTICLES-ENHANCED ENGINE OIL

NUR HAFIZAH BINTI MAT ABAS

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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NUR HAFIZAH BINTI MAT ABAS

This report is submitted in fulfillment of the requirement for the degree of Bachelor of Mechanical Engineering (Automotive)

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2017

DECLARATION

I declare that this report entitled "Frictional Behavior of SK11 in Engine Oil and Nanoparticles-Enhanced Engine Oil" is the result of my own research except as cited in the references.

Signature : ………………………………..

Name : ………………………………..

Date : ………………………………..

APPROVAL

I hereby declare that I have read this report entitled 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 (Automotive).

Signature : ………………………………..

Name of Supervisor : ………………………………..

Date : ………………………………..

DEDICATION

This final report is dedicated to my loving parents who are the most amazing people that could not be replaced with any other things. To my father, thank you for being the man that you are, for being my pillar of strength and fountain of wisdom. To my mother, thank you for teaching me the true meaning of hard work and shows me that I have to give it my all if I want to succeed. To both of you, thank you for endlessly showering me with your support, guidance and love ever since I was born until forever. Truly, words can never express the gratitude that I have and I thank Allah for giving me such a great gift in my life; which is both of you.

ABSTRACT

This final report describes the purpose of the study which to investigate the frictional behavior of SK11 ball bearing in lubricating oil. The frictional behavior was investigated using Four-ball Tester according to the standard test ASTM D4172 as reference. The ball bearings were immersed in two different lubricant condition; engine oil and nanoparticle-enhanced engine oil. Each tests were conducted under varying load and speed, with 100, 300, 500 N and 100, 300, 500 rpm respectively. The tests were undergone under different temperatures which are 27, 50, and 100˚C and the running time was approximately 60 minutes. The investigation was carried under different parameters in order to study which lubricant conditions give significant effects to frictional behavior of SK11 ball bearing and to see the effectiveness of additives when parameters were varied. The nano oil was prepared by dispersing a mixture of approximately composition 0.5 vol.% of 70nm hexagonal boron nitride, hBn with SAE 15W-40 engine oil as base oil. The mixing method used was sonication technique. Based on the results obtained, the varied parameters are compared in term of coefficient of friction and it was then analyzed to see which lubricant conditions possess a better value in coefficient of friction.

ABSTRAK

Laporan akhir ini menerangkan tujuan kajian yang dijalankan untuk menyiasat kelakuan geseran bola *bearing* SK11 dalam minyak pelincir. Kelakuan geseran disiasat menggunakan kaedah *Four-ball Tester* mengikut standard pengujian ASTM D4172 sebagai rujukan. Bola *bearing* telah diletakkan di dalam dua keadaan pelincir yang berbeza; minyak enjin dan minyak enjin yang dipertingkatkan dengan partikel nano. Setiap ujian telah dijalankan di bawah beban dan kelajuan yang berbeza dengan 100, 300, 500 N dan 100, 300, 500 rpm mewakili nilai masing-masing. Sesi pengujian juga dijalankan di bawah suhu yang berbeza iaitu 27, 50, dan 100˚C dan tempoh pengujian dijalankan adalah kira-kira 60 minit. Siasatan telah dijalankan di bawah parameter yang berbeza untuk mengkaji keadaan pelincir yang mana memberi kesan yang penting kepada tingkah laku geseran bola *bearing* SK11 dan untuk melihat keberkesanan bahan tambahan apabila parameter berubah-ubah. Minyak nano telah disediakan melalui campuran kira-kira 0.5 vol.% 70nm komposisi heksagonal boron nitrida, hBN dengan minyak enjin SAE 15W-40 sebagai minyak asas. Kaedah pencampuran yang digunakan adalah melalui teknik *sonication*. Berdasarkan keputusan yang diperolehi, parameter yang berubah-ubah dibandingkan dari segi pekali geseran dan kemudianya dianalisis untuk melihat kondisi pelinciran mana menghasilkan nilai yang lebih baik untuk pekali geseran.

ACKNOWLEDGEMENT

Praise to Allah SWT the Most Merciful and the Most Gracious; I have successfully completed my research for my final year project. Throughout the completion process, I have taken efforts; however, the preparation of this Final Report would not have been completed without the support, hard work and endless efforts of a large number of individuals and institutions. Therefore, I would like to take this opportunity to express my deepest gratitude and special thanks to all those people who gave me the possibility to complete this report successfully.

First of all, I would like to thank to my family for their never ending support. Besides that, I also would like to extend my thankfulness to my Supervisor; Associate Professor Dr Mohd Fadzli bin Abdollah for the reprimand, guidance and constant supervision during my practice, as well as for providing necessary information in completing this Technical report. And not to forget to my panels, thank you for giving such bold comments and constructive criticisms.

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Thank you.

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ρ	-	density	(kg/m^3)
m	-	mass	(kg)
ν	-	volume	(m^3)
μ	-	coefficient of friction	
T	-	frictional torque	(kg.mm)
W	-	normal load applied	(kg)
r	-	rotation radius from rotation axis	(mm)

LIST OF ABBREVIATIONS

COF	Coefficient of Friction
hBN	Hexagonal Boron Nitride
EP	Extreme Pressure
AW	Anti Wear
ICE	Internal Combustion Engine
PTFE	Polytetrafluorethylene

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Lubrication is one of the powerful process or technique to reduce wear on surfaces in close proximity, and moving relative to each another. Besides, it also can act as a cleaning agent and transport debris away from interface, other than provides cooling for a system. Lubricant is essential to lubricate the machine component to reduce friction, wear, and seizure of the bearings. Nowadays, there are different types of substances that can be used to lubricate two contacting surfaces, which normally can be found in machine components. Oil and grease are the most common. Oils can be synthetic, vegetable or mineral-based as well as combination of both of these, while grease is composed of oil and a thickening agent to obtain its consistency.

Ever since in the early developments, friction leads to major issues, one includes it effects to engine performance. Thus, current study conducted is mainly focusing on resolving issues related to engine oil and its effective performance. Reducing friction is a key objective of lubrication. Corrosion prevention is one of lubricating film function as it protects the surface from water and other corrosive substances.

Therefore, study suggested that the usage of engine oil with additive of nanoparticle possessed a better and excellent performance compared to base engine oil. In recent studies, results showed that nano-lubricant is efficient in reducing friction and wear. Besides that, lubricants containing additive are said have significant effects to improve its lubricating properties. In this study, the coefficient of friction (COF) between engine oil and nanoparticles engine oil are to be compared to determine which condition produces low coefficient of friction. Hence, Hexagonal Boron Nitride (hBN) as shown in Figure 1.1 is chosen to be lubricant additive. It comes in powder, which makes it can be dispersed into any oil, grease, or water. Based on (Gao et. al., 2011), hBN possesses unique characteristics; therefore it is suitable as an additive to be dispersed in high temperature lubricant or to be used on high friction contact surface.

Figure 1.1 Hexagonal Boron Nitride (hBN)

(Source: http://www.reade.com/products/boron-nitride-powder-bn-boron-nitride-spray)

1.1 PROBLEM STATEMENT

Since friction effects efficiency and engine performances, the presence of lubricants may reduce the amount of frictional force acting inside the engine. An addition of nanoparticles in engine oil is to be said as one of best way to reduce wear and friction effects thus help to increase efficiency and engine performances.

