FRICTION AND WEAR-CHARACTERISTICS OF BASE OIL DERIVED FROM RE-REFINED WASTE OIL ENHANCED WITH MoS_2 NANO PARTICLE

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BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (MAINTENANCE TECHNOLOGY) WITH HONOURS

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A thesis submitted
in fulfillment of the requirements for the degree of
Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours

Faculty of Mechanical and Manufacturing Engineering Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2022

DECLARATION

I declare that this thesis entitled "Friction And Wear-Characteristics Of Base Oil Derived From Re-Refined Waste Oil Enhanced With MoS_2 Nano Particle" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : Shamalan

Name : SHAMALAN A/L SASIDARAN

Date : 11 JANUARY 2023

APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours.

Signature	:	Taufik
Supervisor Name	:	Dr Mohd Taufik Bin Taib
Date	:	

DEDICATION

To my beloved friends and family who have been a source of strength and inspiration for me and have provided moral, spiritual, and emotional support. To my supervisor Dr. Mohd Taufik Bin Taib for supporting and guiding me in completing the thesis.

ABSTRACT

This thesis is about to compare the friction and wear characteristics of re-refined base oil with additives and without additives. The additives used in the project is Molydenum Disulphide (MoS_2). The main purpose for this project is to identify the tribological properties of re-refined oil with and without additives. Four Ball Tester in Utem used to run the testings and the results were analyzed according to coefficient of friction and wear scar rate. A total of 3 different concentration of MoS_2 with base oil were used to run the testings which is (0.25, 0.5 and 0.75 wt%). Each sample was test using 3 different load which is (20, 40 and 60 N). These 3 different sample finally compared with the test run result of the base oil without additives. The surface defect of ball bearing used in this project were analyzed. The obtained results demonstrate that, the MoS_2 nanoparticle exhibits good lubrication performance. According to the results, the 0.5wt% concentration recorded the lowest friction and wear rate as compared with base oil without Mos_2 nanoparticle. The coefficient of friction and wear scar rate was increases with incleasing load.

ABSTRAK

Tesis ini akan membandingkan ciri-ciri geseran dan haus minyak asas yang ditapis semula dengan bahan tambahan dan tanpa bahan tambahan. Bahan tambahan yang digunakan dalam projek ini ialah Molydenum Disulphide (MoS2). Tujuan utama projek ini adalah untuk mengenal pasti sifat tribologi minyak ditapis semula dengan dan tanpa bahan tambahan. Penguji Empat Bola di Utem digunakan untuk menjalankan ujian dan hasilnya dianalisis mengikut pekali geseran dan kadar parut haus. Sebanyak 3 kepekatan berbeza MoS2 dengan minyak asas digunakan untuk menjalankan ujian iaitu (0.25, 0.5 dan 0.75 wt%). Setiap sampel diuji menggunakan 3 beban berbeza iaitu (20, 40 dan 60 N). 3 sampel berbeza ini akhirnya dibandingkan dengan hasil ujian larian minyak asas tanpa bahan tambahan. Kecacatan permukaan galas bebola yang digunakan dalam projek ini telah dianalisis. Keputusan yang diperoleh menunjukkan bahawa, nanozarah MoS2 mempamerkan prestasi pelinciran yang baik. Mengikut keputusan, kepekatan 0.5wt% mencatatkan kadar geseran dan kehausan yang paling rendah berbanding dengan minyak asas tanpa nanopartikel Mos2. Pekali geseran dan kadar parut haus telah meningkat dengan beban yang semakin berkurangan.

ACKNOWLEDGEMENTS

First of all, I would like to express my gratitude and honour for everything I have achieved since the beginning of my existence, thanks to God's favour. I would like to express my gratitude for offering the study forum to the Universiti Teknikal Malaysia Melaka (UTeM). My sincere thanks go to my main supervisor, Dr. Mohd Taufik Bin Taib, for taking me under his wing and giving me with all the resources I needed to not only complete this research, but also to further develop my character and knowledge. Thank you to my family back home for their sacrifices as well as their unwavering encouragement and support in guiding me to success. Last but not least, I want to express my gratitude to all of my friends and supporters who encouraged and supported me during the completion of my Final Year Project.

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LIST OF SYMBOLS AND ABBREVIATIONS

MoS_2	- Molydenum Disulfide
API	- American Petroleum Institute
SEM	- Scanning Electron Microscope
COF	- Coefficient of Friction
WFE	- Wiped Film Evaporator
WSD	- Wear Scar Diameter
RPM	- Revolutions per Minute
ASTM	- American Society for Testing and Materials

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Base oils are used to make motor oil, metal processing fluids, and lubricating greases among other things. Varied products necessitate different oil compositions and qualities. The most essential aspects in base oil are the viscosity of the liquid at different temperatures. The concentration of base oil molecules and how quickly they can be removed are used to determine if a crude oil is perfect for making into a base oil. Base oil is produced by means of refining crude oil. This is the process of heating crude oil to separate different distillates from one another. During the heating process, heavy and light hydrocarbons are separated and the lighter ones may be refined to make other fuels and other petrol but the heavier hydrocarbons cannot. Base oils are derived from a wide variety of crude oils mined around the world. A paraffinic crude oil is the most prevalent, but there are also naphthenic crude oils that produce products with improved solubility and low-temperature properties. The hydrogenation procedure, in which sulphur and aromatics are removed using hydrogen under high pressure, can be used to produce ultra-pure base oils. These base oils are best used when stringent quality standards are required. Chemical additives are added to basic oils to meet quality standards for final goods, such as friction and cleaning qualities. The American Petroleum Institute (API) divided base oils into five categories in the 1990s. This breakdown is dependent on the refining procedure and the qualities of the base oil, which include viscosity, saturates, and sulphur content, among other things (Freiburg, 2020).

Re-refined base oil is made from used oil that has been vacuum distilled to remove pollutants such as dirt, water, gasoline, and used additives. To eliminate any leftover contaminants, the oil is hydrotreated. This procedure is quite similar to the one used by traditional oil refineries to separate base oil from crude. Finally, the blender blends the re-refined oil with a new additive package to bring it up to industry performance standards. Because oil does not wear out, laboratory testing on re-refined lubricants are unable to distinguish between highly refined base oil and virgin crude base oil (John Engler, Russell J Harding, 2000).

Molydenum Disulfide is another name for MoS_2 nanoparticles. Carl Welhelm Scheele, a Swedish chemist, discovered molybdenum in 1778 in the mineral molybdenite (MoS_2), which had previously been mistaken for a lead compound. Peter Jacob Hjelm discovered molybdenum in 1781. On Earth, molybdenum does not exist as a free metal. In general, these MoS_2 have excellent chemical and thermal stability. They have the ability to generate a highly effective dry lubricating layer. Low friction coefficient, strong catalytic activity, and outstanding physical features characterise MoS_2 nanoparticles. In comparison to bulk material, they have a large active surface area, high reactivity, and improved adsorption capacity. MoS_2 nanoparticles are in black solid particles (Shashavali et al., 2021).

1.2 Problem Statement

Re-refined oil sometime is challenging by reaching exact tribological properties of base oil. To acquire the American Petroleum Institute's certification, lubricants manufactured those re-refined base stocks must proceed the same testing and also meet the same standards as virgin lubricants (API). For that here some of them adding additive along with the oil to obtain same properties with base oil. The additive will blend together with the re-refined oil and run several tests in four ball tester to obtain COF and other tribological properties. In this study, MoS_2 nanoparticles blended together with the re-refined base oil to identify following statement:

- To identify the tribological properties of re-refined oil without additives.
- To identify the tribological properties of re-refined oil with additives.
- The surface defect of ball bearing after additives

1.3 Research Objective

Based on the background and problem statement listed, the objectives of this research studies are as follows:

- To investigate the effect of re-refined base oil to the sliding surface.
- To investigate the effect of re-refined base oil with additive to the sliding surface.
- To investigate the tribological properties of re-refined base oil.

1.4 Scope of Research

The scope of this research are as follows:

a) This study will be focusing on tribological test of re-refined base oil utilizing four ball test.

b) This study will be focusing on tribological test of re-refined base oil with MoS_2.

c) This study will be focusing on investigating worn ball bearing surface using SEM image.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review on friction and wear preventive, coefficient of friction, comparison between normal base oil and base oil enhanced with MoS_2 nano particle. Chapter 2 is made up of summaries of papers written by various authors on pertinent topics. This will help to make the knowledge gained from this research more useful.

2.2 Re-refined method for used oil

The word "re-refining" refers to the process of refining used oil a second time after it was first obtained through crude oil refining. Acid/clay re-refining techniques are currently inadequate for recovering decent base stock from spent oil. Modern re-refining processes are employed to generate clean, high-quality base oils in today's lubricating lubricants. They entail a number of processing processes as well as hydrogenation. When looked at the challenges with spent oil, its use as fuel, and easy recycling in the entry on used collection and oil disposal. The re-refining method provides a lot of long-term advantages. Not only does it have excellent yields, but it also consumes 50 percent less energy than refining crude oil to generate base oil, according to the API, which means less virgin oil is utilised (Infineum et al., 2021). Experts claims that oil does not wear out, therefore it can be refined indefinitely without harming the lubricant's quality. It just becomes unclean, additives deplete, and chemicals degrade. Re-refining cleans up the oil and puts the additives back in. Itelyum operates regeneration plants in Italy that have the annual capacity to refine 180

Ktons of waste oil into Group I and II base oils, gasoil, and bitumen utilising methods such as catalytic hydrofinishing (Infineum et al., 2021).

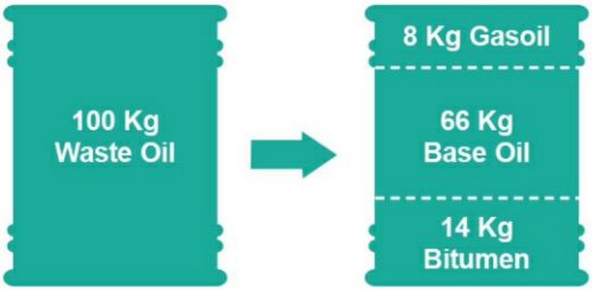


Figure 2.1 Annual capability to re-refined waste oil (Infineum et al., 2021)

2.2.1 Acid Clay Treatment

In this acid clay treatment, used oil are often filtered and then heated to remove water, debris, and solid particles. The waste oil is treated with sulfuric acid in this method. Sulphuric acid act as an oxidizing agent and sulphonating because it is a functional mineral acid. Sulphuric acis also act as a catalyst in some unsaturated hydrocarbon polymerization reactions, therefore treating old oil with sulphuric acid causes oxidation and sulphonation of the degraded products. This acid will react with oxygen compounds and with some sulphur nitrogen-based compounds in resulting form a sludge. In order to remove the unsaturated hydrocarbons, further refining will be done. Even after refining, the oil will retain some colour and odour, which will be eliminated later with the use of activated clay. This method requires about 0.4 lb of clay per gallon of oil. Once the clay filtered from the oil, then can proceed with final step which is neutralization and distillation of the oil. This will do if the raw material contains more than one grade of lube oil. The problem with this approach is that it produces a considerable amount of petroleum-contaminated acid sludge. Because of this problem, the acid-clay technique is today regarded uneconomical. The cost of leftovers is enormous.

