EXPERIMENTAL EVALUATION ON THE TRIBOLOGICAL PROPERTIES OF PALM KERNEL OIL BY ADDING COPPER OXIDE NANOPARTICLE

MUHAMMAD AMIRRUL AMIN BIN MOEN

UNIVERSITI TEKNOLOGI MALAYSIA

EXPERIMENTAL EVALUATION ON THE TRIBOLOGICAL PROPERTIES OF PALM KERNEL OIL BY ADDING COPPER OXIDE NANOPARTICLE

MUHAMMAD AMIRRUL AMIN BIN MOEN

A dissertation submitted in partial fulfilment of the
requirement for the award of the degree of
Master of Science (*Mechanical Engineering*)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

JANUARY 2017

Praise be to Allah, the Lord of the Worlds

Who says (interpretation of the meaning):

"Give thanks to Me and your parents. Unto Me is the final destination"

[Quraan, Luqman 31: 14]

All glory and honor to Him

ACKNOWLEDGEMENT

First and foremost, I would like to thank the Almighty Allah for giving me the crucial time to successfully complete my Master Project thesis. I am indebted to my supervisor, Associate Professor Dr. Syahrullail bin Samion who has given me sufficient information, guidance, advices, knowledge and commitment upon completion of my Master Project thesis writing as well as experimentation procedures. I would to thank UTM's technician especially Mdm Nurul Jannah Alias and Mr. Sahlan Sadiron for helping and sharing a lot of valuable knowledges. I would like to thank other lecturers for their cooperation and help throughout the time. Finally, I would to thank my parents, siblings and friends for their supportive effort and moral advises. I would to thank to those who read this technical report, thank you for spending your precious time.

ABSTRACT

The usage of vegetable oils is favoured upon mineral oils due to its biodegradability and non-toxicity. Since the usage of mineral oils caused environmental pollution, vegetable oils are seen as the alternative for promoting a better environment. Nowadays, vegetable oils are seen as the perfect lubricant since it exhibits good properties of a lubricant such as high viscosity index, low volatility, good lubricity, high flash point and low evaporative loss. Through research, it is found that vegetable oils develop lower coefficient of friction and high wear rate. However, the vegetable oils performance unfavourably when it deals with high pressure condition. Thus, nanoparticle is added as it serves as anti-wear additive. In this research, Palm Kernel Oil (PKO), Palm Olein (PO), Palm Kernel Oil + Copper Oxide Nanoparticle (PKO-CuO), Mineral Oil (SAE-40), Synthetic Oil (SAE15W-50, Syntium 1000) and Semi-Synthetic Oil (SAE15W-50, Syntium 800) are used as lubricant to be evaluated its tribological behaviours using fourball tribotester machine. The objectives of the research are to determine the coefficient of friction and wear characteristics at two different analysis, a) Standard Load Test conforming ASTM D4172 and b) Extreme Pressure Condition conforming ASTM D2783. The results are presented in many findings such as coefficient of friction (COF), wear scar diameter (WSD), surface roughness (Ra) and worn surface observation. For Standard Load Test, PKO-CuO shows better performance compared to Synthetic and Semi Synthetic Oil. However, under extreme pressure test vegetable oils shows bad performance. Among vegetable oils, PKO-CuO shows better performance as it fails at higher load. Hence PKO-CuO have promising lubricant trait and can be used as lubricant.

ABSTRAK

Penggunaan minyak sayuran lebih disenangi berbanding minyak mineral berdasarkan kebolehannya untuk mengurai dan tidak toksik. Memandangkan penggunaan minyak mineral menyebabkan pencemaran alam sekitar, minyak sayuran dilihat sebagai alternative untuk menggalakkan perkembangan alam sekitar yang lebih baik. Pada masa kini, minyak sayuran dilihat sebagai pelincir sempurna memandangkan ia mempamerkan ciri-ciri bagus untuk pelincir seperti indeks kelikatan yang tinggi, kemeruapan yang rendah, pelinciran yang baik, takat kilat yang tinggi dan kadar menguap yang rendah. Berdasarkan penyelidikan, penemuan mengatakan bahawa minyak sayuran membangunkan pekali geseran yang rendah dan kadar kehausan yang tinggi. Walaubagaimanapun, prestasi minyak sayuran tidak memihak apabila diletakkan dalam keadaan tekanan tinggi. Jadi, partikel nano ditambah sebagai aditif anti-haus. Dalam penyelidikan ini, Palm Kernel Oil (PKO), Palm Olein (PO), Palm Kernel Oil + Copper Oxide Nanoparticle (PKO-CuO), Mineral Oil (SAE-40), Synthetic Oil (SAE15W-50, Syntium 1000) dan Semi-Synthetic Oil (SAE15W-50, Syntium 800) telah digunakan untuk dikenalpasti tingkah laku tribology dengan menggunakan mesin fourball tribotester. Objektif penyelidikan ini adalah untuk mengenal pasti pekali geseran dan ciri-ciri haus pada dua analisis yang berbeza, a) Standard Load Test mematuhi ASTM D4172 dan b) Extreme Pressure Condition mematuhi ASTM D2783. Keputusan ditunjukkan dalam pelbagai bentuk termasuklah pekali geseran, diameter parut haus, kekasaran permukaan and pemerhatian permukaan haus. Untuk Standard Load Test, PKO-CuO menunjukkan prestasi yang lebih baik berbanding minyak Synthetic dan Semi Synthetic. Walaubagaimanapun, dibawah analisis Extreme Pressure Test minyak sayuran menunjukkan prestasi yang buruk. Antara minyak sayuran, PKO-CuO menunjukkan prestasi yang baik memandangkan ia gagal pada beban yang lebih tinggi. Oleh itu, PKO-CuO diakatakan mempunyai ciri pelincir dan sesuai digunakan sebagai pelincir.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