Based on several studies that have been conducted, it was found out that the percentage of volume concentration affected hBN nanoparticles performance. A lower concentration of nanoparticles helps in reducing of friction coefficient and resistance to wear, plus it exhibited better tribological properties. For this project, two different tests will be carried out in order to study the effect of hBN nanoparticles in engine oil. Comparison is to be made between ball bearings which are immersed in engine oil and nanoparticles-enhanced engine oil. The tests are done to evaluate which test condition provides lower value of friction coefficient.

Therefore, a Four-ball Tester experiment is proposed in order to study the frictional behavior of SK11 in engine oil and additional of nanoparticles in engine oil. The friction coefficient is calculated and needed to be averaged to average the friction coefficient value for all tests.

1.2 OBJECTIVE

i. To compare the coefficient of friction (COF) of SK11 in engine oil and nanoparticles-enhanced engine oil.

1.3 SCOPE OF PROJECT

The scopes of this project are:

i. Conduct an experiment in order to study the effect of nanoparticles as additives. The experiment is carry out by using Four-ball Tester and the ball bearings will be tested under varying speed, load and temperature.

ii. Recording data in data processing system and calculate the average coefficient of friction (COF) for all tested specimens.

iii. Compare experimental results between ball bearings that are immersed in engine oil and nanoparticles as additives in engine oil.

1.4 REPORT LAYOUT

This project was carried out in order to compare frictional behaviour of SK11 ball bearing while being immersed in two different types of lubricants; engine oil and nanoparticles-enhanced engine oil. The method chosen to investigate frictional behaviour was Four-ball Tester and the project layout consists of five chapters, which presented in this report.

Through this report, Chapter 1 can be said as the beginning where this section explains introduction of lubrication, friction, as well as additives and the flow continued to problem statement, objective until it reached scope of project.

While in Chapter 2, this is the section where review of literature related to the project was comprehensively explained and summarized. The findings and information gathered from various sources will be beneficial in order to give a clear view to the project.

As for Chapter 3, it encompasses the method chosen to carry out experimental procedures by using Four-ball Tester. Proceeding to Chapter 4, this section presents complete results obtained from the project. The findings were interpreted and discussed clearly in this section.

Last but not least, the final chapter which a clear and concise conclusion was made. The conclusion summarized the findings of this project and determined the significant of the findings related to the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Literature review is essential when it comes to writing a research or thesis. For this project, this chapter includes brief explanation on the related published researches, paper works and the studies that have been investigated. On top of that, there are wide ranges of resources and references which can be found not only in a thesis, but in articles, journals, or even text books. Therefore, once all findings and information have been gathered, it was then implemented in this project in order to complete the project with accordance of time given.

2.2 Lubricants

Lubrication is the process or technique employed to reduce wear on surfaces. Lubrication helps in reducing frictional resistance, reduce wear on surfaces as well as reducing noise from the moving component of a machine. Besides that, lubrication helps in carrying excessive heat away from two contacting parts and one of the examples of lubricant is engine oil. Somehow, lubricant may act as 'cleaning' agent where it helps to remove debris or particles and additionally produces a seal between two parts to prevent contamination in parts, machines or engines. Despite its purposes in reducing friction, lubricant may influence friction in concentrated contact.

2.2.1. Classifications of Lubrication

There are some classifications of lubrication based on its physical properties.

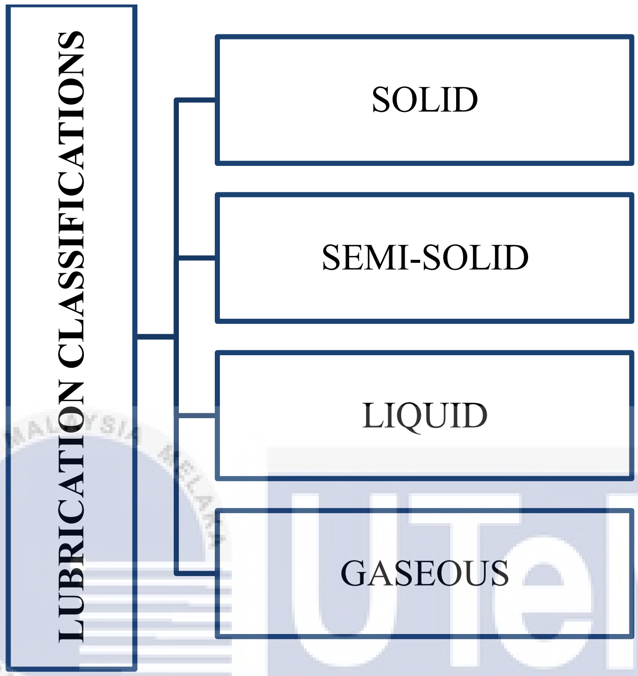


Figure 2.1: Lubrication classifications

2.2.1.1 Solid Lubricant

Solid lubricant comes as solid materials. Under high loads, it reduces coefficient of friction and wear between two contacting parts while preventing direct contact between both surfaces. Besides its ability to work under high loads, solid lubricant possesses high thermal stability which makes it suitable to be used as additives mainly in oils and greases. Particles such as graphite and molybdenum disulfide are common solid lubricant, while boron nitride and polytetrafluorethylene (PTFE) are some other types of solid lubricant normally used.

2.2.1.2 Semi-solid Lubricant

Semi-solid lubricant comes in form of grease which purposely used in bearings as lubrication. Grease mainly contains lubricating oils, which usually has quite low viscosity that has been thickened by finely dispersed solids called thickeners. Normally, it carries up to 75% to 95% base oil, 0% to 5% additives and 5% to 20% minute thickener fibers. Other than providing a better mechanical lubrication cushion in extreme conditions, it is also water resistant and beneficial in reducing oil vapor problems.

2.2.1.3 Liquid Lubricant

One of many purposes of liquid lubricant is it acts as liquid films while bearings are floating on them. These liquid films exist between two surfaces and there is resistance to abrasion contained in the liquid. Vegetable oils, animal fats and mineral oils are some classifications of liquid lubricant. Liquid lubricant is used to help in cleaning of a bearing by transporting debris or particles and cooling it by carrying excess heat away.

2.2.1.4 Gas Lubricant

Normally, gas lubricant is used when there is a separation or an ultra-thin film thickness presence between tribo-pairs. Some examples of gas lubricant are Helium, Nitrogen and Air. Gas lubricant has low viscosity hence making it as an ultra-low friction lubricant. Besides, there is no seal needed when gas lubricant is used as lubrication.

2.2.2. Types of Lubrication

There are three types of lubrication, namely boundary, mixed and full film. Full-film lubrication may be broken down into two parts which are hydrodynamic and elastohydrodynamic. Hydrodynamic lubrication is said to occur when there is two surfaces in sliding motion. These surfaces are fully separated by a film of fluid. As for elastohydrodynamic lubrication, it is quite similar to hydrodynamic but it occurs when the surfaces are in a rolling motion. However, the film layer produced in elastohydrodynamic conditions is much thinner than that of hydrodynamic lubrication while the pressure on the film is greater.

Irregularities are still present even when the surfaces are smooth and polished. They stick out of the surface forming peaks and valleys at a microscopic level. Somehow, these peaks are called as asperities. For a full-film condition, the lubricating film must be thicker than the length of the asperities. This type of lubrication is said to be the most effective in protecting surfaces.