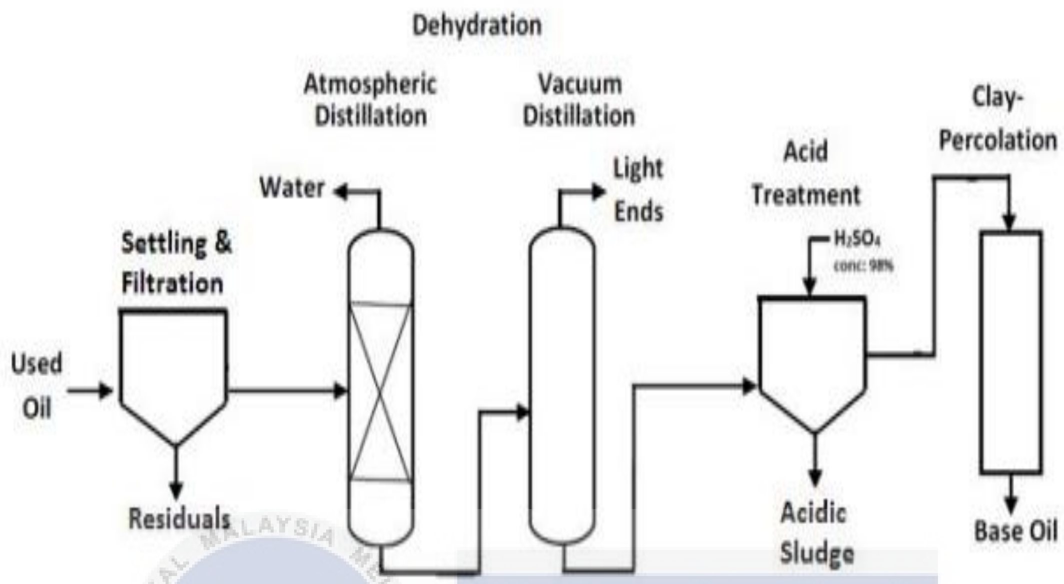


Figure 2.2 Acid/clay treatment process flow diagram (Bhongade, 2019).

2.2.2 Wiped Film Evaporation or Vacuum Distillation Method

The WFE method can be used instead of vacuum distillation. The agitated thin-film evaporator (ATFE) is another name for the wiped film evaporator (WFE). It's a machine that purifies liquids with viscosities of up to 105 poise (Singh et al., 2017) Temperature-sensitive mixes are only allowed a brief stay in the heated zones in WFE. WFEs are normally in vertical cylinders. The feed material is dispersed on the cylinder's inner surface. Axial blades or roller wipers are also positioned on the inside surface. When the liquid is distributed via these blades, it forms a thin film downwards. The double walled evaporator jacket will constantly heat by using a suitable medium. The amount of pressure in the vacuum system controls the distillation chamber. The discharge nozzle allows the vapour to leave the chamber and go to the external condenser. The non-volatile liquid and sludge are discharged to the lower end of the evaporator. The temperature will be kept high enough around 150-

2000 Celsius so that whenever the oil stock is sprayed on to the thin film, it will evaporate as vapour and residue left on the screen is wiped off. Finally, these vapours are condensed either within the system or using an external condenser to obtain the impurity free oil stock. A study on re-refining of automotive lubricating oil using wiped film evaporator stated that the viscosity of recycled oils is much lower than virgin oils in their virgin state, but all other qualities are comparable for both recycled and virgin oils (Singh et al., 2017).

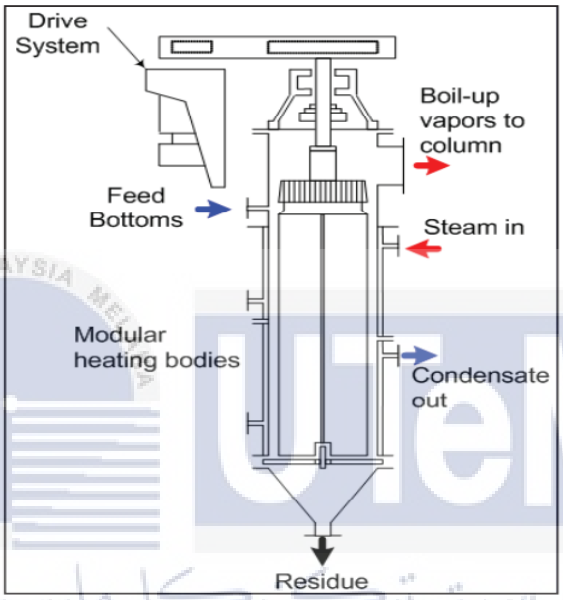


Figure 2.3 Vertical thin film evaporator (Singh et al., 2017)

2.2.3 Solvent Extraction Method

Solvent extraction is the preferred approach for re-refining spent lubricating oils because it does not require complex processes. It delivers adequate recovered base oil qualities which requires less energy, and is less expensive than other methods. This method is to separate compounds based on their relative solubilities into 2 different immiscible liquids which is water and other organic solvent. It is the extraction of a substance from one liquid phase to another. A separating funnel is used to accomplish solvent extraction, which is a common technique in chemical laboratories. Solvent extraction is especially suitable for the processing of large capasities. This is the main reason of using solvent extraction frequently by oil industry. The quality of lubricant distillate produced by a vacuum distillation process can be improved by solvent extraction. Polar chemicals, additives, and colour bodies are extracted using the solvent. Aromatics are removed, and saturates are increased. Solvent extraction has the disadvantage of removing unsaturated molecules, lowering overall yield. Hydrotreating, on the other hand, transforms these chemicals. Due to its inability to remove sulphur, solvent extraction generates API Group I base oil that meets motor oil criteria but does not meet API Group II specifications. Solvent Extraction is the process of diffusing a solvent into the raw material's oil-bearing cells, resulting in an oil-in-solvent solution. Extraction can be done with a variety of solvents.

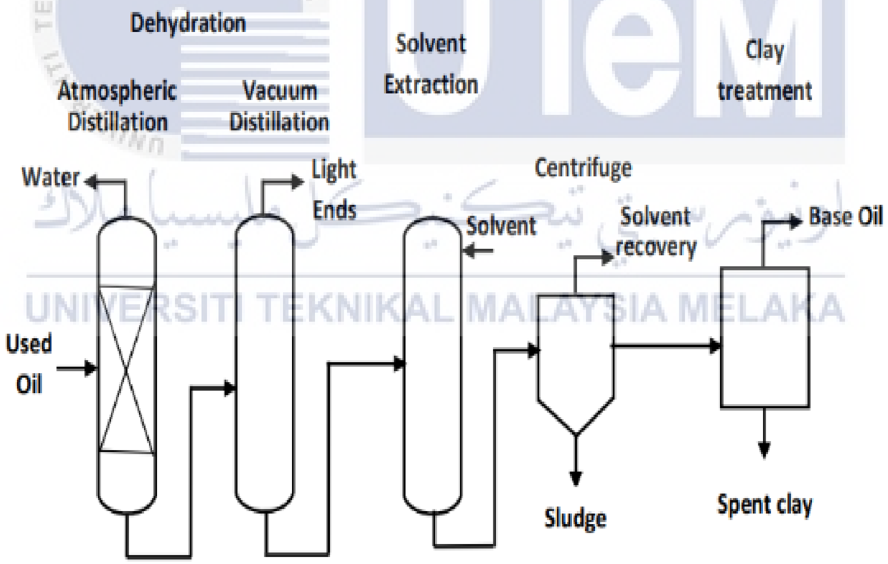


Figure 2.4 Major step in solvent extraction process (Emam & Shoaib, 2012)

2.3 Base Oil

A base oil is present in all lubricants. Lubricants are typically composed of 90% base oil and 10% additives. The American Petroleum Institute (API) divides base oils into 5 categories based on viscosity index, sulphur content, and saturate content. Petroleum crude oil is refined into the first three classes. Full synthetic (polyalphaolefin) oils make up Group IV base oils. All additional base oils not found in Groups I through IV fall into Group V. Lubricating oils start out as one or more of these five API groups before all of the additives are added (Infineum, 2018)

2.3.1 Group I

Group I base oils are less than 90% saturates and more than 0.03 percent sulphur. These base oils also have viscosity index of 80 to 120. The temperature range for these oils are around 32 to 150 degrees Fahrenheit. These Group 1 base oil the most affordable base oils because its have a simpler refining process.

2.3.2 Group II

The viscosity index of Group II base oils is around 80 to 120. They contain more than 90% saturates and lesser percent sulphur which is 0.03. They're frequently produced using hydrocracking, a more difficult method than Group I base oils, because the hydrocarbon molecules in these oils are totally saturated. Also these base oils have greater antioxidant capabilities. They are in clearer colour and more expensive than Group I base oils. Group II base oils. Therefore, these oil are becoming more popular on market, and the prices are almost same as Group I oils.

2.3.3 Group III

The viscosity index for these base oils are greater than 120 and include more than 90% saturates. The percentage of sulphur is less than 0.03. This oils are refined more than Group II base oils, and they are frequently hydrocracked (heat and higher pressure). The goal of this more time-consuming procedure is to obtain a purer base oil. Despite the fact that they are made from crude oil, Group III base oils are frequently referred to as synthetic hydrocarbons. These oils are becoming more popular, as are Group II base oils.

2.3.4 Group IV

Group IV base oils are made up of polyalphaolefins (PAOs). Synthesizing is the process of making synthetic base oils. They have a far broader temperature range, making them suitable for use in both extreme cold and extreme heat.

2.3.5 Group V

Group V base oils include polyalkylene glycol (PAG), phosphate ester, biolubes, polyolester, silicone, and other base oils. These base oils are occasionally blended with other base stocks to improve the oil's properties. Esters are a type of Group V base oil that is used to improve the properties of other base oils in lubricant formulations. Ester oils, when compared to PAO synthetic base oils, may endure higher temperatures and provide stronger detergency, allowing for longer periods of use.