PKO	-	Palm Kernel Oil
SAE	-	Standard of Automotive Engineer
ASTM	-	American Society of Testing of Material
PO	-	Palm Olein

ACKNOWLEDGEMENTS

First and foremost, I would like to thank the Almighty Allah for giving me the crucial time to successfully complete my Master Project thesis. I am indebted to my supervisor, Associate Professor Dr. Syahrullail bin Samion who has given me sufficient information, guidance, advices, knowledge and commitment upon completion of my Master Project thesis writing as well as experimentation procedures. I would to thank UTM's technician especially Mdm Nurul Jannah Alias and Mr. Sahlan Sadiron for helping and sharing a lot of valuable knowledges. I would like to thank other lecturers for their cooperation and help throughout the time. Finally, I would to thank my parents, siblings and friends for their supportive effort and moral advises. I would to thank to those who read this technical report, thank you for spending your precious time.

ABSTRACT

The usage of vegetable oils is favoured upon mineral oils due to its biodegradability and non-toxicity. Since the usage of mineral oils caused environmental pollution, vegetable oils are seen as the alternative for promoting a better environment. Nowadays, vegetable oils are seen as the perfect lubricant since it exhibits good properties of a lubricant such as high viscosity index, low volatility, good lubricity, high flash point and low evaporative loss. Through research, it is found that vegetable oils develop lower coefficient of friction and high wear rate. However, the vegetable oils performance unfavourably when it deals with high pressure condition. Thus, nanoparticle is added as it serves as anti-wear additive. In this research, Palm Kernel Oil (PKO), Palm Olein (PO), Palm Kernel Oil + Copper Oxide Nanoparticle (PKO-CuO), Mineral Oil (SAE-40), Synthetic Oil (SAE15W-50, Syntium 1000) and Semi-Synthetic Oil (SAE15W-50, Syntium 800) are used as lubricant to be evaluated its tribological behaviours using fourball tribotester machine. The objectives of the research are to determine the coefficient of friction and wear characteristics at two different analysis, a) Standard Load Test conforming ASTM D4172 and b) Extreme Pressure Condition conforming ASTM D2783. The results are presented in many findings such as coefficient of friction (COF), wear scar diameter (WSD), surface roughness (Ra) and worn surface observation. For Standard Load Test, PKO-CuO shows better performance compared to Synthetic and Semi Synthetic Oil. However, under extreme pressure test vegetable oils shows bad performance. Among vegetable oils, PKO-CuO shows better performance as it fails at higher load. Hence PKO-CuO have promising lubricant trait and can be used as lubricant.

ABSTRAK

Penggunaan minyak sayuran lebih disenangi berbanding minyak mineral berdasarkan kebolehannya untuk mengurai dan tidak toksik. Memandangkan penggunaan minyak mineral menyebabkan pencemaran alam sekitar, minyak sayuran dilihat sebagai alternative untuk menggalakkan perkembangan alam sekitar yang lebih baik. Pada masa kini, minyak sayuran dilihat sebagai pelincir sempurna memandangkan ia mempamerkan ciri-ciri bagus untuk pelincir seperti indeks kelikatan yang tinggi, kemeruapan yang rendah, pelinciran yang baik, takat kilat yang tinggi dan kadar menguap yang rendah. Berdasarkan penyelidikan, penemuan mengatakan bahawa minyak sayuran membangunkan pekali geseran yang rendah dan kadar kehausan yang tinggi. Walaubagaimanapun, prestasi minyak sayuran tidak memihak apabila diletakkan dalam keadaan tekanan tinggi. Jadi, partikel nano ditambah sebagai aditif anti-haus. Dalam penyelidikan ini, Palm Kernel Oil (PKO), Palm Olein (PO), Palm Kernel Oil + Copper Oxide Nanoparticle (PKO-CuO), Mineral Oil (SAE-40), Synthetic Oil (SAE15W-50, Syntium 1000) dan Semi-Synthetic Oil (SAE15W-50, Syntium 800) telah digunakan untuk dikenalpasti tingkah laku tribology dengan menggunakan mesin fourball tribotester. Objektif penyelidikan ini adalah untuk mengenal pasti pekali geseran dan ciri-ciri haus pada dua analisis yang berbeza, a) Standard Load Test mematuhi ASTM D4172 dan b) Extreme Pressure Condition mematuhi ASTM D2783. Keputusan ditunjukkan dalam pelbagai bentuk termasuklah pekali geseran, diameter parut haus, kekasaran permukaan and pemerhatian permukaan haus. Untuk Standard Load Test, PKO-CuO menunjukkan prestasi yang lebih baik berbanding minyak Synthetic dan Semi Synthetic. Walaubagaimanapun, dibawah analisis Extreme Pressure Test minyak sayuran menunjukkan prestasi yang buruk. Antara minyak sayuran, PKO-CuO menunjukkan prestasi yang baik memandangkan ia gagal pada beban yang lebih tinggi. Oleh itu, PKO-CuO diakatakan mempunyai ciri pelincir dan sesuai digunakan sebagai pelincir.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Vegetable oils mainly divided into two types which are edible oil and non-edible oil. As the time moves forward, vegetable oils used in many industries for cooking purpose and etc. Since it has can adapt with extreme conditions, vegetable oils are used not only for culinary, it also being applied to the lubrication side. Basically, vegetable oils are mostly used for food processing such as food machinery lubricants, agriculture machinery as hydraulic oil for tractor, cutting machinery as coolant and etc. Since Malaysia is one of the biggest palm oil producer, palm oil has been manipulated drastically as cooking oil. Due to its abundant supply, many research has been done by the researchers to exploit the palm oil. Basically, palm oil is favoured upon the petroleum-based-lubricant since it carries many advantages for lubrication purposes.