While in boundary lubrication, conditions such as frequent starts and stops, and shock-loading are usually found in it. As full film cannot protect surfaces due to speed, load or other factors, some oils have extreme-pressure (EP) or anti-wear (AW) additives. These additives cling to metal surfaces and form a sacrificial layer that protects the metal from wear. Hence, when EP or AW layer protecting two contacting surface, boundary lubrication is said to occur. However, itis not ideal, as it causes high friction, heat and other undesirable effects.

Mixed lubrication is a mixture between boundary and hydrodynamic lubrication. As the bulk of the surfaces are separated by a lubricating layer, the asperities still make contact with each other. The three different types of lubrication are visualized as shown in Stribeck Curve in Figure 2.2 below.

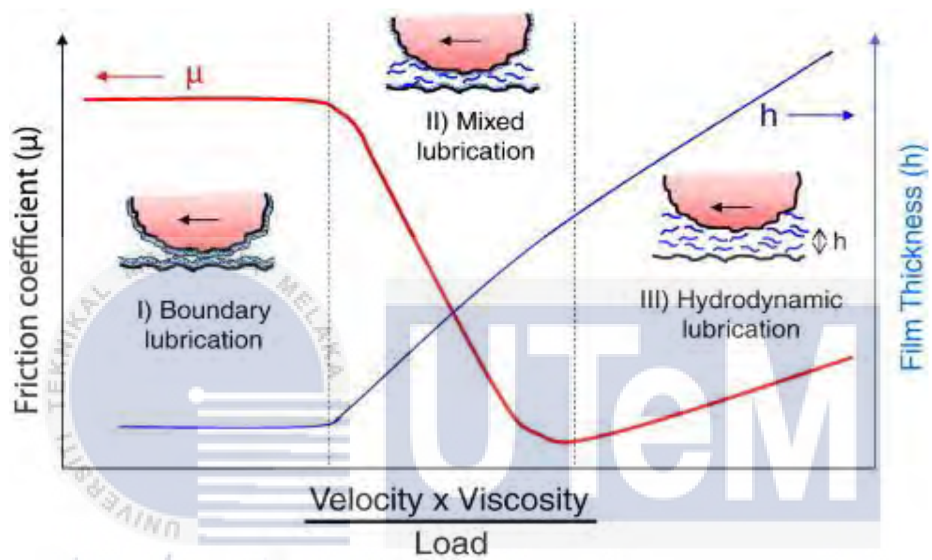


Figure 2.2: Stribeck curve

(Source: https://www.researchgate.net/figure/259357833_fig1_Figure-1-Model-Stribeck-curve-where-the-friction-coefficient-ant-the-fluid-film)

2.2 Friction

Friction can be defined as a force that resists the relative motion of any surfaces or materials that are in contact. Friction presence when there is a relative motion between two contacting surfaces. Since early development, friction has always been a major issue that needed to be faced, especially in engineering fields. Friction is bothersome and may lead to danger. Since earlier, from the invention of wheel and the usage of lubricants to the studies of coated and micro-texturized surfaces, effort has been put on improvements to eventually overcome resistance to motion (Dowson). Internal combustion engine (ICE) can be taken as one of the example which shows significant source of friction; leading to fuel consumption and pollutant emission since its early development.

Based on Holmberg et al. (2012), a yearly amount of 72000 million liters of fuel is estimated to overcome ICE internal friction. It is a worrisome estimation value, hence it is important to improve engine efficiency. However, it is not an easy task as there will be challenging factors in order to carry out improvements. The reason behind its difficulty is because lack in understanding of interaction between oil and surface. Additionally, engines changed significantly not only in terms of its oil formulation, but surface finishing and development of new materials as well, however friction losses are still high; 11.5 %.

2.2.1. Coefficient of Friction

Determination of lubricant friction coefficient friction is a kind of oiliness test in the friction and wear test. Over the past, as stated by Cai et al., (2001), Oiliness Testing Machine and Falex Ring-Block Test Machine were used to test lubrication friction coefficient. This test only determines lubricant friction coefficient at certain load and cycles. The anti-wear performance and load carrying capacity of oil film are determined by wear test and extreme pressure (EP) test. However, the performances of friction reduction, anti-wear and EP property are hard to distinguish by using different formula of some old friction and wear test. Hence, at boundary lubricating condition, Four-ball test is conducted as friction coefficient, wear scar diameter and oil film cracking load are tested at varying load, speed and temperature.

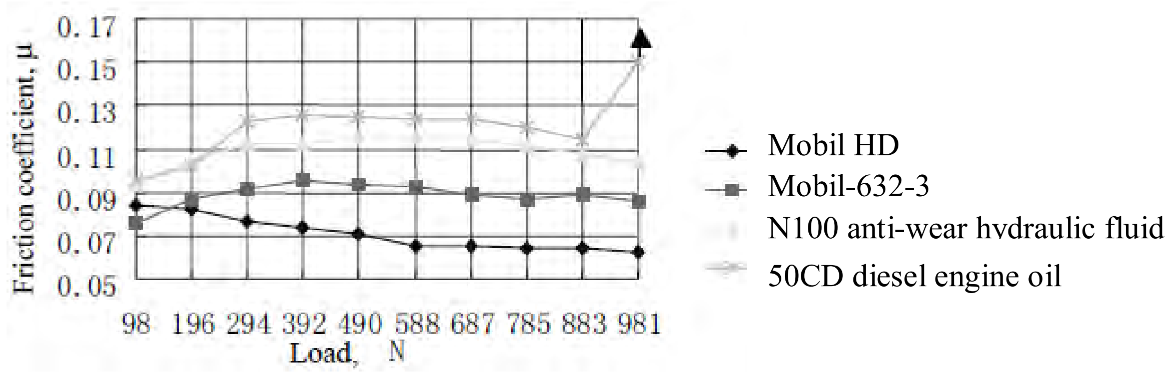


Figure 2.3: Graph of friction coefficient of four different types of oils (Cai et. al., 2001)

Based on the graph shown, the test was carried out to four different types of oils. The curve shows that the friction coefficient decreases as the load applied increases. A study conducted by Cai et al. (2001) stated that if the friction coefficient is between 0.05 - 0.1, it falls in boundary lubricating state. This condition helps to reduction of friction coefficient, decrease wear rate, increase load carrying capacity and as well as improving boundary lubricating effect.

2.3 Additives

Additives are synthetic chemical substances that can improve lots of different properties of lubricants. They can enhance existing properties, against undesirable properties and propose new properties in the base fluids. Other than protecting metal surface, additives may extend the range of lubricant applicability and might as well extend lubrication life. Besides being used as corrosion inhibitors, additives are also good antioxidants. On the contrary, additives are somehow sacrificial. The reason is in case contaminants are present, additives will 'cling' or attach to contaminants which eventually makes it settle to the bottom or wash out. In simple words, once additives are gone, they are gone.

However, larger percentage of additives added in lubricant does not mean it will be effective. As more additives added in lubricant, no benefits are gained and at certain condition, the performance deteriorates. Although additives improve one property of lubricant, it simultaneously degrades another property in which causes the quality of lubricant to be affected.