Group	Vis. Index	Saturates		Sulfur	Other
I	80≤ x <120	<90%	and / or	>0.03%	
II	80≤ x <120	≥90%	and	≤0.03%	
II Plus	>about 110				
III	≥120	≥90%	and	≤0.03%	
III Plus	>about 135				
IV					PAO (Poly Alpha Olefins)
V					Everything Else
VI		Europe Only (ATIEL)			PIO (Poly Internal Olefins)

Figure 2.5 API base oil classification (Infineum, 2018)

2.4 Base Oil with Additives

Lubricants today are made up of a range of "ingredients." The foundation is a base oil, which is found in significantly more than 50% of the final product. The most prevalent mineral oils are paraffin-based mineral oils, which are made from crude oil distillates in a lubricating oil refinery. When qualities such as biodegradability, high ageing stability, or enhanced viscosity temperature behaviour are desired, synthetic base fluids are utilised. Most of the time, the base oil is insufficient to cover the vast variety of duties that an oil must accomplish for the application at hand. Individual additions or even complicated mixtures of active substances, known as additives, are added to base oils to provide reliable lubrication and long-term and smooth functioning. Chemical components of lubricant additives must blend properly with the basic oil in order to act as a single fluid. Several additives are often sold together in an additive package and diluted with a base oil at a greater concentration. The additive package is then added into the lubricant blend at an optimum treat rate to achieve the desired performance by the lubricant producer (Puhan, 2020).

2.4.1 Molybdenum disulphide (MoS_2)

Molybdenum disulphide, like Tungsten disulphide (WS_2), is a transition metal dichalcogenide that works on the mechanism of interlamellar shear between covalently bound hexagonal basal planes like graphite (Puhan, 2020). It's made composed of small particles that are excellent at coating metallic surfaces, despite the fact that it's solid. The friction between surfaces is reduced by the coating effect. Because of its low-friction qualities, which are similar to those of graphite, it is often employed as a solid lubricant. Its strong load-bearing capacity and the fact that it is relatively inert, unaffected by dilute acids or oxygen.

Various study regarding MoS_2 as a additives with different types of oil is created. For an example, a study on engine oil with molybdenum disulphide by Łukasz Makowski. In this study they use MoS_2 as a additives in engine oil to enhance oil's tribological and rheological properties. With increasing temperature, the density of measured oils drops linearly. A small rise in density in proportion to the base oil was noticed in each nanosuspension. Due to the increased density of pure molybdenum disulfide, the nanosuspension with the reference and produced MoS_2 showed the most significant variations (up to 0.43 percent). In this study, they concluded that the additives provide the 10W40 oil a minor boost in density and specific heat capacity. They were able to eliminate viscous heating effects and rectify engine oil rheograms in the region of high shear rates using the non-isothermal Couette flow model. At low temperatures, the nanohybrid suspensions of MoS_2 in the base oil had the lowest apparent viscosity typical for cold engine start up. However, at high temperatures and high shear rates, the effect of the various MoS_2 additions on the oil's apparent viscosity disappears (Makowski et al., 2022).

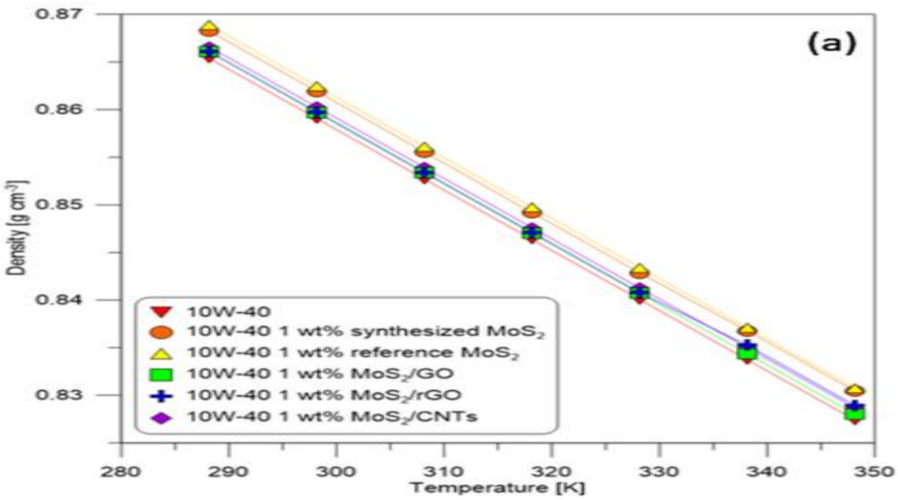


Figure 2.6 Density vs temperature graph (Makowski et al., 2022)

In another study by Mohammad Hanief and Zahid Mushtaq, they added MoS_2 in biodiesel named jatropha oil to identify friction and wear performance. The nanoparticles were added in three different mass ratios to perform tribological testing. The friction and wear variations with load were also calculated. As the result, when the scar was lubricated with base oil without nanoparticles, the maximum wear rate was obtained at 60N. At 15N, the lowest wear rate was reported when nanoparticle concentration was 0.5 percent. When the nanoparticles added to base oil, the wear rate was reduced by up to 35% (Mushtaq & Hanief, 2021). MoS_2 nanoparticles were shown to be extremely effective at reducing friction and wear. Therefore, jatropha oil has excellent lubricating properties, which can be improved by adding MoS_2 nanoparticles. It could be a good lubricant to replace mineral oils and contribute to a cleaner, more sustainable environment.

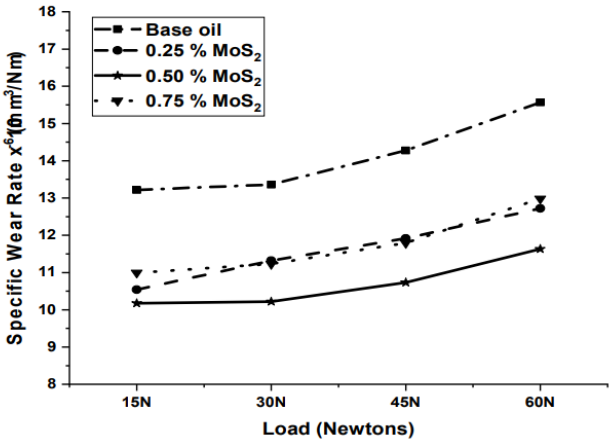
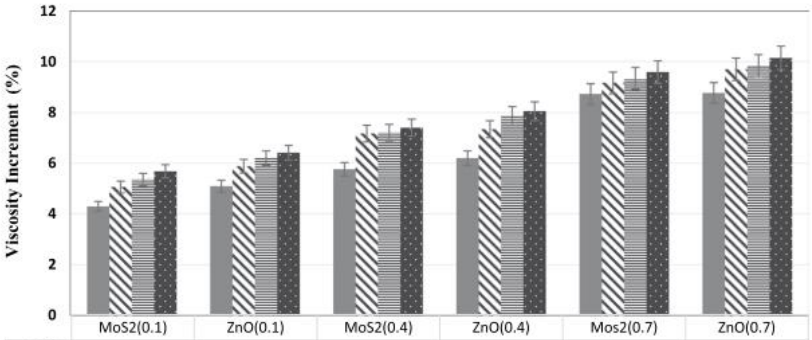


Figure 2.7 Specific wear rate values recorded on various testing conditions (Mushtaq & Hanief, 2021)

Finally, utilising MoS2 and ZnO nano-additives, a study was conducted to examine the tribological and thermophysical properties of lubricating oil. The nanoparticles were suspended in a commercial diesel oil using Triton X-100 at three different concentrations in this study (0.1, 0.4, and 0.7 wt percent). Thermophysical and tribological features of the resultant nano lubricant, such as pin mass loss, friction coefficient, and worn surface morphologies, were examined and compared to pure diesel oil. The inclusion of nano MoS_2 reduces the mass loss values of the pins by 93 percent due to the nano MoS_2 lubricant effect, according to the overall results of this experiment. At 100°C, the viscosity of MoS_2 and ZnO nano lubricants increased by around 9.58 percent and 10.14 percent, respectively, with 0.7 wt. percent nanoparticles concentration. The viscosity index increased when MoS_2 and ZnO nanoparticles were added to the pure fluid, and this rise was greater at higher concentrations (Mousavi et al., 2020). When compared to the pure lubricant, the pure diesel oil containing MoS_2 and ZnO nanoparticles demonstrated better anti-friction and anti-wear properties.



	MoS2(0.1)	ZnO(0.1)	MoS2(0.4)	ZnO(0.4)	Mos2(0.7)	ZnO(0.7)
40 °C	4.29	5.09	5.76	6.2	8.73	8.77
60 °C	5.06	5.88	7.17	7.34	9.16	9.69
80 °C	5.35	6.2	7.2	7.87	9.34	9.82
100 °C	5.68	6.41	7.4	8.05	9.58	10.14

Figure 2.8 Variation of pressure diference as a function of fow rate for the pure diesel oil (Mousavi et al., 2020)

2.5 Four Ball Test

The four ball tester are normally used to characterise lubricant qualities like wear prevention (WP), extreme pressure (EP), and frictional behaviour. The tester is made up of four balls arranged in an equilateral tetrahedron as illustrated in the diagram below. The upper ball rotates and makes contact with the below three balls, which remain stationary. The four ball test also can be used to assess lubricant performance in terms of wear. The upper center ball is rotated against the rest of the fixed balls during the test. Unlike the severe pressure test, the load is performed under defined parameters which is load, temperature and speed.

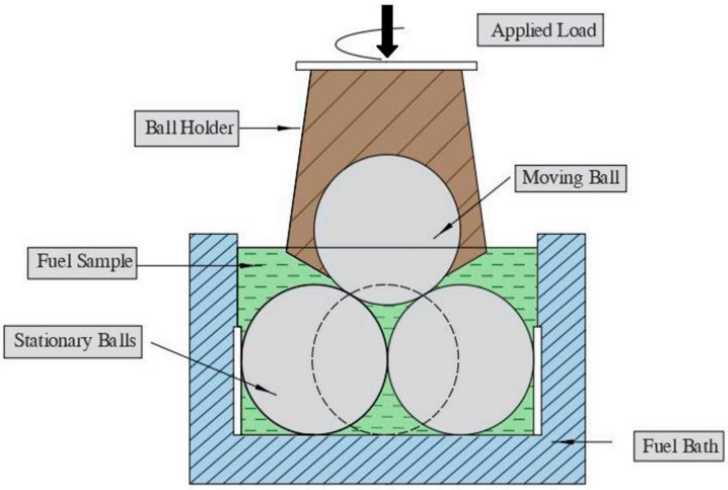


Figure 2.9 Four ball tester schematic (Yaqoob et al., 2020)

2.5.1 Testing Standards for Four Ball Test

Standard	Lubricant	Type of test	Load [N]	Duration	Speed [rpm]	Temperature [°C]
ASTM D 2262	Grease	Wear	392	60 min	1200	75
ASTM D 4172	Oil	Wear	147(A) / 392(B)	60 min	1200	75
ASTM D 2596	Grease	Extreme Pressure	59 up to 7848	10 s	1770	18 - 35
ASTM D 2783	Oil	Extreme Pressure	59 up to 7848	10 s	1770	19 -35
IP 239	Grease / Oil	Extreme Pressure + Wear	60 up to 7940	Wear: 60 min EP: 10 or 60 s	1450	not specified
DIN 51350-2	Oil	Extreme Pressure	2000 up to 12000	60 s	1450	18 -40
DIN 51350-3	Oil	Wear	150 (A) / 300 (B)	60 min	1450	18 -40
DIN 51350-4	Grease	Extreme Pressure	2000 up to 12000	60 s	1450	18 -40
DIN 51350-5	Grease	Wear	150(C) / 300(D) / 1000(E)	60 min	1450	18 -40

Figure 2.10 Testing parameters of common four-ball tester standards (Rigo & Kovačócy, 2018)

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this Chapter 3 is we will go over the implementation of methodology and the elements that are employed in the project that is recommended in this report in greater detail. This chapter will go over all the important process and flow. To begin, the chapter will discuss the project plan that will be employed to ensure the project's success. The next section will be the requirement flow-chart were shown the project's flow. Methods used during this research including blending process of base oil derived from re-refined waste oil with MoS_2. And then continue with four ball tester to identify wear and friction.