The reason of vegetable oils favoured upon petroleum-based-lubricant because it is biodegradable, high lubricity, and high viscosity index meanwhile petroleum-based-lubricant is toxic to the environment and difficult to dispose of after use. The dependency on the petroleum-based stock caused environmental problem and pollutions. Vegetable oils have the capability to contribute towards the goal of energy independence and the continuity of non-renewable resource. Since it has high content of oleic acid, vegetable oils has the great potential to substitute the petroleum-based-stock in lubrication industries.

In Malaysia, vegetable oils like palm oil is being produced abundantly. Palm oil is known as it used for cooking but in the meantime it is being manipulated. Palm oil can be categorize as one of edible oils that has been broadly developed to be used as lubricant. Palm oil plant is originated from West African tropical rain forest and scientifically it is known as *Elaeis guinensis*. Palm oil has been harvested for its oil. Palm oil comes from the family of coconut whereby it shows the highest content of vegetable fat. From its physical condition, palm oil exist as semi solid in room temperature due to its saturated and unsaturated fats content. From the historical perspective, palm oil has been used since Egyptian times when the archaeologies found its trace in earthenware jar back dated 5000 years ago. Palm oil has been used from time to time. Since the usage of palm oil is flexible and cheap, it was manipulated during industrial revolution in 19^{th} century in Europe as a lubricant.

The usage of palm oil is favourable compared to petroleum-based-lubricant since it is biodegradable and non-toxic. Palm oil is chosen over mineral because it exhibits most properties needed for a good lubricant, such as high index viscosity, low volatility, good lubricity, high flash point and low evaporative loss.

1.2 Background of Research

Lubricant is a crucial element when there is moving surface between to metal to prevent friction, wear, reduce heat and etc. Lubricity of fluid property that reduces the friction and or wear in mechanical system. Besides, function of lubricants also to collect foreign particles such soot in combustion chamber or metal chip causes by friction or wear and reduce engine from heat. Basically, lubricants are classified into a few groups, such as mineral lubricants, synthetic lubricants, bio-lubricants and solid lubricants.

In the early days of human civilization, the lubrication using oils has been practically used. Since the environmental awareness awake in the society, the usage of mineral oils has been substituted to the vegetable oils. Vegetable oils is favoured upon mineral oil since they are wholly biodegradable, non-toxic and environmental

friendly. Indeed, vegetable oils exhibit the properties of a good lubricant, such as good contact lubrication, high viscosity index, high flash-point and low volatility. The usage of mineral-based-stock creates several environmental problems such as pollutions and depletion of natural resources. Vegetable oils provide intrinsically strong lubricating film and as such possess higher lubrication properties than conventional mineral oil. Vegetable oils work effectively as a boundary lubricants since the high polarity of the entire base oil allows strong interactions with lubricated surfaces. Although it acts as a good lubricant, vegetable oils still has a few weaknesses such as poor oxidation stability and less effective at high load. With the current interest in lubricants from renewable sources, studies of vegetable-oil-based lubricants and means of predicting their performance are important.

Palm oil finds mention as lubricant among other widely used vegetable oils such as olive oil, rapseed oil. Palm oil shows good lubricating properties such as high viscosity index, good lubricity, high flash point and low evaporative loss. One of the weakness spotted on the usage of palm oil is that, wear rate is higher compared to the mineral oil. Palm oil has a very high pour point because of its high content of saturated fatty acids. Vegetable oil lubricates effectively under boundary lubrication mode.

Tribology is the study of friction, wear and lubrication at macro level. Nanotribology revolves on the lubricant and the surface that are contacting each other at macro and micro level. The term of nanolubricant used in the research shows a lubricant which being infused with nanoparticles. In this present study, nanolubricant is used to represent the palm oil with copper oxide (CuO) nanoparticles as the additive. Many researches had been done on the tribological properties of lubricants with different nanoparticles added. A few researchers reported that by adding the nanoparticles into lubricant, wear and friction is reduced effectively. Due to good performance of lubrication and tribological properties, nanoparticles have been regarded as excellent candidates to traditional EP and AW additives. Theoretically, the friction-reduction and anti-wear performance depends on the size, shape and concentration of the nanoparticles. The commonly size used for any research has been mostly in the range of 20 – 150 nm.