2.3.1 Nanoparticles as Additives

Over the years, nanoparticles have said to be one of important factors as lubricant additives in order to reduce emission and improve fuel economy. This is due to their characteristics which normally less than 100nm, eases them to enter the contact region. Besides that, nanoparticles are stable at elevated temperature compared to organic additives. This makes nanoparticles are favorable as lubricant additives which stated by Dai et al. (2016).

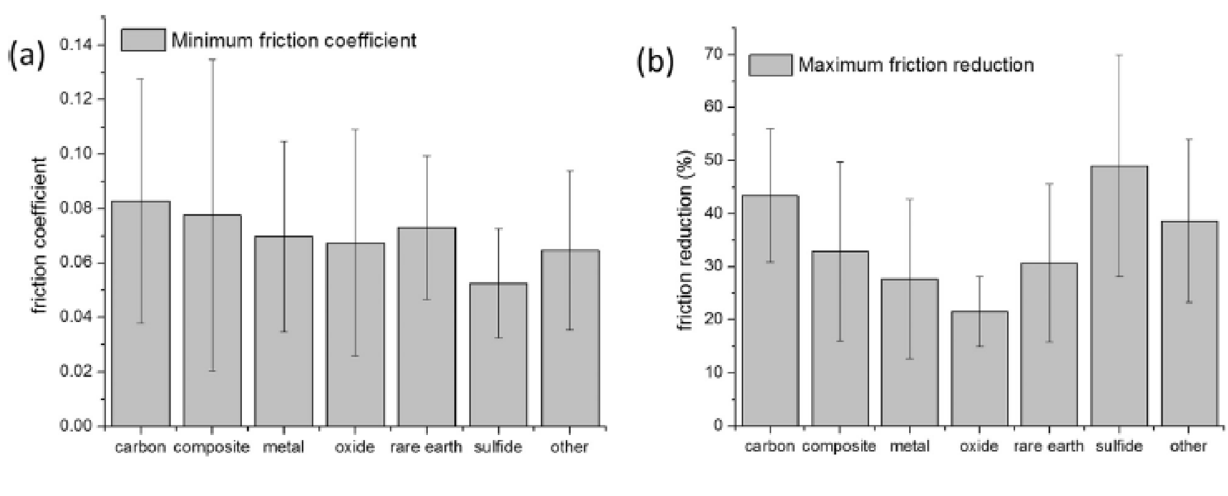


Figure 2.4: Comparison of tribological performance for different chemical composition: (a) minimum coefficient friction, (b) maximum friction reduction (Dai et. al., 2016)

Recently, studies had been conducted to investigate the performance and effect of hBN nanoparticles as friction modifier and anti-wear additive in engine oil. Studies shown that with the optimum composition of 0.5 vol.% of 70nm hBN nanoparticles dispersed in SAE 15W-40 could help in reduction of friction coefficient and increase wear resistance, compared to conventional diesel engine oil (Abdullah et al., 2016).

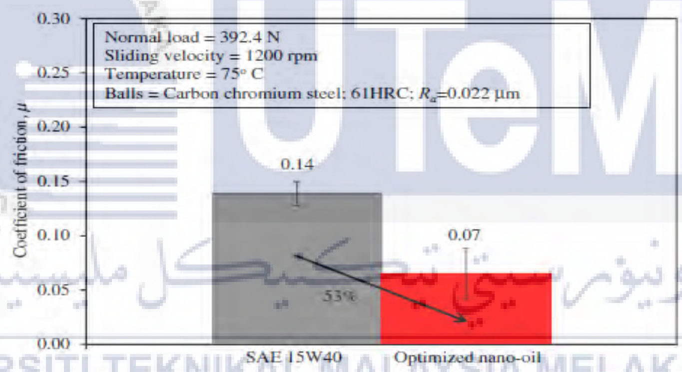


Figure 2.5: Comparison of average coefficient of friction between conventional diesel engine oil and optimized nano-oil (Abdullah et. al., 2016)

From the chart shown, the average coefficient of friction for optimized nano-oil decreased by 53% with the friction reduction ranged from 0.14 to 0.07, compared to conventional diesel engine oil. The friction reduction was believed due to tribofilm generated by boron oxide (B_2O_3) and from view point of boundary lubrication, higher calculated film thickness ratio also lead to reduction in friction coefficient, which is shown in Table 2.1 below.

Table 2.1: Lubrication regime for conventional diesel engine oil and optimized nano-oil

Properties	Sample	
	SAE 15W-40	Optimized nano-oil
Dimensionless minimum film thickness, $H_{\min}$	0.00337	0.00343
Minimum film thickness, $h_{\min}$ (μm)	1.07×10^{-5}	1.09×10^{-5}
Film thickness ratio, λ	0.017605	0.143341
Lubrication regime	Boundary	Boundary

2.4 Four-ball Tester

B.S Kothavale, (2016) stated that tribology related failure constitute about 30% failure in mechanical systems and components in plants. However, the problem can be minimized by proper selection of lubricant for particular mechanism from friction and wear consideration. Tribological testing was carried to determine the coefficient of friction (COF) using Four-ball Tester. The testing was conducted based on ASTM standard D4172 procedures as reference. The Four-ball Tester is designed to evaluate performance under much higher unit loads, hence designed as Extreme Pressure (EP).

The testing was done by rotating one ball bearing against the other three stationary ball bearings at varying load, speed and temperature. The three balls are held in cup and locked by a locking ring and lubricant is poured into the cup. The fourth ball is fixed in a chuck of vertical shaft; the lubricant cup assembly is then brought in contact with the fourth ball.

(a) (b)

Figure 2.6: (a) Four-ball apparatus, (b) Ball assembly (B.S Kothavale, 2011)

For this test, each specimen was tested for duration of 60 hours and the data is recorded by using data processing system.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter outlines works that need to be accomplished for this project. This chapter briefly covers the details explanation of methodology that will be used to ensure smooth flow of this project and can be completed prior to the time given. The methods that have been chosen are used to achieve the objectives of the project in order to accomplish a perfect result. These methods are used to find and analyze data related to the project.