3.1 Project Plan

The project plan is to investigate the tribology performance of base oil derived from re-refined waste oil. The execution of the project plan will be focused on a four ball tester machine. The wear and friction need to be evaluated according to the ASTM D4172 standard test method for wear preventive characteristics of lubricating fluid. Finally, the SEM image for wear mechanism need to be analysed. The four ball testing need to run 3 times for each original base oil and base oil enhanced with MoS_2 to analyse the both result. Project workflow is the basic explanation or visualization of the business or overall flow of the project that will be established. Below is the project flow chart for the project preparation.

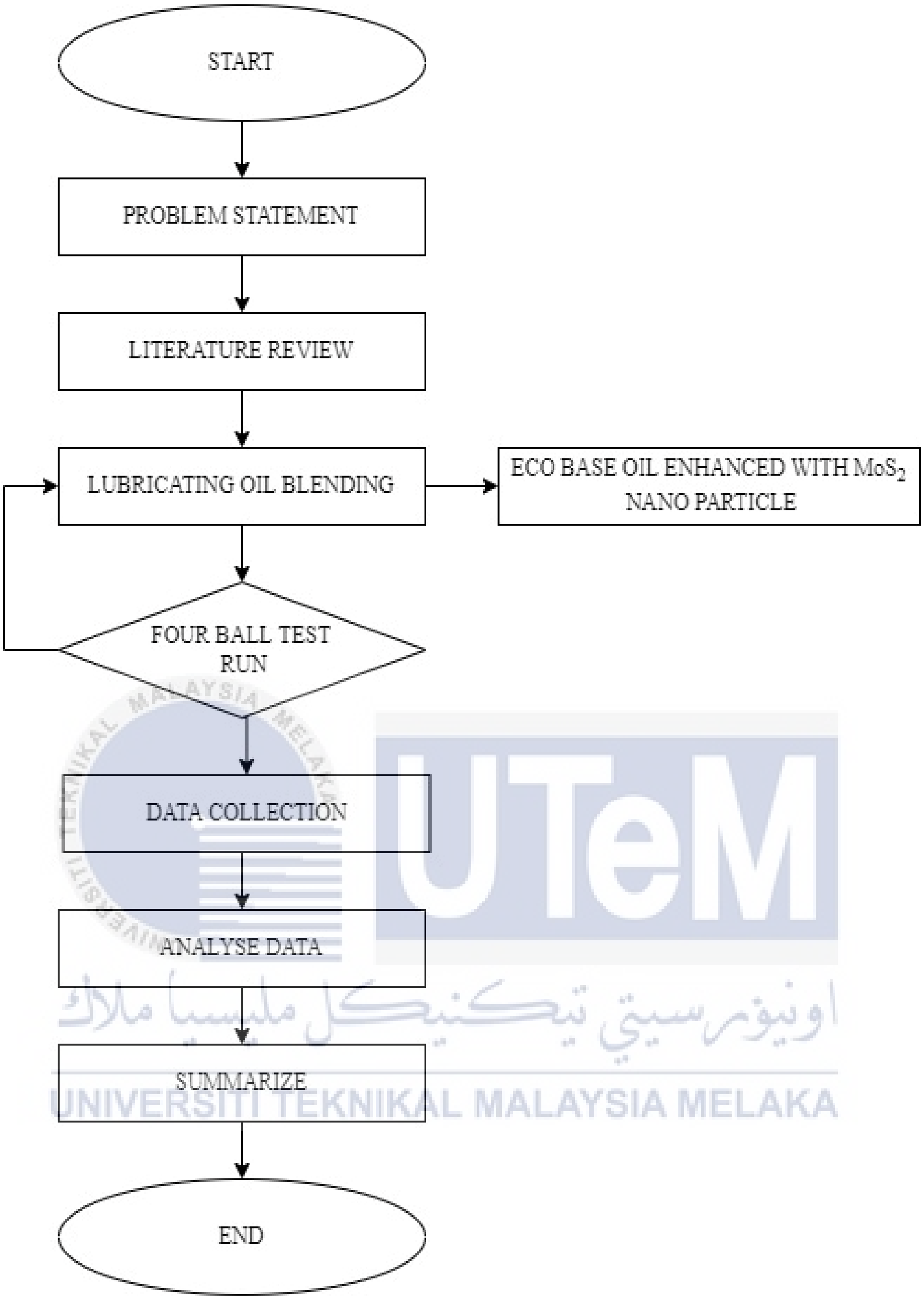


Figure 3.7 Project flow chart

3.2 Selection of Oil and Machine

For this project, base oil derived from re-refined waste oil is used. Oil manufacturers blends the base oil and combine it with additives to create finished lubricants such as motor oil, transmission fluid, and grease. Refined oil is a final blend of base oils and additives that can be either 100 percent re-refined or combined with virgin base oil. Used oil may be re-refined countless times and it never degrades.

3.2.1 Type of Base Oil

For this project, we purchased eco base oil SN 150 from Pentas Flora Sdn Bhd. This company has been providing eco base oil since years. Pentas Flora is one of Malaysia's few re-refineries having the potential to produce base oil. Base oil is a fundamental component of oil that is blended with additives to generate lubricating oil. Base Oil SN 150 is a light grade base oil that meets the lower end of the Grade I light base oil standards.

Figure 3.8 Pentas Flora Eco Base Oil SN 150

3.2.1.1 Physical Properties

Table 3.1 Physical properties of Eco Base Oil SN 150

Properties	Eco Base Oil SN150
Density @ 15.6°C (60°F)	7.16 lb/gal
Viscosity @ 100°C (212°F)	5 mm2/s - 5.5 mm2/s
Boiling point	>316°C (600°F)
Specific gravity @ 15.6°C (60.1°F)	0.86 – 0.87
Flash point	200 °C (392 °F) Minimum

3.2.2 Types of Machines

The machine that used for this project is Koehler K93190 Four Ball Tester. This machine is placed in one of the FTKMP laboratories at Universiti Teknikal Malaysia Melaka.

The Four Ball Tester measures the wear and frictional properties of lubricants under sliding steel-on-steel test circumstances using both Extreme Pressure (EP) and Wear Preventative (WP) studies. The tests are carried out using the most recent ASTM and IP published methodologies. Load cells are used to monitor the normal load on the ball assembly as well as frictional torque. Steel ball wear scars are measured using a scale microscope and recorded using an optional CCD camera. TriboDATA, an advanced data collecting and processing software package, is used to process and store data. The results of the tests can be plotted, compared, and exported to other programmes.

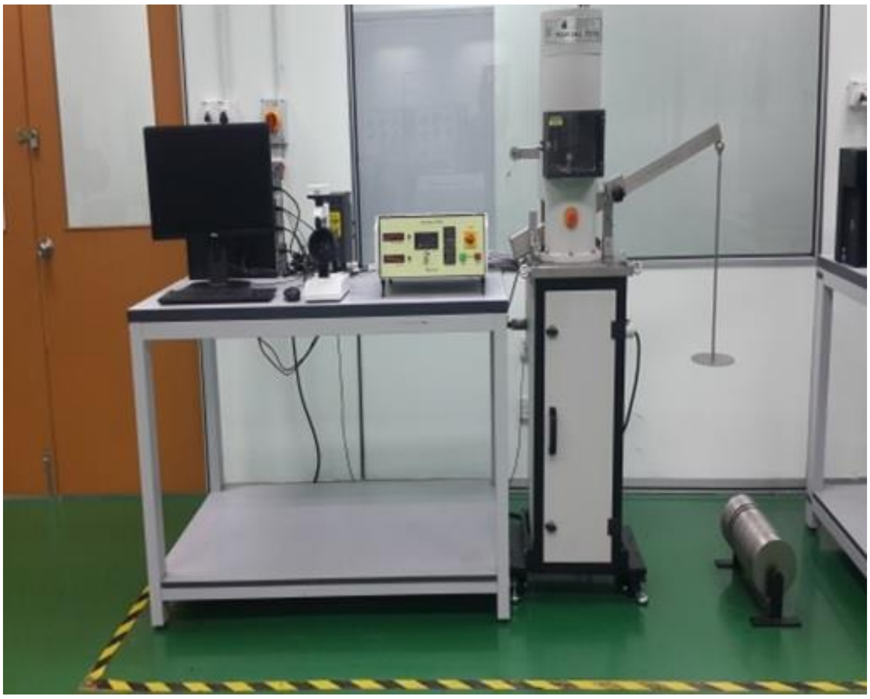


Figure 3.9 Koehler K93190 four ball tester

The Koehler TriboDATA System is designed to acquire and process analogue data from Koehler's and other tribology instrument manufacturers' tribology test instruments. The four analogue inputs on the analog-to-digital converter card are used to record and show test results in real time. A total of four graphs can be presented at the same time. The data can be saved on disc for future reference or exported to other software packages in ASCII text format. With the data, critical test parameters are also recorded. Data acquisition of critical test parameters like as normal load, friction load, temperature, and time can be done easily using the TriboDATA hardware and software package, ensuring that your test findings are reliable and repeatable within prescribed test circumstances. A CCD camera kit is available as an option for capturing wear scar images and storing them on a PC for analysis.

3.2.2.1 Four Ball Tester Parameters

Table 3.2 Specification of Four Ball Tester

Four Ball Tester Parameters	**Specifications**
Standards	ASTM D4172, D2793, D5183, D2596, D2266, D2783; IP 239, IP 300
Drive Motor	1.5 kW
Test Speeds	1200, 1440. 1760 rpm
Maximum Axial Load	10000 Newton at 3000 rpm / 12000 Newton at 1800 rpm
Test Duration (min/max)	1/9999 min
Test Ball Diameter	12.7 mm

3.3 Blending Process

Blending process is a process that mix Eco Base Oil SN 150 with MoS_2 nano particle using magnetic stirrer on hot plate. Hot plates are tabletop laboratory tools for evenly heating and mixing a variety of liquids and solutions. The measure base oil is poured on a container and then placed on top of the regulator hot plate. The temperature of base oil is then maintained at 60 degree celcius . At this temperature, the Molydenum Disulphide (MoS_2) were added into the base oil. Then the base oil were stirring for 3 hours and then preparing for run test in Four Ball Tester.