The objective of the present study is to evaluate the tribological properties of palm oil by the addition of CuO nanoparticles. In this study, there are another lubricants used as the benchmark to be compared with the nanolubricant, such as SAE-40, fully-synthetic, semi-synthetic and palm olein.

1.3 Problem Statement

Modern world created by human induced a lot of environmental damages and pollutions to the earth. The utilization and usage of non-renewable resource like petroleum and fossil fuels contribute to air and water pollution and hence it affect the other life organisms like humans, animal, plant and other aquatic plant. Petroleum is a form of liquid that naturally occur from decomposition of animal and sea plant that buried underneath of thousand meter of silt, sand or mud. The formation of petroleum took millions of years of decomposition process. It consist complex mixture of element formed by hydrocarbons with trace other impurities such as sulphur.

The usage of petroleum resulted in the removal of harmful wastes and products. The harmful wastes affect and disrupt the balance in environment. The hydrocarbon products from the petroleum are deadly to many living organisms including humans due to its toxicity. Petroleum that derived beneath earth not only contain useful element, it also contain trace of sulphur and nitrogen element. The increment of sulphur and nitrogen in the air increase the level toxicity, in which it is not favourable to any living organisms. As earth becomes more polluted, human tend to increased their awareness regarding environmental and health issue, society put an extra effort to replace or reduce the usage of conventional petroleum based lubricant.

Pollution caused by petroleum can be reduced by using vegetable oils as the alternative. Since vegetable oils is flexible, it can be used to substitute the petroleum and it is applicable for many industries like automotive. Vegetable oils is favoured upon petroleum because it is renewable, environmental friendly and biodegradable, thus make it as another alternative to replace the conventional lubricant.

Furthermore, the most important aspect is vegetable oil can be consider non-toxic to human health. In Malaysia, richness of the palm oil has potential to develop and used it as alternative lubricant.

The usage of vegetable oil instead of mineral oil shows lower coefficient of friction. However, vegetable oils behave unfavourably when it deals with high pressure. It cannot produce a good protective film at high load and temperature. The performance of vegetable oils can be treated by the addition of nanoparticles. A few researches have been made and found that the addition of nanoparticles displayed good wear and friction reduction characteristics. Due to good performance of lubrication and tribological properties, nanoparticles have been regarded as excellent candidates to traditional EP and AW additives.

1.4 Objectives of Research

The main purpose of this research is to develop the mixture of palm kernel oil and cupper nanoparticle as a lubricant tested under extreme pressure condition and the sub-objectives of the research are shown as below:To investigate the lubrication effect of copper nanoparticle addition into palm kernel oil

a) To determine the coefficient of friction and wear characteristic of the mixture of palm kernel oil with copper nanoparticle using fourball tribotester conforming ASTM D4172 – 94 (2010).

b) To investigate the ability of the mixture of palm kernel oil with copper nanoparticles to run under extreme pressure conforming ASTM D2783 – 03 (2014).

1.5 Scope and Limitation of Research

Malaysia is one of the largest palm oil around the globe. The main purpose of the research is to test the ability of palm kernel oil to lubricate between contacting surfaces and serves as the alternatives for petroleum-based-lubricant. The lubrication performance of palm kernel oil also being test with the addition of copper oxide nanoparticles. Following are the scope of study and limitation of the research:

a) Palm kernel oil used as lubricant in this research.

b) Copper oxide (CuO) nanoparticle, size 40nm used as the additive in palm kernel oil.

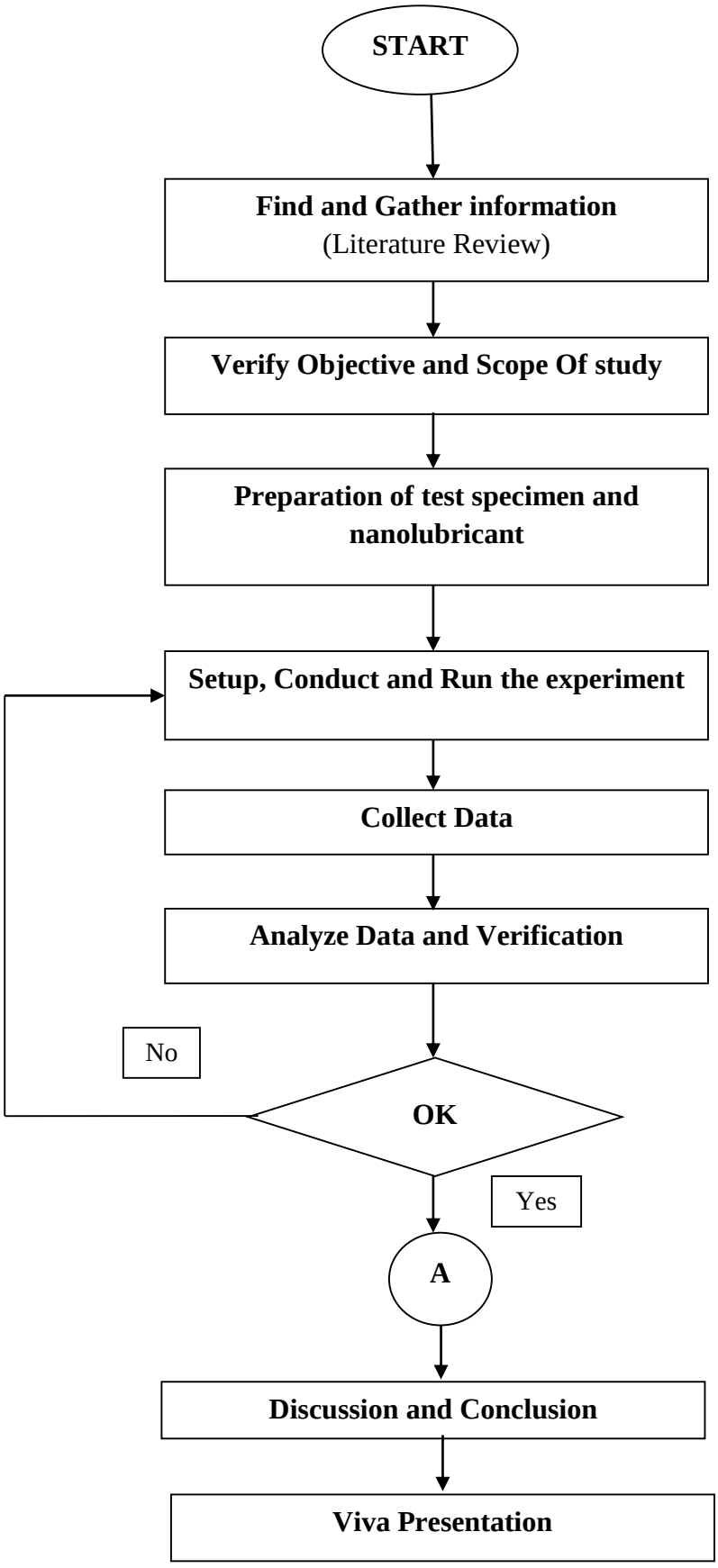
c) The weight percentage of CuO added into palm kernel oil is 0.34 wt%.