3.2 General Methodology

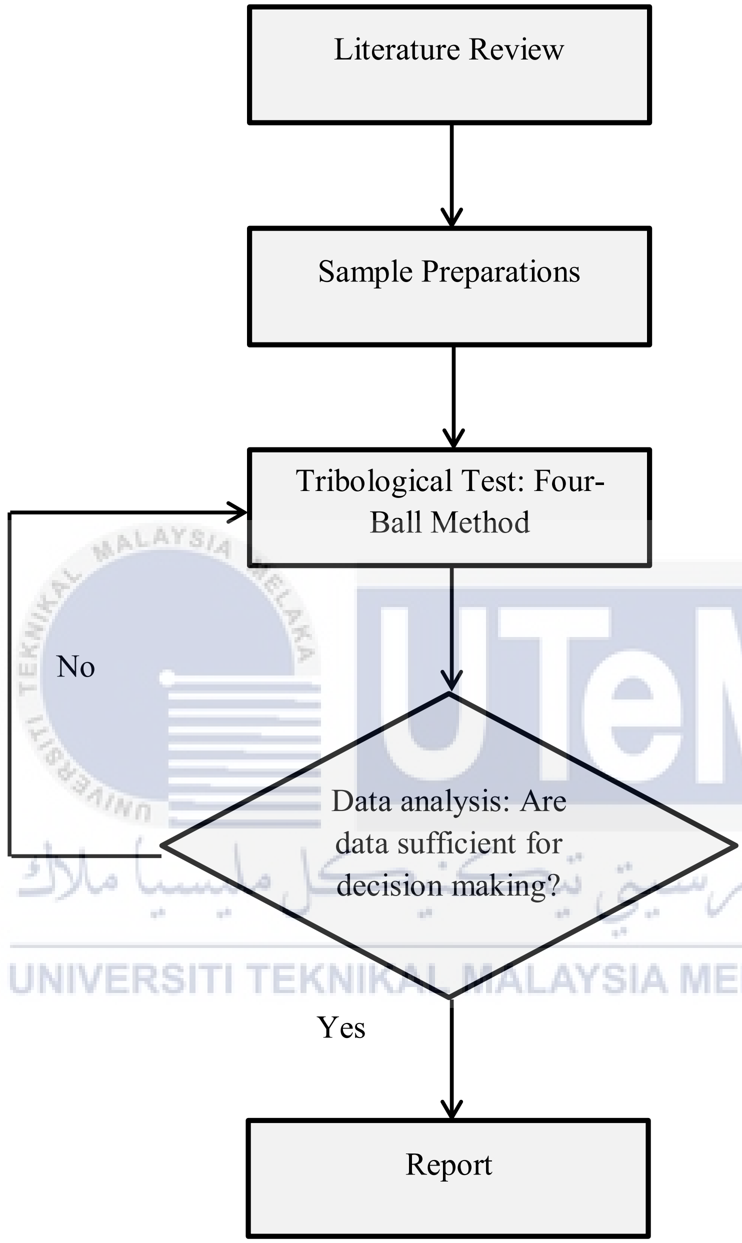


Figure 3.1: Flowchart of general management

3.3. Experimental Specimen

3.3.1 SK11 Ball Bearing

The specimen tested for this project is SK11 ball bearings. The ball bearing diameter is 12.7mm and the detailed mechanical properties of the ball bearings are shown in Table 3.1.

Table 3.1: Mechanical properties of ball bearing material (Abdullah et. al., 2016)

[a]Properties	Ball bearing material
Hardness (H), HRC	61
Density (ρ), g/cm^3	7.79
Surface roughness (R_a), μm	0.022

[a]From laboratory measurements

3.3.2 Testing Oil

The lubricant used for the whole project is diesel engine oil SAE 15W-40. This type of engine oil meets the requirements needed to carry out the experiment.

Table 3.2: Properties of engine oil SAE 15W-40 and optimized nano-oil (Abdullah et al., 2016)

[a]Properties	SAE 15W-40	Optimized nano-oil
Kinematic viscosity @40˚C, m^2s^{-1}	1.06×10^{-4}	1.03×10^{-4}
Kinematic viscosity @100˚C, m^2s^{-1}	1.35×10^{-5}	1.44×10^{-5}
Viscosity index	127	131
Flash point temperature, ˚C	218	218
Total base number (TBN)	7.38	9.58
Total acid number (TAN)	4.70	5.63

Note: [a]From laboratory measurements

3.3.3 Nanoparticles

Hexagonal Boron Nitride (hBN) is the additive used in order to study the effect of nanoparticles to the ball bearings. Gao et al. (2011) stated hBN is suitable as an additive whether for high temperature lubrication or high friction of contact surfaces. This is due to its characteristics of strong thermal resistance, good thermal conductor and good insulator.

Table 3.3: Physical and chemical properties of hBN nanoparticles (Abdullah et. al., 2016)

[a]Properties	hBN nanoparticles
Appearance	White powder
Chemical formula	BN
Crystal structure	Hexagonal
Melting point, °C	3,000 dissociates
Average diameter particle size, nm	70
Density, kgm^{-3}	2.3
Hardness, HRC	40
Maximum use temperature in air, °C	1,000
Thermal conductivity, $Wm^{-1}K^{-1}$	27
Thermal expansion coefficient @25-1000°C	1×10^{-6}/°C (parallel to press dir.)

Note: [a] From manufacturer

3.4 Samples Preparation

3.4.1 Engine Oil

After the ball bearings were cleaned, they were put inside four different beakers. A solution called Acetone was then poured into the beakers and the specimens were inside an Ultrasonic Bath. The duration for the experiment was 60 minutes for all tests, with varying load (100N, 300N, 500N), speed (100rpm, 300rpm, 500rpm) and three states of temperature; (27˚C, 50˚C, 100˚C).

3.4.2 Engine Oil mixed with hBN Nanoparticles

Nano-oil was prepared by dispersing an optimal composition 0.5 vol.% of 70nm hBN in SAE 15W-40 diesel engine oil by sonication technique, using ultrasonic homogenizer (Sartorius Labsonic P) for 20 minutes with 50% amplitude and an active interval of 0.5. Samples were then stabilized by adding surfactant; oleic acid to prevent sedimentation of nanoparticles. However, the added surfactant is said to be no significant effect on the tribological performance of the lubricants (Abdullah et al., 2013a). The Figure 3.2 below shows an illustration of preparation of nanoparticles in engine oil.

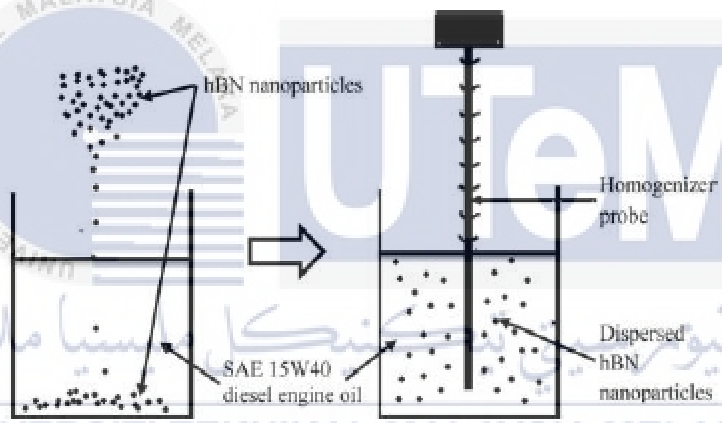


Figure 3.2: Illustration of preparation of nanoparticles in engine oil (Abdullah et. al., 2016)

The composition of hBN nanoparticles was converted into gram before adding into engine oil. The conversion can be calculated by using density, ρ, where the general density of hBN nanoparticles is 2.3 g/cm^3. The calculation can be referred as follows:

$$\rho = \frac{m}{v} \tag{1}$$

$$2.3\text{g/cm}^3 = \frac{m}{0.5cm3}$$

m = 1.15g hBN nanoparticles

3.5 Tribological Test

The tribological test was carried out by using a four-ball tester with accordance to the ASTM D4172 Standard as reference. The ASTM D4172 is the standardized method in order to measure extreme pressure (EP) properties of lubricating fluids (Four-ball Tester). The testing started by placing three carbon chromium steel ball in which each ball's diameter is 12.7mm in a test cup, while the fourth steel ball (referred as the top ball) was placed in a collet inside a spindle where it is rotated by an AC motor, as illustrated in Figure 3.3.