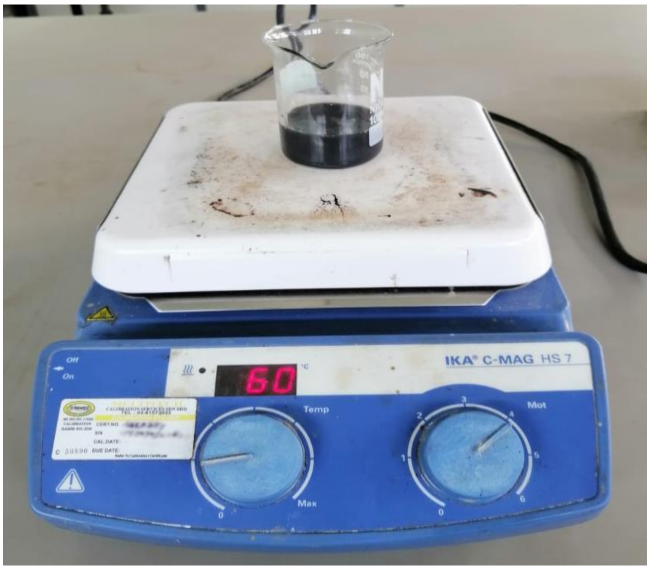


Figure 3.10 Magnetic stirrer

3.4 Coefficient of Friction

The four-ball tester is used to determine the COF automatically. A load cell in contact with the moment arm fixed to the ball pot in the four-ball tester was used to measure friction torque (Joysula et al., 2021). According to ASTM D4172, the coefficient of friction was determined using the measured friction torque and the applied load. The user could view and save real-time changes in friction coefficient data. The mean of all the friction coefficient readings obtained during a pass load test for the base oil was used to compute the average friction coefficient.

3.5 Wear Scar Diameter (WSD)

According to ASTM D4172, an optical microscope would be used to measure the wear scar diameter of steel balls with a 0.01 mm resolution. The image of the wear scar was captured using computer software and an optical microscope. Therefore, the programme was used to calculate the wear scar diameter, and this technique is repeated for each different concentration of base oil.

3.6 Sample Preparation

For the sample preparations, 30ml base oil SN150 is added into a beaker. Then, the digital electronic weighing scale used to measure the weight of MoS_2 for each concentration of base oil as shown in figure 3.4. The measured weight of MoS_2 is recorded in table 3.3. The MoS_2 mixed with the base oil and then the mixture was stirred using magnetic stirrer for 3 hours to allow uniform dispersion of particles.

Table 3.3 Measured weight for MoS_2

Sample concentration	Weight (grams)
0.25wt%	0.075
0.5wt%	0.15
0.75wt%	0.225

Figure 3.11 Measuring the weight of MoS_2 before blending

3.7 Four Ball Test Run Preparation

Before the test run, the equipment and the ball bearing were cleaned using hexane. A total of 4 ball bearing and 10ml of sample oil required for each test run. Once cleaned, the equipment assembled, and sample oil were injected for test run. Three different loads were tested for each concentration of base oil. The duration for one complete test run is 1 hour. The result of Cof and Wsd was taken once the test run completed.

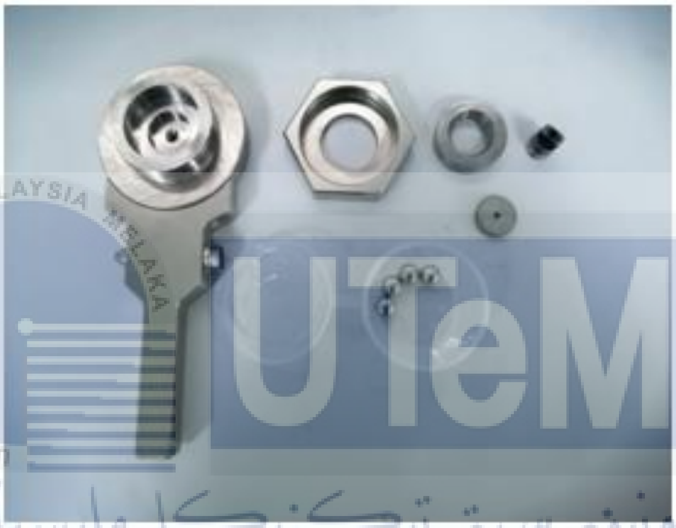


Figure 3.12 Equipment cleaned using hexane before test run

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In this experiment 2 different lab equipment's used which is a four ball testes and magnetic stirrer. Four ball tester used to measure the coefficient of friction and friction torque. Magnetic stirrer used to blend the MoS_2 with base oil for different composition 0.25%, 0.5% and 0.75%. Each composition gone through 3 tests run and a total of 12 test run taken for analyzing the result. The experiment was carried out carefully and handled with proper procedure before and after the experiment to avoid error on results. The main purpose of this chapter is to clarify the results of the study, by evaluate and explain the coefficient of friction and wear of the base oil enhanced with MoS_2.

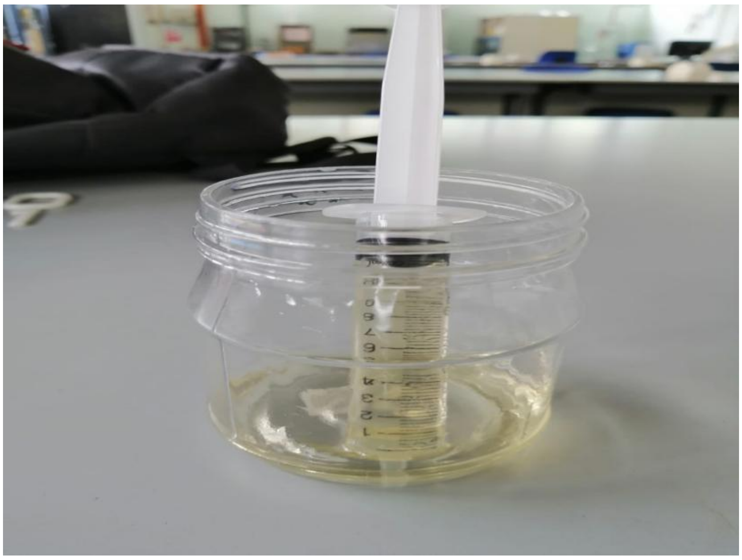


Figure 4.6 Base oil sample

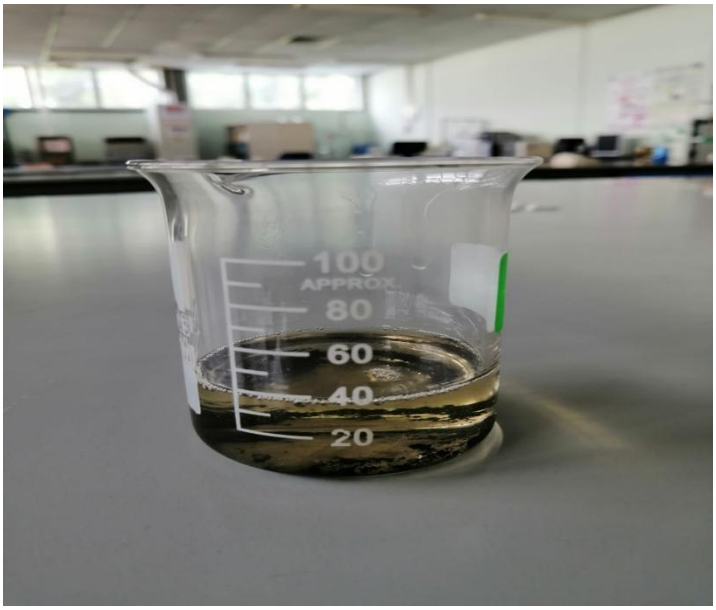


Figure 4.7 Base oil added with $M0S_2$

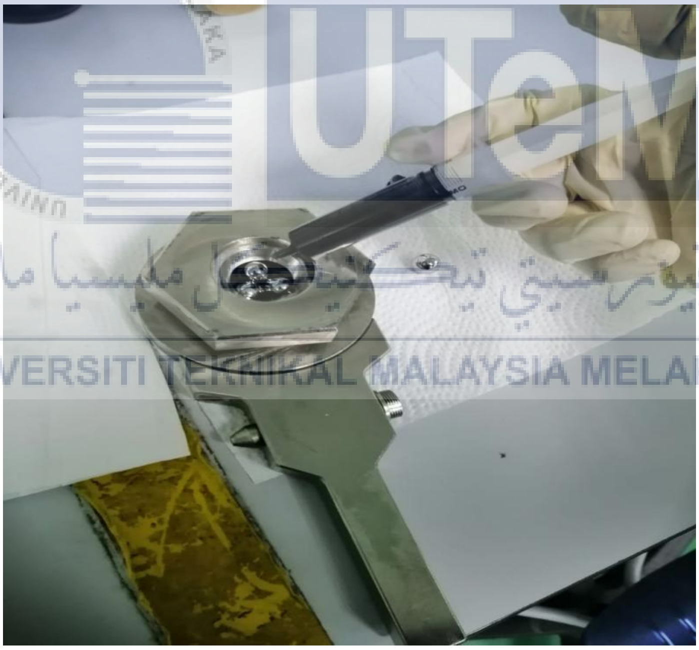


Figure 4.8 Base oil sample after blending process

Based on the method described in the previous chapter, the results of this experiment were achieved. Graphs, tables, and the wear image of each ball bearing were all used to convey the experimental data. The main purpose of this chapter is to clarify the results of the study, by evaluate and explain the difference between coefficient of friction before and after adding MoS_2.

4.2 Analysis of friction

Table 4.1 Base oil sample with average coefficient of friction

Oil sample	Load (Newton)	Average Coefficient of Friction
Base oil without MoS_2	20N	0.08127
	40N	0.083752
	60N	0.086055
Base oil with 0.25% wt MoS_2	20N	0.078929
	40N	0.075756
	60N	0.084324
Base oil with 0.50% wt MoS_2	20N	0.068624
	40N	0.06968
	60N	0.082807
Base oil with 0.75% wt MoS_2	20N	0.079842
	40N	0.085294
	60N	0.090054

The above table shows the number of samples without MoS_2 and 3 different MoS_2 composition. Each sample were used to run four ball testing under three different loads which is 20N, 40N and 60N. The average coefficient of friction is calculated and tabulated in table 4.1 respectively.