d) Research for normal load condition will follow ASTM D4172-94(2010) standard with normal load (40 kg), spindle speed (1200 RPM), operating lubricant temperature (75 ℃) and run for 60 minutes.

e) Performance of palm kernel oil are tested under extreme pressure follow ASTM D2783-03 (2014) standard with load starting from 120 kg and increase until wear scar diameter reach 4 mm, operating lubricant temperature (35 ℃) and run for 10 second for each load.

1.6 Project Outline

The project flow chart shows the outline of the research starting from the literature review until documentation process. Project flow chart is used as a visual aid to give a clearly understand about the project management methodology. Figure 1.1 shows the step taken in order to achieve the main objectives.


START
Find and Gather information
(Literature Review)
Verify Objective and Scope Of study
Preparation of test specimen and nanolubricant
Setup, Conduct and Run the experiment
Collect Data
Analyze Data and Verification
No
OK
Yes
A
Discussion and Conclusion
Viva Presentation

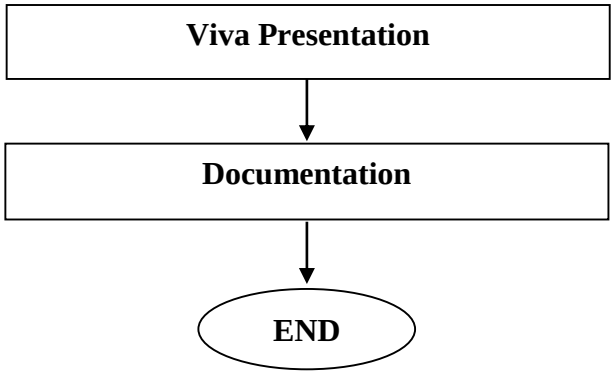


Figure 1.1 : Project Outline

1.7 Thesis Outline

There are five chapters organized in this thesis, the brief explanation for each chapter are shown as follow:

a) Chapter 1 gives the comparison between vegetable oils and petroleum-based-lubricant. This chapter presents a general research background, problem statement, objectives, scope and limitation, project flow chart and the organization of this thesis.

b) Chapter 2 discusses and review the past and current work made by a lot of researchers. This chapter is mainly being divided into 3 main sections. First section mainly revolves on the concept of tribology and lubrication. Second section discusses on the vegetable oils and its properties. Third section discusses on nanolubricant.

c) Chapter 3 explains on the method of preparation of nanolubricant, physical test analysis and method of conducting the standard load test and extreme pressure test. Besides that, all assumptions and calculations are also explained in detail.

d) Chapter 4 explains on all the results based on the coefficient of friction, wear characterisctics, wear scar diameter and surface roughness; and discuss in detail about the results that are obtained and collected throughout this investigation. Then, the results are then presented in graph and tables for a clearer view and understanding.

e) Chapter 5 includes the conclusions obtained along this study. Last but not least, in this chapter also presents the recommendations for further research and future work based on the analysis and evaluation proposed method of the experiment.

1.8 Significant of Research

The development of the world towards a modern life leads to many pollutions and depletion of natural resources like fossil fuel. Normally, half usage of lubricants turn out into environment because lack of awareness and high cost for proper disposal of lubricant. The usage of mineral oils lubricant which is being manufactured from petroleum fraction is lethal to the environment. The removal of waste product petroleum based lubricant is hazardous and poor degradability. In order keep the balance in the ecosystem, government promotes any environmental friendly product. The establishment of environmental friendly product like vegetable oils can conserve the environment.