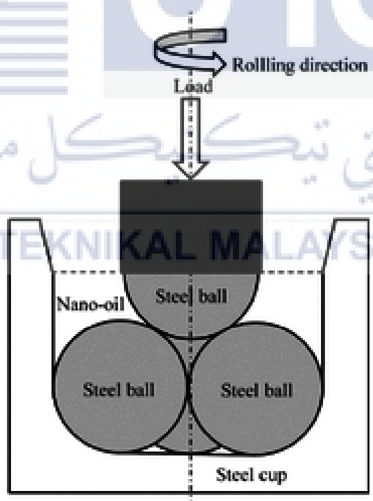


Figure 3.3: Schematic diagram of four-ball tester (Abdullah et. al., 2016)

3.6 Experimental Data and Analysis

As mentioned on previous section, the parameters involved for the experimental investigation are Load (N), Speed (rpm), and Temperature (˚C). In this experimental investigation, there are a total number of 54 tests that will be carried out; 27 tests for Engine Oil and 27 tests for Nanoparticle-enhanced Engine Oil. Table 3.4 shows the parameters that are tabulated following each case to be investigated.

Table 3.4: Experimental data for engine oil and nanoparticle enhanced engine oil

Load (N)	Speed (rpm)	Temperature (˚C)
100	100	27
		50
		100
	300	27
		50
		100
	500	27
		50
		100
300	100	27
		50
		100
	300	27
		50
		100
	500	27
		50
		100
500	100	27
		50
		100
	300	27
		50
		100
	500	27
		50
		100

As stated earlier, the parameters that had been chosen are load, speed and temperature. These three parameters were varied in order to compare coefficient of friction values obtained between engine oil and nanoparticles-enhanced engine oil. Relatedly, testing was conducted under different parameters to observe whether there are significant effects of hBN nanoparticles in lubricant as friction reducer.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Friction coefficient

A series of tests were conducted to study the frictional behavior of SK11 ball bearings in engine oil and nanoparticle-enhanced engine oil using the Four-ball tester. The speed and load were set to 100, 300, 500 rpm and 100, 300, 500 N respectively. The temperatures were 27, 50 and 100˚C. Once the test was completed, the value obtained for Coefficient of Friction (COF) was averaged to obtain the average COF for each specimen tested.

The equation of COF is given by

$$\mu = \frac{\sqrt{6}T}{3Wr} \qquad (2)$$

where μ is coefficient of friction, T (kg.mm) is frictional torque, W (kg) is normal load applied, and r is rotation radius from rotation axis, which was predefined as 3.67mm by the test equipment manufacturer.

The experimental results were tabulated as shown in Table 4.1 and Table 4.2. The highlights show the lowest value of coefficient of friction obtained at temperature 27, 50 and 100˚C with varying loads and speeds.

4.2 Experimental Results

The experimental results of the investigation are tabulated below:

4.2.1 Parameters of Engine Oil

Table 4.1: Experimental result of Coefficient of Friction (COF) for Engine Oil

Load, N	Speed, RPM	Temperature, ˚C	COF
100	100	27	0.055112
		50	0.287670
		100	0.154148
	300	27	0.024028
		50	0.154184
		100	0.114110
	500	27	0.132637
		50	0.144581
		100	0.133355
300	100	27	0.114850
		50	0.096020
		100	0.132942
	300	27	0.125055
		50	0.071823
		100	0.065358
	500	27	0.108300
		50	0.090431
		100	0.063767
500	100	27	0.122113
		50	0.096421
		100	0.088137
	300	27	0.077133
		50	0.117776
		100	0.072649
	500	27	0.094893
		50	0.093023
		100	0.152066

4.2.2 Parameters of Nanoparticle-enhanced Engine Oil

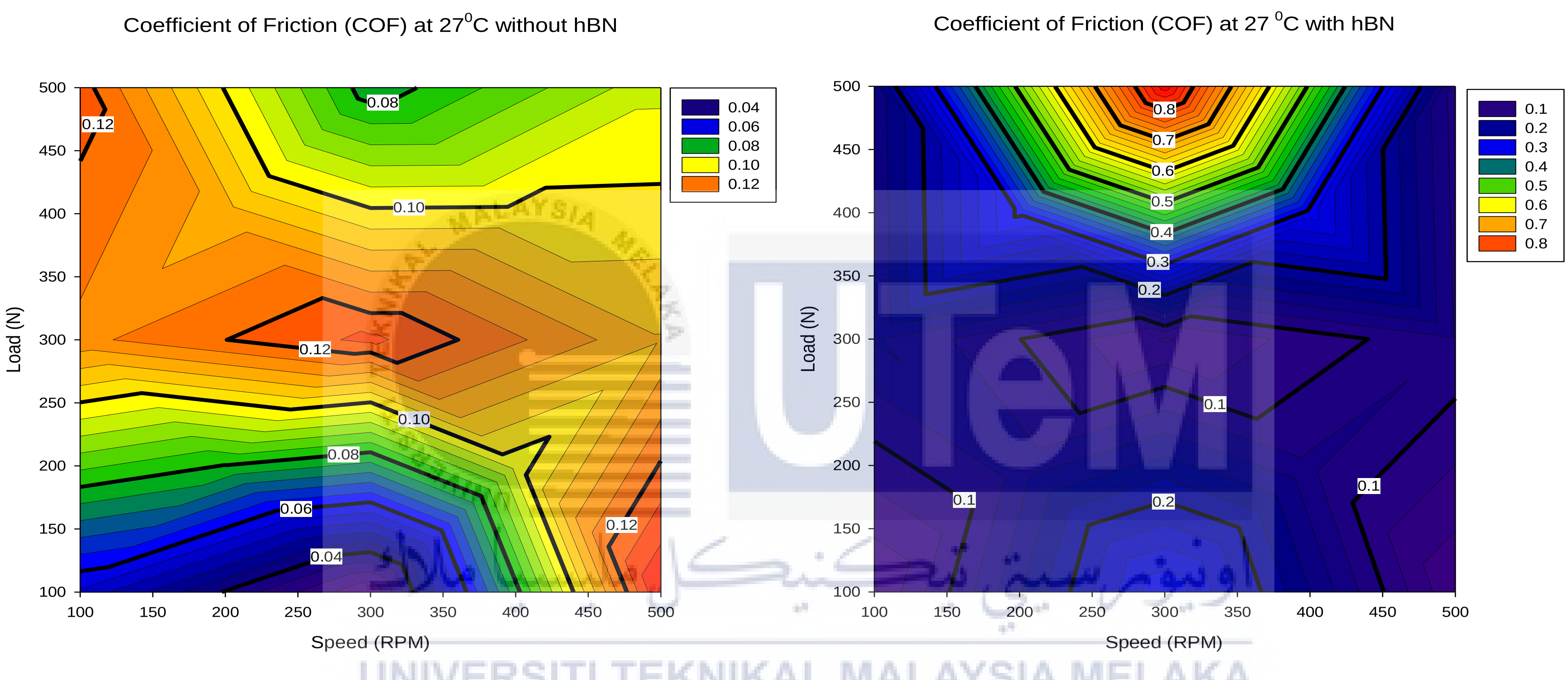
Table 4.2: Experimental Result of Coefficient of Friction (COF) for Nanoparticle-enhanced Engine Oil

Load, N	Speed, RPM	Temperature, ˚C	COF
100	100	27	0.037745
		50	0.261821
		100	0.161785
	300	27	0.278928
		50	0.144585
		100	0.230872
	500	27	0.041668
		50	0.154660
		100	0.155113
300	100	27	0.142321
		50	0.128484
		100	0.160212
	300	27	0.058283
		50	0.074506
		100	0.109337
	500	27	0.117933
		50	0.103161
		100	0.049513
500	100	27	0.146986
		50	0.127019
		100	0.086610
	300	27	0.087519
		50	0.125590
		100	0.142653
	500	27	0.110098
		50	0.093470
		100	0.101727

Based on results tabulated in Table 4.1 and Table 4.2, the condition observations were divided into three parts; low, medium and high temperature condition where 27˚C, 50˚C and 100˚C represented each condition respectively. From both tables, it can be seen that in some condition, coefficient of friction increases as load and speed increase. However, there were sort of discrepancies in some conditions as results obtained were having fluctuation. Fluctuation can be assumed to occur due to competitions between two aspects in order to maintain on both of contacting surfaces. Besides that, changed in lubrication condition might as well cause deformation under different parameters, resulting in fluctuation of coefficient of friction values.

