FRICTION AND WEAR ANALYSIS OF PALM KERNEL METHYL ESTER CONTAINING A POLYMERIC VISCOSITY INDEX IMPROVER

MUHAMMAD ARIF BIN DANDAN

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Philosophy

School of Mechanical Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

JULY 2019

DEDICATION

This thesis is dedicated to my beloved parent,
Norlidah binti Awang,
Dandan bin Abdullah,
Siblings,
And all my friends.

ACKNOWLEDGEMENT

"In the name of Allah the Most Compassionate, the Most Merciful"

All praises to Almighty Allah (S.W.T) for giving me the spirit and strength to complete my master's degree. Peace and blessing be upon our noble Prophet Muhammad (S.A.W), his family and companions.

First and foremost, I would like to express my deepest gratitude to my supervisor, Professor Ir. Dr. Syahrullail bin Samion for his support, guidance, advice, knowledge and commitment towards the success of this project. His valuable comments and encouragement made me feel confident to complete this project successfully.

I would also like to thank my fellow friends for their help in providing good ideas, guidance, knowledge and information related to this research. Special thanks goes to the staff of the Tribology Laboratory, Mr. Sahlan Sadiron and Mrs. Nurul Jannah Alias for their guidance and assistance in handling the laboratory equipment.

Finally, I am also grateful and thankful for my family members especially my parents, Dandan bin Abdullah and Norlidah binti Awang for their continuous motivation and encouragement throughout this research. Not to forget, thank you very much to each individual who has contributed directly or indirectly to the success of this research.

ABSTRACT

The search for renewable resources and the development of bio-lubricants as a substitute for mineral oils are being considered as a top priority in the fuel and energy fields. Bio-lubricants derived from vegetable oils are an attractive alternative to conventional petroleum-based lubricants due to their renewability, biodegradability, high lubricity and high flash point. Nevertheless, some types of vegetable oils have a few issues with regard to their low viscosity that limit their potential to be used as bio-lubricants in automotive applications. Thus, the present work featured a specific study on the application of ethylene-vinyl acetate (EVA) copolymer as a viscosity index improver (VII) additive inside vegetable oils. The lubrication performance of palm kernel methyl ester (PKME) with the added EVA copolymer was experimentally evaluated using a four-ball tribotester and modified pin-on-disc tester. Tests were performed with 2%, 3% and 4% concentrations of EVA copolymer at various loads, temperatures and sliding speeds. The results obtained were compared to the commercial mineral engine oil, SAE 40, for reference purposes. The present research revealed that the addition of 4% EVA copolymer managed to enhance the viscosity index of PKME by up to 61% of its original value. Based on the four-ball test, it was found that the PKME formulated with 4% EVA copolymer produced slightly better friction-reducing properties and smoother worn surfaces than SAE 40. Meanwhile, the results of the modified pin-on-disc test showed that the application of EVA copolymer successfully minimized the coefficient of friction (COF) of PKME and also enabled it to give a better performance than SAE 40. Thus, the reduction of frictional force by using this formulated bio-lubricant will contribute to the efficiency of internal combustion engine in the future. However, the anti-wear performance of PKME added with EVA copolymer is slightly lower than SAE 40. Therefore, further improvisation method should be taken in order to solve this issue. Finally, it is suggested that the EVA copolymer shows good potential as a VII for enhancing the tribological performance of vegetable oils.