The enhancement made in lubrication industry is very important since it reduced wear and friction problem that moving part experience until now. Thus, modified vegetable oil selected as based oil for engine lubrication for keep the wear and friction at minimum level as possible. The development of vegetable oils with the right formulation might serve as new apprentice in lubrication and automotive industries. The good performance of lubricant in reducing coefficient of friction and wear contribute to a longer life span of moving components and hence reduce the cost for maintenance.

The lubricant used for this research is palm kernel oil. As Malaysia is second world largest producers of palm oil now after Indonesia over the first ranking, there is abundant supply of palm oil throughout the time. The development of palm oil as lubricant can reduce the environment pollution. Currently, palm oil has been manipulated by adding additive so that it can be used as biodiesel for combustion in engine oil. The development of palm kernel oil in lubrication acts as one of the trusted alternative in the mechanical system whereby it promotes safer environment.

REFERENCES

[1] Blau PJ. Friction science and technology: from concepts to application. Taylor and Francis Group/CRC Press; 2009.

[2] Demydov D, Adhvaryu A, McCluskey P, Malshe AP. Advanced lubricant additives of dialkyldithiophosphate (DDP)-functionalized molybdenum sulfide nanoparticles and their tribological performance for boundary lubrication. In: Nanoscale materials in chemistry: environmental applications. American Chemical Society; 2010. p. 137-63.

[3] Holmberg K, Andersson P, Erdemir A. Global energy consumption due to friction in passenger cars. Tribol Int 2012;47(0):221-34.

[4] Choi Y, Lee C, Hwang Y, Park M, Lee J, Choi C, Jung M. Tribological behavior of copper nanoparticles as additives in oil. Curr Appl Phys 2009;9(2 Supplement):e124-7.

[5] Mortier RM, Fox MF, Orszulik ST. Chemistry and technology of lubricants. 3rd ed. Springer; 2010.

[6] Chapter 3-lubricants and their composition. In: StachowiakGW, BatchelorAW, editors. Engineering tribology. 4th ed. Boston: Butterworth-Heinemann; 2014. p. 51-104.

[7] Joly-Pottuz L, Dassenoy F, Vacher B, Martin JM, Mieno T. Ultralow friction and wear behaviour of Ni/Y-based single wall carbon nanotubes (SWNTs). Tribol Int 2004;37(11e12):1013-8.

[8] Joseph, M.P., Waleska, C. and David, E.W. ‘‘The effect of chemical structure of basefluids on antiwear effectiveness of additives’’, Tribology International, 38, pp. 321–326 (2005).

[9] Mobarak, H. M., Mohamad, E. N., Masjuki, H. H., Kalam, M. A., Mahmud, K. A. H. Al, Habibullah, M., & Ashraful, A. M. (2014). The prospects of biolubricants as alternatives in automotive applications. *Renewable and Sustainable Energy Reviews*, *33*, 34–43.

[10] Erhan, S.Z., Sharma, B.K. & Perez, J.M., 2006. Oxidation and low temperature stability of vegetable oil-based lubricants. , 24, pp.292–299.

[11] Delgado, M.A., Quinchia, L.A. and Galegos, C. ‘‘Viscosity modification of different vegetable oil with EVA copolymer for lubricant applicants’’, Industrial Crops and Products, 32, pp. 607–612 (2010).

[12] Alves SM,Barros BS,Trajano MF,Ribeiro KSB,Moura E.Tribological behaviour of vegetable oil-based lubricants with nanoparticles of oxides in boundary lubrication conditions.TribolInt2013;65:28–36.

[13] Ing, T. C., Rafiq, A. K. M., Azli, Y., & Syahrullail, S. (2012). Sharif University of Technology Tribological behaviour of refined bleached and deodorized palm olein in different loads using a four-ball tribotester. *Scientia Iranica*, *19*(6), 1487–1492.

[14] Kalin, M. and Vizintin, J. ‘‘A comparison of the tribology behaviour of steel/steel, steel/DLC and DLC/DLC contacts when lubricated with mineral and biodegradable oil’’, Wear, 261, pp. 22–31 (2006).

[15] Bowden, F.P. and Tabor, D. ‘‘The nature of metallic wear’’, In The Friction and Lubrication of Solids, In Oxford Classic Texts, pp. 285–298, Oxford University Press, New York (2001).

[16] Syahrullail, S., Kamitani, S., & Shakirin, A. (2013). Performance of Vegetable Oil as Lubricant in Extreme Pressure Condition. Procedia Engineering, 68(0), 172-177

[17] Jayadas, Ajithkumar G, (2007). "Tribological evaluation of coconut oil as an environmental friendly lubricant," Tribology International, vol. 40, pp. 350-354.

[18] Sharma, Y., Singh, B., An ideal feedstock for preparation of biodiesel : Optimization of Parameters. Fuel 2010;89:1470-4

[19] Karaosmanoglu, F., Tuter, M., Yanmaz, S., Altintig, E. Fuel Properties of Cotton Seed Oil. Energy Sources 1999; 21:821-8.