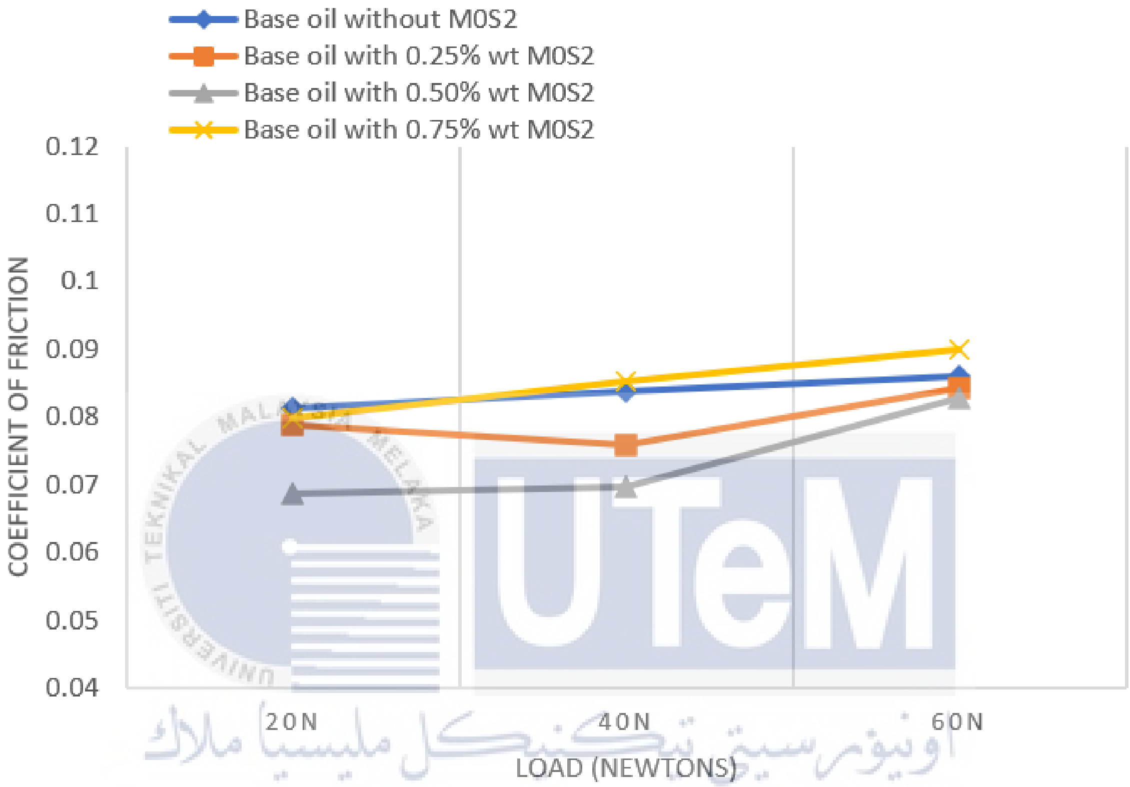


Figure 4.9 Average coefficient of friction value recorded at various testing conditions.

Figure 4.4 displays the variation of average coefficient of friction (Cof) at different loads and MoS_2 mass ratios. The Cof between the friction pair was higher when lubricated with base oil. As the addition of nanoparticles was started, the Cof values began to drop as shown in figure 4.4. But the base oil with MoS_2 mass ratio 0.75% is slightly higher then base oil without MoS_2. The nanoparticles react between the surfaces of friction-pair, limit their direct contact, and cover the asperities. The nanoparticles react with the base oil and the ambient atmosphere to form a protective layer on the surface. This layer serves as a barrier and avoids direct contact between the surfaces and reducing the Cof (Mushtaq & Hanief, 2021). The

Cof also increased with the increase in loads from 20N to 60N when it lubricated with all base oil sample. This increment can be due to more rigid engagement between asperities higher load in absence of protective layer. The highest Cof was (0.09) was recorded for 0.75% concentration of nanoparticle at 60N while as the lowest Cof (0.069) was recorded at 0.5% concentration of nanoparticle at 20N. The Cof started to slightly increase when the weight ratio of nanoparticles was raised to 0.75% because there were too many nanoparticles present. Therefore, a nanoparticle concentration of 0.5% weight ratio was optimal for achieving the lowest CoF in the base oil.

4.3 Analysis of wear scar

Table 4.2 Base oil sample with average wear scar diameter.

Oil sample	Load (Newton)	Average Wear Scar Diameter
Base oil without MoS_2	20N	1.088 mm
	40N	1.224 mm
	60N	2.792 mm
Base oil with 0.25% wt MoS_2	20N	0.888 mm
	40N	1.130 mm
	60N	2.618 mm
Base oil with 0.50% wt MoS_2	20N	0.750 mm
	40N	0.994 mm
	60N	2.258 mm
Base oil with 0.75% wt MoS_2	20N	1.154 mm
	40N	1.208 mm
	60N	2.825 mm

The above table shows the number of samples without MoS_2 and 3 different MoS_2 composition. Each sample were used to run four ball testing under three different loads which is 20N, 40N and 60N. The average wear scar diameter is calculated and tabulated in table 4.2 respectively.

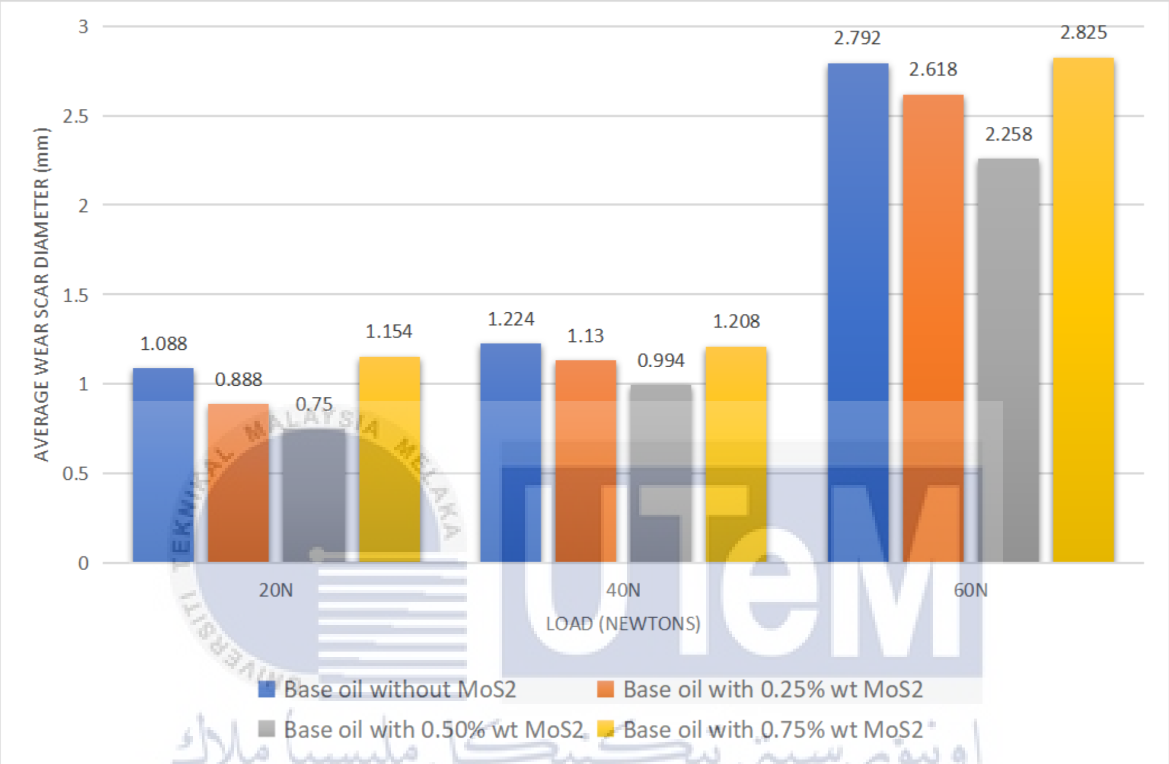
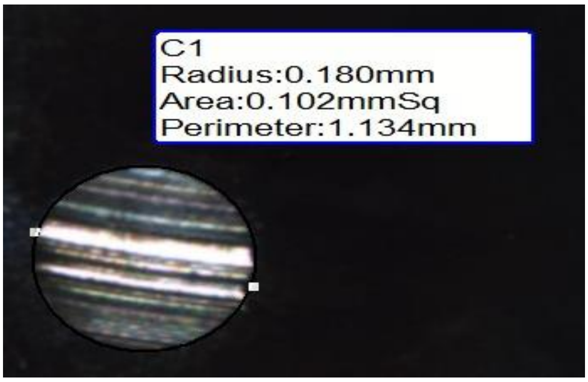


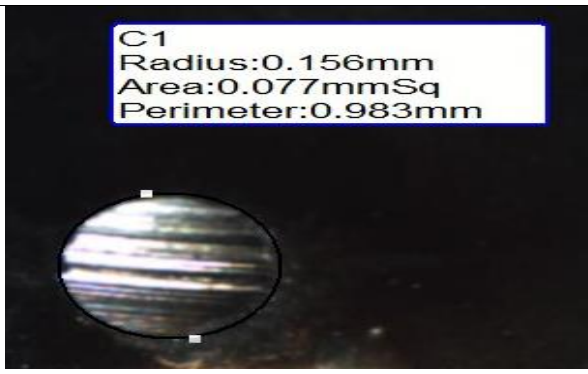
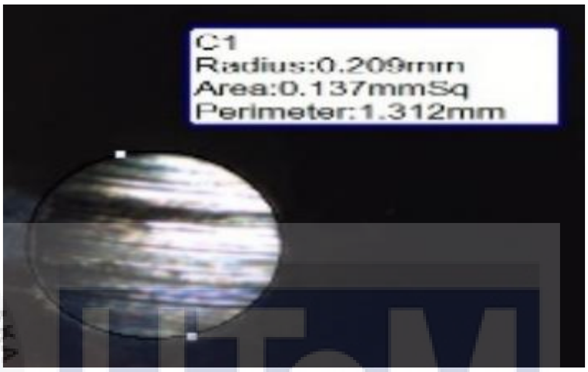
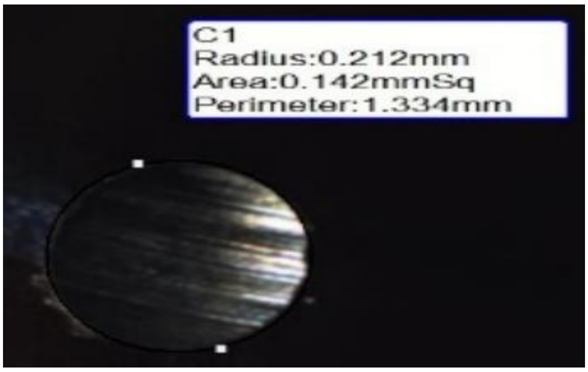
Figure 4.10 Average wear scar diameter recorded at various testing conditions.