ABSTRAK

Usaha untuk meneroka sumber yang boleh diperbaharui dan pembangunan minyak pelincir bio untuk menggantikan minyak mineral kini menjadi keutamaan dalam bidang tenaga dan bahan api. Minyak pelincir bio yang dihasilkan daripada minyak sayuran adalah alternatif yang menarik untuk menggantikan minyak pelincir konvensional berasaskan petroleum disebabkan oleh sifat boleh diperbaharuinya, boleh terbiodegradasi, dengan keupayaan pelinciran yang tinggi dan takat meledak yang tinggi. Walaubagaimanapun, beberapa jenis minyak sayuran mempunyai sedikit permasalahan dengan tahap kelikatan mereka yang rendah yang membataskan potensi mereka untuk diaplikasi dalam industri automotif. Kajian ini akan memaparkan analisis khusus aplikasi ethylene-vinyl acetate (EVA) kopolimer sebagai aditif penaik indeks kelikatan di dalam minyak sayuran. Prestasi pelinciran minyak isirong sawit metil ester (PKME) yang telah ditambah dengan EVA kopolimer telah dinilai menggunakan ujian empat-bola tribo dan ujian *pin-on-disc* yang telah dimodifikasi. Ujian telah dijalankan ke atas kepekatan EVA kopolimer 2%, 3% dan 4% pada beban, suhu dan halaju yang berbeza. Keputusan yang diperolehi telah dibandingkan dengan minyak enjin mineral komersial, SAE 40 untuk tujuan rujukan. Kajian ini menunjukkan bahawa penambahan sebanyak 4% EVA kopolimer berhasil untuk menaiktaraf indeks kelikatan minyak isirong sawit metil ester (PKME) sebanyak 61% daripada nilai asalnya. Berdasarkan ujian empat-bola tribo, dapat dilihat bahawa PKME yang diformulasikan dengan 4% EVA kopolimer menghasilkan sifat pengurangan-geseran yang rendah dan permukaan haus yang lebih licin daripada SAE 40. Sementara itu, keputusan daripada ujian *pin-on-disc* menunjukkan bahawa aplikasi EVA kopolimer telah berjaya meminimakan nilai pekali geseran untuk PKME dan memberikan prestasi yang lebih baik dari SAE 40. Pengurangan daya geseran dengan penggunaan minyak pelincir bio ini akan menyumbang kepada tahap efisien enjin pembakaran dalaman di masa hadapan. Walaubagaimanapun, prestasi anti-haus untuk PKME diformulasikan dengan EVA kopolimer masih lagi rendah berbanding SAE 40. Oleh itu, usaha penambahbaikan lanjut seharusnya dijalankan untuk menyelesaikan isu ini. EVA kopolimer dicadangkan sebagai aditif penaik indeks kelikatan bagi tujuan peningkatan prestasi minyak sayuran.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AISI	-	American Iron and Steel Institute
ASTM	-	American Society for Testing and Materials
AW	-	Anti-Wear
CO	-	Castor Oil
COF	-	Coefficient of Friction
EC	-	Ethyl Cellulose
EHD	-	Elastohydrodynamic
EP	-	Extreme Pressure
EVA	-	Ethylene-Vinyl Acetate
FAME	-	Fatty Acid Methyl Ester
FFA	-	Free Fatty Acid
FFB	-	Fresh Fruit Brunch
FFL	-	Fully Formulated Lubricant
FTIR	-	Fourier Transform Infrared Spectroscopy
HFRR	-	High Frequency Reciprocating Test Rig
HOSO	-	High Oleic Sunflower Oil
ISL	-	Initial Seizure Load
LNSL	-	Last Non-Seizure Load
NMR	-	Nuclear Magnetic Resonance Spectroscopy
OFR	-	Oscillatory Flow Reactor
PFAD	-	Palm Fatty Acid Distillate
PK	-	Palm Kernel
PKME	-	Palm Kernel Methyl Ester
PO	-	Paraffin Oil
POME	-	Palm Oil Methyl Ester
PMA	-	Poly (alkyl) methacrylate
PME	-	Palm Methyl Ester
PS	-	Palm Stearin
RBD	-	Refined, bleached and deodorised
SAE	-	Society of Automotive Engineers
SBS	-	Styrene-Butadiene-Styrene

SO - Sunflower Oil
SYO - Soybean Oil
TMP - Tri-methylolpropane
VI - Viscosity Index
VII - Viscosity Index Improver
WL - Weld Load
WSD - Wear Scar Diameter
ZDDP - Zinc-dialkyldithiophosphates

LIST OF SYMBOLS

μ - Coefficient of Friction

D_h - Hertz diameter of the contact area

F - Force

g - Gravity = 9.81 m/s

h - Fluid film thickness

H - Kinematic viscosity at 40°C of an oil of 100 viscosity index having the same kinematic viscosity at 100°C as the oil whose viscosity index is to be calculated mm2/s (cSt).