Referring to results recorded through all testing that had been done, supposedly, when load, speed and temperature increased, coefficient of friction should increase as there was increase in amount of heat generated. The heat accumulated causes instability of friction contact between surfaces thus resulting in increase of coefficient of friction as can be clearly seen in those three temperature conditions where some of the results fluctuated towards the end of the experiment.

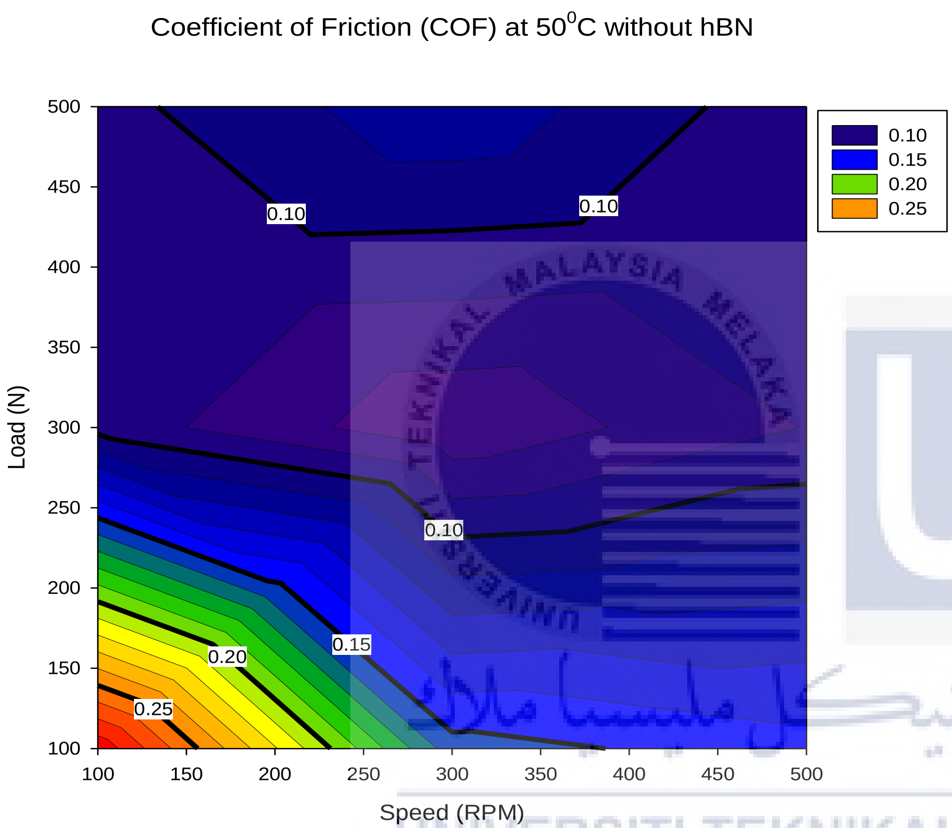
In contrast, there was reduction in coefficient of friction recorded not only in low temperature condition, but in medium and high temperature condition as well. The reduction in values can be said due to smoother surface produced on contacting ball bearings with additional cooling effect of lubricant that could prevent adhesion.



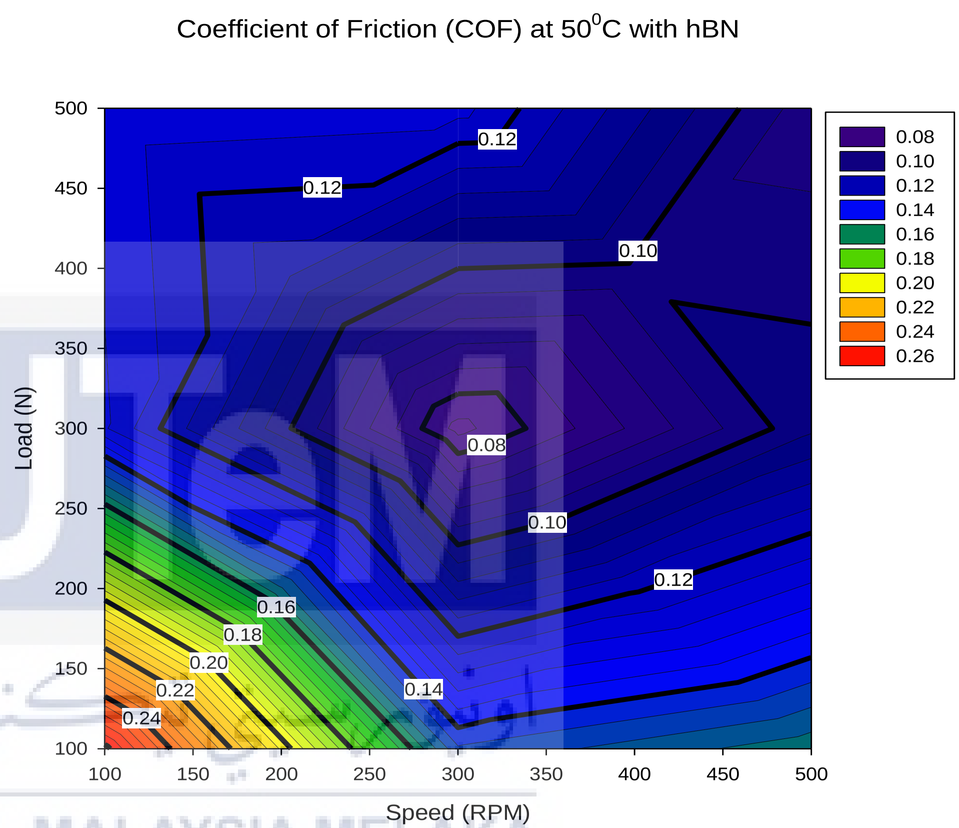
(a) (b)

Figure 4.1: At 27˚C, (a) Coefficient of Friction (COF) without hBN nanoparticles (b) Coefficient of Friction (COF) with hBN nanoparticles

Based on Figure 4.1, it illustrates that the coefficient of friction for SK11 ball bearing immersed in engine oil and nanoparticle-enhanced engine oil. With rough comparison made between those two lubricant conditions, the coefficient of friction in engine oil was lower than in nanoparticle-enhanced engine oil. At beginning, both graphs show similar trend as the load and speed increased, the coefficient of friction increased too. The lowest coefficient of friction value obtained in engine oil was 0.024028, while 0.037745 was for nanoparticle-enhanced engine oil. However, for engine oil, the coefficient of friction fluctuated within ranges of 0.08 to 0.12 while for nanoparticles-enhanced engine oil; fluctuation range is between 0.1 and 0.2. Referring to Figure 4.1 (b), it indicates that hBN nanoparticles failed to perform its effectiveness in engine oil. Additionally, at 27˚C under higher load and speed conditions, hBN nanoparticles were unable to act as friction reducer.