[20] Usta, N., Aydogan, B., Uguzdogan, E., Ozkal, S. Properties and Quality Verification of Biodiesel Produced from Tobacco Seed Oil. Energy Convers Manag 2011;52:2031-9

[21] Singh, D., Singh, S. Low Cost Production of Ester from Non-edible of Argemone Mexicana. Biomass Bioenergy 2010;34:545-9

[22] Wang, R., Hanna, M., Zhou, W., Bhadury, P., S., Chen, Q., Song, B., A. Production and Selected Fuel Properties of Biodiesel from Promising Non-Edible: Euphorbia lathyris L., Sapiumsebiferum L. and Jatrophacurcas L. Bioresour Technol 2011;102:1194-9

[23] Li X. Wang YD., Enzymatic Production of Biodiesel from Pistacia Chinesis Seed using Immobilized Lipase. Fuel 2012;92:89-93.

[24] Wang R, Zhou W, Hanna M, Biodiesel Preparation, Optimization and Fuel Properties from Non-Edible Feedstock. Fuel 2012;91:182-6

[25] Mofijur M., Masjuki H., Kalam A., Hazrat A., Liaquat M., Shahabuddin M., Prospect of Biodiesel from Jatropha in Malaysia. Renew Sustain Energy Rev 2012;16:5007-20.

[26] S.A.Lawal, 2012. Application of vegetable oil-based metalworking fluids in machining ferrous metals: A review. International Journal of Machine Tools & Manufacture, 52, pp.1-12.

[27] Husnawan, M., Saifullah, M.G. & Masjuki, H.H., 2007. Development of friction force model for mineral oil basestock containing palm olein and antiwear additive. Tribology International, 40(1), pp.74–81.

[28] Bergert, D. L. (2000). Management Strategies of Elaeis Guineensis (Oil Palm) in Response to Localized Markets in South Eastern Ghana, West Africa. (Master of Science in Forestry), Michigan Technological University.

[29] Rasiah, R. and Shahrin, A. (2001). Development of Palm Oil and Related Products in Malaysia and Indonesia.

[30] Sime Darby (2014). Palm Oil Facts & Figures. Retrieved April 2015, from Sime Darby Plantation, http://www.simedarbyplantation.com/upload/Palm-Oil-Facts-and-Figures.pdf

[31] MPOC (2011). The Oil Palm Tree. Retrieved May 2015, http://www.mpoc.org.my/The_Oil_Palm_Tree.aspx

[32] Razak, D. M., Syahrullail, S., Sapawe, N., Azli, Y., & Nuraliza, N. (2014). A New Approach Using Palm Olein, Palm Kernel Oil, and Palm Fatty Acid Distillate as Alternative Biolubricants: Improving Tribology in Metal-on-Metal Contact. *Tribology Transactions, 58*(3), 511-517.

[33] Musa, J. J. (2009). Evaluation of the Lubricating Properties of Palm Kernel Oil. *Leonardo Electronic Journal of Practices and Technologies*, 107-114.

[34] Ojolo, S. J., Ohunakin, O. S. (2011). Study of Rake Face Action on Cutting Using Palm-Kernel Oil as Lubricant. *Journal of Emerging Trends in Engineering and Applied Sciences*, 2(1), 30-35.

[35] Calhoun, S.F., 1960. Antiwear and extreme pressure additives for greases. Tribol. Trans. 3, 208–214.

[36] Hernandez Battez A., González R., Felgueroso D., Fernández E., Rocio Fernández R., García MA, et al. Wear Prevention Behaviour of Nanoparticle Suspension Under Extreme Pressure Conditions. Wear 2007;263:1568-5747.

[37] Ma S, Zheng S, Cao D, Guo H. Anti-wear and friction performance of ZrO_2 nanoparticles as lubricant additive. Particuology 2010;8:468-72.

[38] Wu YY., Kao MJ., Using TiO_2 Nanofluid Additive For Engine Lubrication Oil. Industrial Lubrication and Tribology 2011;63(6):440-5

[39] Peng DX ,Kang Y, Hwang RM,Shyr SS,ChangYP. Tribological Properties of Diamond and SiO_2 Nanoparticles Added in Paraffin. Tribology International 2009;42:911–7.

[40] Hernandez Battez A, González R, Viesca JL, Fernández JE, Dias Fernández JM, Machado A,et al.CuO, ZrO2 and ZnO Nanoparticles as Antiwear Additive in Oil Lubricants. Wear 2008;265:422–8.

[41] Battez AH, Viesca JL, Gonzalez R, Blanco D, Friction Reduction Properties of CuO Nanolubricant as Lubricant for Ni Coating. Wear 2010;268:325-8

[42] Tarasov S, Kolubaev A, Belyaev S, Lerner M, Tepper F. Study of Friction Reduction by Nano Copper Additives to Motor Oil. Wear 2002;252:63–9.

[43] Hern, A., Gonz, R., Viesca, J. L., Fern, J. E., Machado, A., Chou, R., & Riba,J.(2008). CuO , ZrO_2 and ZnO nanoparticles as antiwear additive in oil lubricants, 265, 422–428.

[44] A.H. Battez, Viesca, R., Gonza'lez D, Friction Reduction Properties of a CuO nanolubricant used as Lubricant for a NiCrBSi Coating, Wear 268(2010) 325-328.

[45] Zhang, M., Wang, X., Liu, W., Fu, X., 2009. Performance and antiwear mechanism of Cu nano-particles as lubricating additives. Ind. Lubr. Tribol. 61 (6), 311–318.