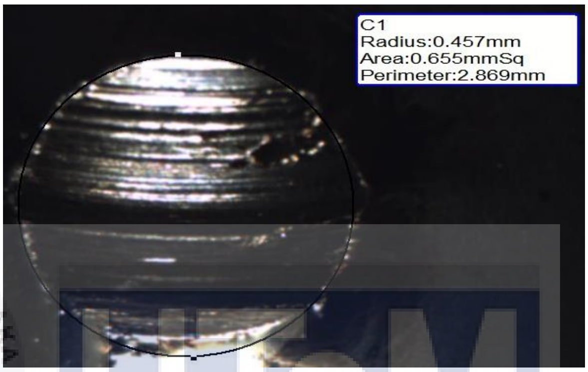
Figure 4.5 displays the average wear scar diameter at different loads and MoS_2 mass ratios. The wear scar rate was higher when lubricated with base oil at increasing load. As the addition of nanoparticles was started, the wear scar diameter began to drop as shown in figure 4.5. But the base oil with 0.75% concentration of MoS_2 is slightly higher than base oil without MoS_2. The nanoparticles react between the surfaces of friction-pair, limit their direct contact, and cover the asperities. The nanoparticles react with the base oil and the ambient atmosphere to form a protective layer on the surface (Mushtaq & Hanief, 2021). This layer serves as a barrier and avoids direct contact between the surfaces and reducing wear rate diameter. The highest wear scar diameter (2.825mm) was recorded for 0.75% concentration of nanoparticle at 60N while as the lowest wear scar diameter (0.75mm) was recorded at 0.5% concentration of nanoparticle at 20N. The wear scar diameter started to slightly increase as the weight ratio of nanoparticles was raised to 0.75% because there were too many nanoparticles present. As a result, the base oil's nanoparticle concentration of 0.5% weight ratio achieved the smallest wear scar diameter.

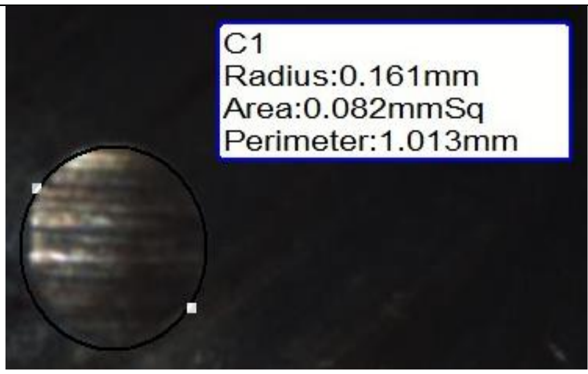
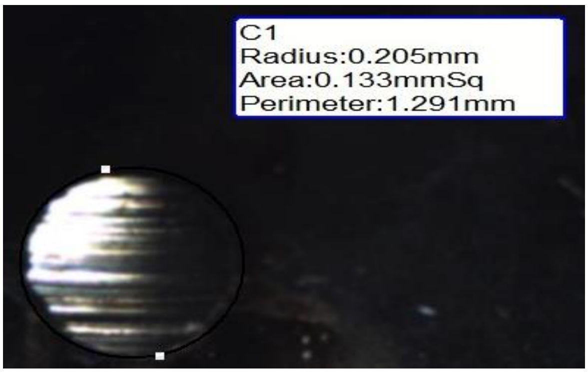
4.4 Optical images of ball bearing

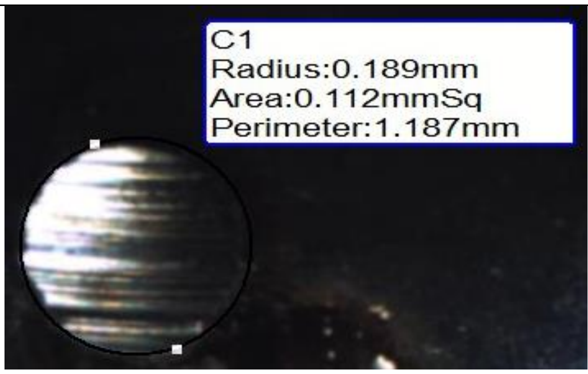
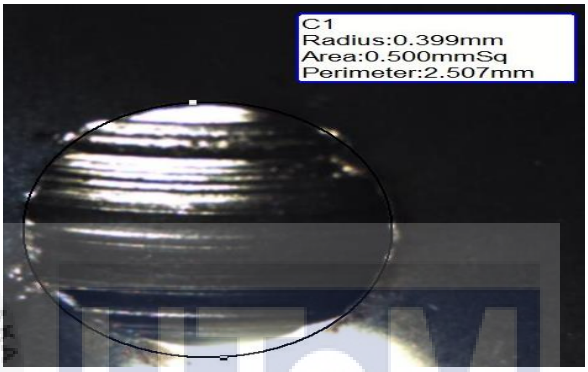
Table 4.3 Optical images of ball bearing at different oil composition and loads.

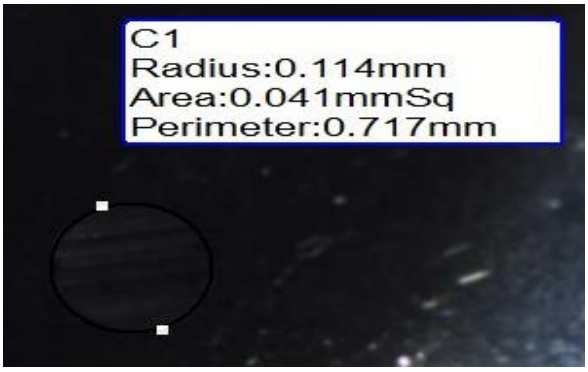
Oil sample	Load	Ball bearings
Base oil without MoS_2	20N	 

		
	40N	  

	60N	  
Base oil with 0.25% wt MoS_2	20N	

		C1 Radius:0.161mm Area:0.082mmSq Perimeter:1.013mm C1 Radius:0.144mm Area:0.065mmSq Perimeter:0.904mm
	40N	C1 Radius:0.171mm Area:0.092mmSq Perimeter:1.073mm C1 Radius:0.205mm Area:0.133mmSq Perimeter:1.291mm

		
	60N	  

<table>
<tr><td rowspan="2">Base oil with 0.5% wt MoS_2</td><td>20N</td><td>


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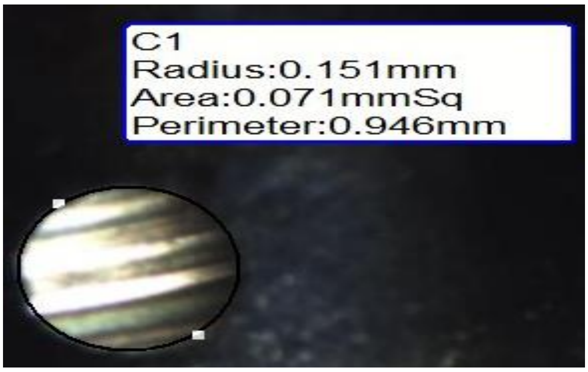
<tr><td>40N</td><td>


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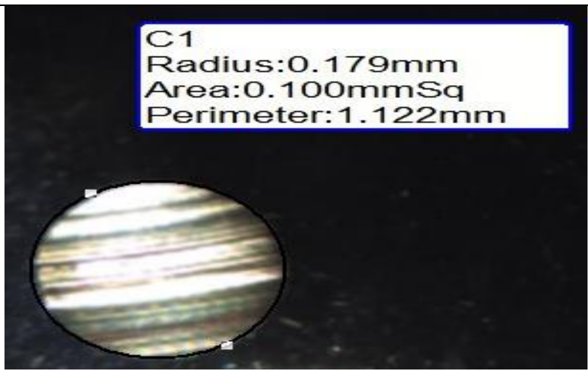
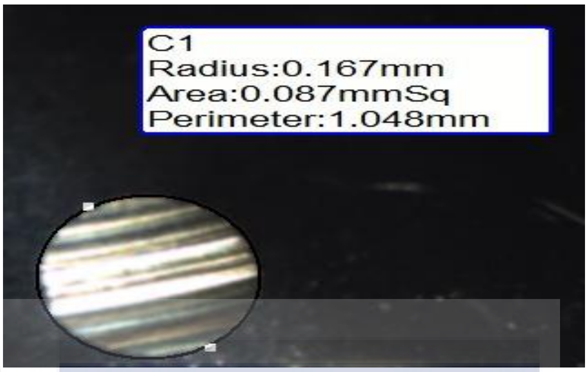
<tr><td></td><td></td><td>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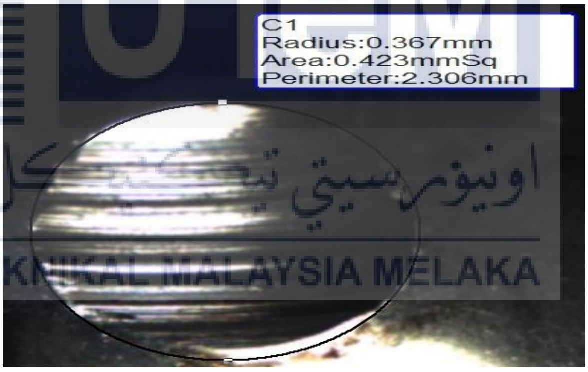
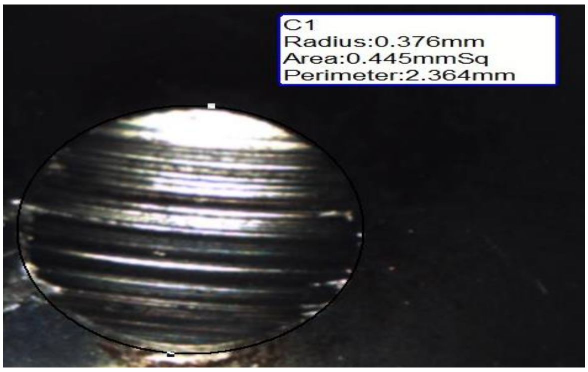
<tr><td></td><td>60N</td><td>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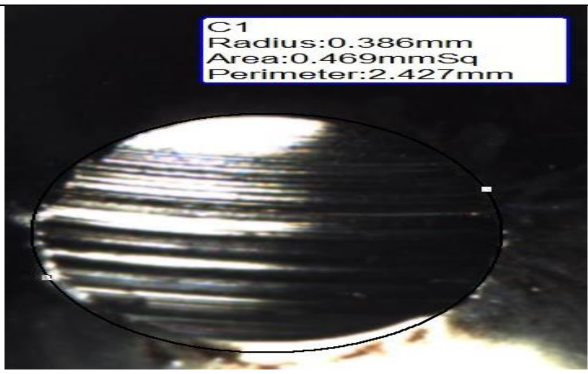
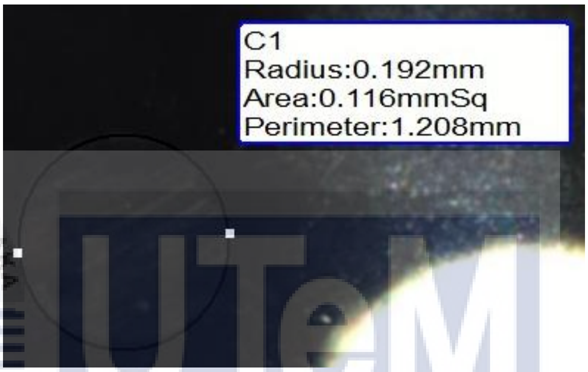
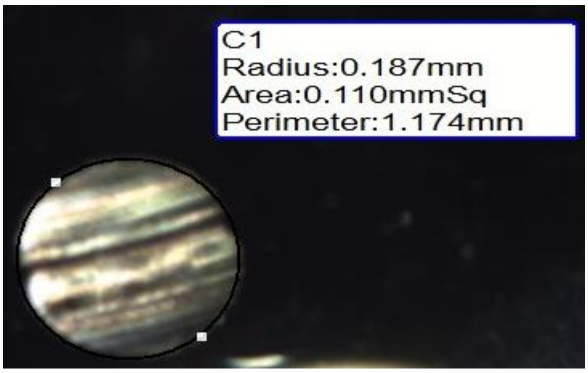
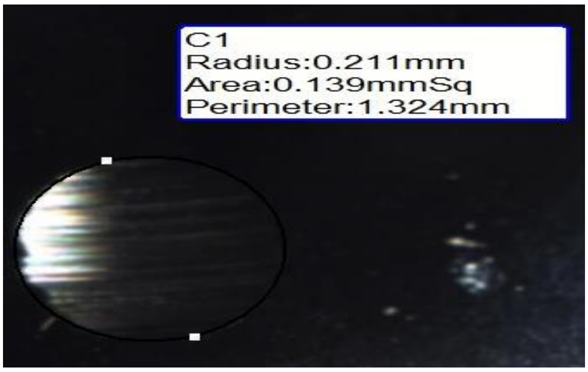
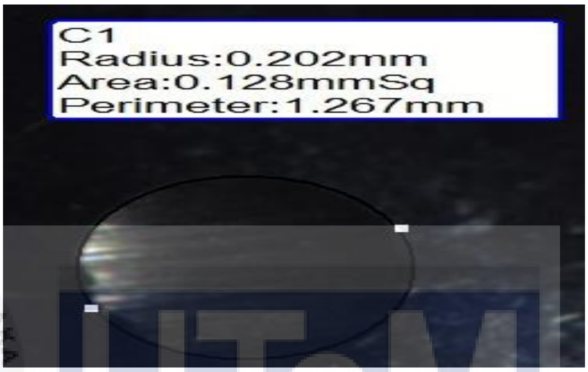
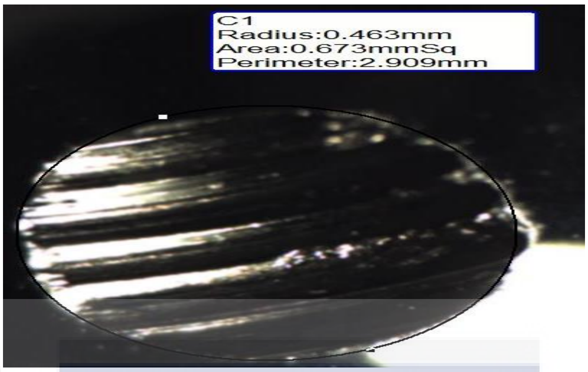
		