N - Applied Normal Load

P - Static Applied Load

Ra - Surface Roughness

Rv - Deep Valley

U - Kinematic viscosity at 40°C of the oil whose viscosity index is to be calculated mm2/s (cSt).

VI - Viscosity Index

Y - kinematic viscosity at 100°C of the oil whose kinematic viscosity is to be calculated, mm2/s (cSt).

Yi - Profile Deviation

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of study

In recent years, energy conservation has become a very important issue that requires attention. The loss of energy in any mechanical system is mainly due to friction, which causes the system to be less effective and consumes costs for maintenance at short intervals. This problem can be reduced by the use of a proper lubrication process. However, the most common source of lubricants is petroleum-based oil because of its well-known properties and performance. In fact, about 38 million metric tons of lubricants have been used globally in the last decade, with the majority of these being from petroleum-based lubricants (Syahir et al., 2017). This situation poses a constant threat to the environment due to the inherent toxicity and non-biodegradable nature of petroleum-based oils.

In response to this issue, there is mounting pressure to reduce or eliminate the usage of petroleum-based oils as they pollute the environment and cause health problems in industrial workers. Recently, there has been an increasing interest to develop vegetable oils as an alternative lubricant with environmental-friendly characteristics. The main reasons why vegetable oils are being considered as a new type of bio-lubricant resource are their biodegradability, generally lower toxicity and renewability. Thus, they can be used in a sensitive environment and are able to prevent pollution because of their environmental benefits. In addition, they also have good lubricity, a high flash point, lower volatility and good skin compatibility (Mobarak et al., 2014).

Vegetable oil, especially palm oil, is one of the good candidates that can be developed to replace petroleum-based oil as a new type of bio-lubricant oil. As is known, the automotive industry is a major consumer of lubricants. Bio-lubricants with a low pour point are in demand because they can perform well even at low temperatures and provide excellent lubrication during cold starts (De Carvalho et al., 2010). Thus, systematic researches and studies have to be carried out in order to develop bio-lubricants that can fulfil automotive standards of performance for lubricants.

The aim of this study was to solve the current issues concerning palm kernel oil, including stability at low temperatures and low viscosity characteristic. Thus, a chemical modification technique was selected to derive a bio-lubricant with a lower pour point by using an established experimental setup. Meanwhile, a major part of this research was focused on discussing about the application of ethylene-vinyl acetate (EVA) copolymer as a viscosity index improver (VII) additive inside palm kernel oil. In general, VII have been used in lubricant industry to increase the kinematic viscosity and viscosity index of the base lubricant oils. The improvement in their kinematic viscosity and viscosity index of the lubricant oil up to an optimum level will generate a sufficiently thick film for reducing friction and wear. EVA copolymer was selected for use in this study because it has been proven from a previous research that this substance is able to increase the viscosity of vegetable oil (Quinchia et al., 2010; Quinchia et al., 2014). Next, the tribological performance of this formulated bio-lubricant was evaluated using a four-ball tribotester and modified pin-on-disc tester.

1.2 Problem Statement

Nowadays, many industries are experiencing significant growth worldwide, and this will lead to a continuous increase in the demand for petroleum-based lubricants in the future (Nagendramma and Kaul, 2012). This phenomenon will have a negative impact on the environment because petroleum-based lubricants are non-biodegradable and toxic.

Palm oil is the most widely consumed vegetable oil on the planet due to its versatility, where it can be used for both food and non-food products. It can be processed into many products such as cosmetics, shampoo and laundry detergent. Palm olein is widely used in the food industry as a cooking oil. However, it has been reported that there is still an excess supply of palm oil in the form of palm kernel and palm stearin because it has yet to be utilized to its full potential (Jayadas et al., 2007). The bright future of palm oil will not be disturbed as the latest food-producing industries are using various palm oil products.