[46] Z.Y.Xu,K.H.Hu,C.L.Han,X.G.Hu,Y.F.Xu,Morphological influence of molybdenum disulfide on the tribological properties of rapeseed oil,Tribol. Lett. 49(2013)513–524.

[47] M.V. Thottackkad, R.K Perikinalil, P.N. Kumarapillai, Experimental Evaluation on the Tribological Properties of Coconut by the Addition of CuO nanoparticles, Int. J. Precis. Eng. Manuf. 13(2012)111-116.

[48] S.M. Alves, B.S. Barros, M.F. Trajano, K.S.B. Ribeiro, E.Moura, Tribological Behaviour of Vegetable Oil-based Lubricants with Nanoparticles of Oxides in Boundary Lubrication Conditions, Tribol. Int. 65(2013)28-36.

[49] Zulkifli, N. W. M., Kalam, M. A., Masjuki, H. H., & Yunus, R. (2013). Experimental Analysis of Tribological Properties of Biolubricant with Nanoparticle Additive. Procedia Engineering, 68(0), 152-157.

[50] Choi, B. G. A. U. S., Kwon, O. K., Chunt, Y. J.(1997) "Tribological behaviour of some antiwear additives in vegetable oils," Tribology International, vol. 30, pp. 677-683.

[51] Zaslavsky, R. N. Z. YU. S., Berlin, A. A., Cherkashin, M. I., Beloserova, K. E. & Rusakova, V. A. (1971). "Anti-wear, Extreme pressure and antifriction action of friction polymer forming additives," wear, vol. 20, pp. 287-297.

[52] Liaquat, A., Masjuki, H., Kalam, M., & Rasyidi, A. (2012). Experimental analysis of wear and friction characteristics of Jatropha oil added lubricants. Paper presented at the Applied Mechanics and Materials.

[53] Peng DX,Kang Y,Hwang RM,ShyrSS, ChangYP. Tribological properties of diamond andSiO2 nanoparticles added inparaffin. Tribology International 2009;42:911–7

[54] American Society for Testing and Materials (2010). ASTM D4172-94. Pennsylvania: ASTM International

[55] Mustafa M.M.B., Masripan N.A.B., Abdollah M.F.B., & Basiron J. (2015). Preliminary study on Tribological properties of banana peel broth as additive in paraffin oil. Proceedings of Mechanical Engineering Research Day 2015: MERD'15, 2015, 51-52.

[56] Husnawan M., Saifullah M. G., & Masjuki H. H. (2007). Development of friction force model for mineral oil basestock containing palm olein and antiwear additive. *Tribology International, 40*(1), 74-81.

[57] Degarmo, E. P., Black, J., & Kohser, R. A. (2003). Materials and Processes in Manufacturing (9th ed.): Wiley.

[58] Masjuki, H.H., Maleque, M. (1997) Investigation of the anti-wear characteristics of palm oil methyl ester using a fourball-ball Tribotester test. Wear; 206:179–86.

[59] Bowden, F.P. and Tabor, D. (2001).The nature of metallic wear. In: The Friction and Lubricant ion of Solids, In Oxford Classic Texts, pp. 285–298, Oxford University Press New York.

[60] Wain, K.S., Perez, J.M., Chapman, E., Boehman, A.L. (2005) Alternative and low sulfer fuel ofuel options: boundary lubrication performance and potential problems. Tribol Int, 38:3 38:31:3–9.

[61] Xu, Y., Wang, Q., Hu, X., Chen, J. (2007). Preliminary study on the tribological performance of straw based bio-fuel. In: Procedings of the STLE/ASME international joint tribology conference: IJC2007, USA p. 1022–4.

[62] Sharma, B. K., Kenneth M Doll, Erhan, S. Z. (2008). Ester hydroxy derivatives of methyl oleate: tribological oxidation and low temperature properties. Bioresour Technol; 99:gg7399:33–40.

[63] Zulkifli, N. M., Kalam, M. A., Masjuki, H. H., Shahabuddin, M., & Yunus, R. (2013). Wear prevention characteristics of a palm oil-based TMP (trimethylolpropane) ester as an engine lubricant. Energy, 54, 167-173.

[64] Syahrullail, S., Kamitani S., Shakirin A. (2014). Tribological Evaluation of Mineral Oil and Vegetable Oil as a Lubricant. Jurnal Teknologi (Sciences & Engineering) 66:3 (2014), 37–44

[65] Fazal, M. A., Haseeb, A. S., & Masjuki, H. H. (2013). Investigation of friction and wear characharacteristics of palm biodiesel. Energy Conversion and Management, 67, 251-256.

[66] Kushairi, A. (2014). Evaluation of Palm Oil Lubricity with Varies Rotating Speed Using Four – Ball Tribotester. (Bachelor of Engineering (Mechanical), UTM.

[67] Thottackkad, M.V., Perikinalil, R.K. & Kumarapillai, P.N., 2012. Experimental evaluation on the tribological properties of coconut oil by the addition of CuO nanoparticles. *International Journal of Precision Engineering and Manufacturing*, 13(1), pp.111–116.

[68] Asrul, M. et al., 2013. Tribological properties and lubricant mechanism of Nanoparticle in Engine Oil. *Procedia Engineering*, 68, pp.320–325.