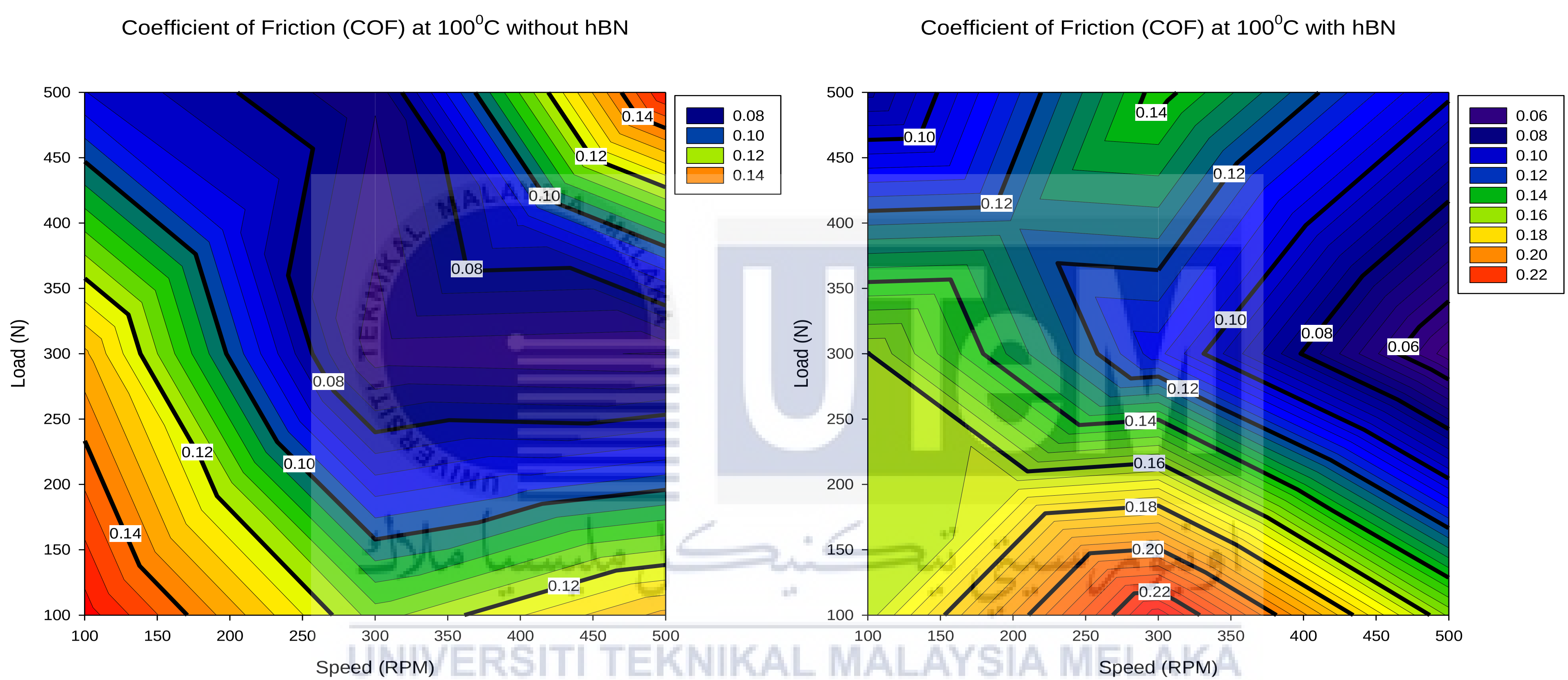
(a)



(b)

Figure 4.2: At 50˚C, (a) Coefficient of Friction (COF) without hBN nanoparticles (b) Coefficient of Friction (COF) with hBN nanoparticles

From Figure 4.2, the coefficient of friction in nanoparticle-enhanced engine oil shows quite similar trend as in engine oil, which at speed of 300 rpm as load incremented, the coefficient of friction obtained decreases in value. In case of engine oil, it can be said that the coefficient of friction reduced due to less collision between two contacting surfaces. However, for nanoparticle-enhanced engine oil, the tribofilm produced in the lubricant was said can reduce the collision between two contacting surfaces; hence reduction in coefficient of friction. As compared from previous figure; Figure 4.1, the lowest coefficient obtained in engine oil was 0.287670 while for nanoparticle-enhanced engine oil; the lowest coefficient of friction recorded was 0.074506. Apart from that, it was recorded that towards the end of the experiments, both lubricants became darker and thicker. This was due to oxidization which took place during testing was conducted. Oxidization prevents additives to react with lubricant to produce a lower coefficient of friction which proved presence of fluctuation in some conditions. Though both lubricant conditions show decreased in value, the coefficient of friction fluctuated starting at 300rpm and 100N.



(a) (b)

Figure 4.3: At 100˚C, (a) Coefficient of Friction (COF) without hBN nanoparticles (b) Coefficient of Friction (COF) with hBN nanoparticles

Referring to Figure 4.3, it shows the coefficient of friction of SK11 ball bearing immersed in engine oil, with and without hBN nanoparticles. From the figure, it can be seen that the coefficient of friction obtained for engine oil as shown in Figure 4.3 (a) was lower than in nanoparticle-enhanced engine oil. The lowest coefficient of friction recorded in case of engine oil was 0.063767, while 0.049513 was the lowest coefficient of friction produced by nanoparticle-enhanced engine oil. As comparison made between those two lubricant conditions, the coefficient of friction value in engine oil decreased throughout the test for temperature 100˚C can be assumed due to less collision between two contacting surfaces. Meanwhile for nanoparticle-enhanced engine oil, the coefficient of friction increases was due to high collision effect between two contacting surfaces and the inability of tribofilm being produced to reduce the collision effect resulting in increased of coefficient of friction. In case of nanoparticle-enhanced engine oil, the result fluctuated between ranges 0.8 to 0.14 which it was assumable that at temperature of 100˚C, hBN nanoparticles only effective at certain load and speed condition.

CHAPTER 5

CONCLUSION

As concluding remarks, the comparison of coefficient of friction between two lubricant conditions; engine oil and nanoparticle-enhanced engine oil was shown in this study. The hBN nanoparticles added into engine oil was said able to improve tribological properties of lubricant and additionally acts as a friction reducer. Based on results obtained, under different temperatures with varying loads and speeds, the coefficient of friction recorded for both lubricant conditions were different for each tests. Though there were fluctuations in values obtained, the lowest coefficient of friction was recorded at 27˚C; 0.024028 for engine oil and 0.037745 for nanoparticles-enhanced engine oil. This was due to less collision effect between two contacting surfaces and it was assumable that hBN nanoparticles added in engine oil carried out its effectiveness under certain temperature, load and speed. Therefore, future investigation for different percentage of hBN nanoparticles dispersed in engine oil with varying temperature, load and speed need to be done in order to study its significant effect to reduce coefficient of friction.

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