Base oil with 0.75% wt MoS_2	20N	  

	40N	 C1 Radius:0.211mm Area:0.139mmSq Perimeter:1.324mm  C1 Radius:0.202mm Area:0.128mmSq Perimeter:1.267mm  C1 Radius:0.191mm Area:0.115mmSq Perimeter:1.200mm
	60N	 C1 Radius:0.448mm Area:0.630mmSq Perimeter:2.815mm

The table 4.3 shows the optical images of ball bearing used to calculate the wear scar diameter on different oil samples and load. For each load, there are 3 different ball bearings optical images were captured. The wear scar diameter began to rise as the increasing load and the depth of scar are higher at 60N.

CHAPTER 5

CONCLUSION

5.1 Conclusion

The results given in this research demonstrate the ability of Molydenum Disulfide nano particles to reduced the base oil's resistance to wear and friction after being made from recycled waste oil. The four ball tester was lubricated with base oil both with and without MoS2 nanoparticles to measure wear and friction. It was discovered that the MoS2 nanoparticle was particularly good in reducing wear and friction. This was ascribed to the protective layer that formed on the steel ball bearing surface employed in the four ball tester by preventing metal-to-metal contact. For the least amount of friction and wear rate, MoS2 nanoparticle weight ratio was found to be 0.5wt%. Due to the nanoparticles' excessive presence, friction and wear rate started to rise after the concentration of nanoparticles was increased to 0.75wt%. With relation to an increasing load, the wear rate and friction increased.

The main objective for this study will look into how re-refined base oil interacts with and without additives to the sliding surface. Hence, the result obtained clearly stated that re-refined base oil with additives were found to be very effective compared to without additives. Every one of the objectives achieved successfully and concluded according to the outcomes of the data analysis. It was determined that base oil made from recycled waste oil had exceptional lubricating properties. which MoS2 nanoparticles can be added to improve. It may be an excellent alternative as lubricant to replace mineral oils and help maintain a clean, sustainable environment.

5.2 Recommendation

Re-refined oil sometimes is challenging by reaching exact tribological properties of base oil. Therefore, addtives are blend together with re-refined base stocks for getting a better tribological properties. According to the experiment, MoS2 can lessen the wear and friction characteristics in oil. This technique may be an excellent substitute for mineral oils in future lubricants and may help to maintain a sustainable and less dirty environment.

REFERENCES

Bhongade, M. O. (2019). Recent Methods Available for Recycling of Plastic Waste: A Review. *International Journal for Research in Applied Science and Engineering Technology*, *7*(8), 858–862. https://doi.org/10.22214/ijraset.2019.8127

Emam, E. A., & Shoaib, A. M. (2012). *Re-refining of Used Lube Oil, II- by Solvent/Clay and Acid/Clay-Percolation Processes*.

Infineum. (2018). Lubricant base stocks. *Infineum Insight*, https://www.infineuminsight.com/media/1814/3-lubri. https://www.infineuminsight.com/media/1814/3-lubricant-base-stocks-na.pdf

Infineum, F., Limited, I., & Stocks, B. (2021). *The rise of re-refining*. *August*, 1–5.

Joysula, S. K., Dube, A., Patro, D., & Veeregowda, D. H. (2021). On the fictitious grease lubrication performance in a four-ball tester. *Lubricants*, *9*(3). https://doi.org/10.3390/lubricants9030033

Makowski, Ł., Bojarska, Z., & Rożeń, A. (2022). Rheological Properties of Engine Oil with Nano-Additives Based on MoS2 Materials. *Nanomaterials*, *12*(4), 4–15. https://doi.org/10.3390/nano12040581

Mousavi, S. B., Heris, S. Z., & Estellé, P. (2020). Experimental comparison between ZnO and MoS2 nanoparticles as additives on performance of diesel oil-based nano lubricant. *Scientific Reports*, *10*(1), 1–17. https://doi.org/10.1038/s41598-020-62830-1

Mushtaq, Z., & Hanief, M. (2021). Friction and Wear Performance of Jatropha Oil Added with Molybdenum Disulphide Nanoparticles. *Smart Innovation, Systems and Technologies*, *213 SIST*, 715–722. https://doi.org/10.1007/978-981-33-4443-3_69

Puhan, D. (2020). Lubricant and Lubricant Additives. In A. Patnaik, T. Singh, & V. Kukshal (Eds.), *Tribology in Materials and Manufacturing*. IntechOpen. https://doi.org/10.5772/intechopen.93830

Rigo, J., & Kovačócy, P. (2018). Problems with Tribological Testings of Marketable Oils Using Laboratory Model Test Rigs. *Research Papers Faculty of Materials Science and Technology Slovak University of Technology*, *26*(42), 35–46. https://doi.org/10.2478/rput-2018-0004

Shashavali, S., Dev Singh, D., & Patil, A. (2021). Experimental investigation of tribological properties of TiO2nanoparticles in engine oil. *Materials Today:*

Proceedings, *46*(1), 883–889. https://doi.org/10.1016/j.matpr.2020.12.1120

Singh, C., Tiwari, S., & Yadav, G. (2017). Re-Refining of Automotive Lubricating Oil Using Wiped Film Evaporator. *INterNatIONal JOurNal Of ReSearch IN MechaNIcal ENgINeerINg & TechNOlOgy*, *7*, 130–133.

Yaqoob, H., Teoh, Y. H., Jamil, M. A., Rasheed, T., & Sher, F. (2020). An experimental investigation on tribological behaviour of tire-derived pyrolysis oil blended with biodiesel fuel. *Sustainability (Switzerland)*, *12*(23), 1–13. https://doi.org/10.3390/su12239975

APPENDICES

APPENDIX 1: Gantt Chart for PSM 1

YEAR		2022																	
#	PROJECT ACTIVITIES	MAR					APRIL					MAY				JUN			
A	BACHELOR DEGREE PROJECT 1	1	2	3	4		1	2		3	4	1		2	3	1	2	3	4
1	BRIEFING					COMPLETE CHAPTER 1			COMPLETE CHAPTER 2			MID SEM BREAK	COMPLETE CHAPTER 3						
2	GETTING TOPIC RELATED MATERIAL																		
3	CHAPTER 1																		
4	GETTING REQUIRED MATERIAL																		
5	CHAPTER 2 COMPLETION																		
6	CHAPTER 3 WRITING																		
7	CHAPTER 3 COMPLETION																		
8	PRELIMINARY FINDINGS																		
9	SUBMISSION FIRST DRAFT																		
10	TURNITIN CHECK																		
11	CORRECTION																		
12	FINAL DRAFT PSM 1																		
13	SLIDE PRESENTATION																		
14	PRESENTATION																		

APPENDIX 1: Gantt Chart for PSM 2

No	PROJECT ACTIVITIES	Plan/ Actual	Week 1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Writting Chapter 3	Plan														
		Actual														
2	Adding Literature Review	Plan														
		Actual														
3	Adding Methods in Chapter 3	Plan														
		Actual														
4	Adding Results in Chapter 4	Plan														
		Actual														
5	Submit the results	Plan														
		Actual														
6	Do discussion	Plan														
		Actual														
7	Do conclusion and recommendation	Plan														
		Actual														
8	Submit discussion, conclusion and recommendation	Plan														
		Actual														
9	Do correction of Chapter 4 and chapter 5	Plan														
		Actual														
10	Submit Full report of PSM 2	Plan														
		Actual														
11	Prepare for presentation of PSM 2	Plan														
		Actual														
12	Presentation for PSM 2	Plan														
		Actual														