Several other palm oil products for non-food applications include palm kernel (PK), palm stearin (PS) and palm fatty acid distillate (PFAD). All of them usually exist in solid form below room temperature due to their high pour point. Thus, direct applications of these types of palm oil will not be possible due to the fluidity issue for the lubrication of important parts. The issue of the high pour points of PK, PS and PFAD can be solved using the available chemical modification techniques, especially transesterification. The aim of transesterification is to convert the free fatty acid content of palm oil together with alcohol to produce fatty acid ester and glycerol (McNutt, 2016).

Recently, transesterification process of vegetable oil was carried out in order to derive methyl ester for the production of bio-diesel. The transesterification of methyl ester will reduce the pour point by removing the free fatty acid from the oil content and breaking the crystalline structure. Besides, bio-diesel resulted from this process will have low viscosity characteristics and helps to solve the clogging issue inside fuel injectors of diesel engines (Ali et al., 2016).

However, low viscosity characteristic of methyl ester is not desirable in the automotive lubricant industry because it is unsuitable to be used directly as an engine oil (Zulkifli et al., 2014). Usually, the minimum value for the viscosity of commercialized mineral engine oil is around 20 cSt under 100 °C. However, the value of viscosity for the vegetable oil which facing this problem is much lower than that. Low viscosity issue will makes it difficult for the methyl ester to generate a sufficiently thick film to protect the cylinder liner surfaces and lead to severe wear. The addition of viscosity index improver (VII) is among the common applied method to overcome this issue. This substance will increase the viscosity of the lubricant and should be able to resist the thinning effects due to the increment of temperature. Recently, EVA copolymer are being tested as VII inside several types of vegetable oil by the previous researchers. Based on the finding, this kind of polymer able to enhance the viscosity of vegetable oils significantly and can contribute to the friction-reducing properties as well. In this study, EVA copolymer was tested as VII inside palm kernel methyl ester in order to prepare a bio-lubricant which possess good viscosity characteristics and decent lubricity performances.

1.3 Objectives of Study

The objectives of this study are as follows:

i. To study the effects of polymeric viscosity index improver (VII) additive, ethylene-vinyl acetate copolymer on the viscosity index increment of palm kernel methyl ester.
ii. To establish the tribological performance of palm kernel methyl ester formulated with different percentages of VII additive using the four-ball tribotester under normal loading and extreme pressure condition.
iii. To analyse the lubricity of the lubricant samples in terms of coefficient of friction, surface roughness and wear condition of the piston ring using a modified pin-on-disc tribotester.

1.4 Scope and Limitations of Study

The scope and limitations of this study are as follows:

i. Refined, bleached and deodorised (RBD) palm kernel oil was chosen in this study due to its availability and cost.
ii. Ethylene-vinyl acetate copolymer with 25% of vinyl acetate content was used as the VII additive inside the palm kernel methyl ester at various concentrations of 2%, 3% and 4% of weight percent.
iii. Commercial mineral engine oil (SAE40) was used as the reference lubricant for comparison purposes.

iv. The four-ball test was conducted according to ASTM D4172 with different sets of temperatures including 0 °C, 30 °C, 75 °C and 90 °C. Then, an extreme

v. The modified version of the pin-on-disc test was conducted according to ASTM G99 using a real piston ring and curve rotating disc. The applied loads were varied at 1 kg, 3 kg and 5 kg under a constant sliding speed of 1.5 ms^{-1}. Subsequently, the sliding speeds were varied at 1.5 ms^{-1}, 2 ms^{-1} and 2.5 ms^{-1} under a constant applied load of 1 kg.

1.5 Significance of the Study

The development of palm oil as a new source of bio-lubricant is one of the most significant contributions of this research. As is known, the volume of palm oil production in Malaysia is one of the highest among the producing countries. It surely makes a huge contribution to the Malaysian economy in terms of annual exports. By considering the great potential of palm oil, Malaysia should take this opportunity to be a market leader in the bio-lubricant industry. Besides, Malaysia has to show its commitment and play an active role in utilising palm oil as a source of renewable energy in order to reduce greenhouse gas emission and ultimately, global warming.

However, before palm oil can be commercialized as a bio-lubricant, systematic researches and development procedures have to be executed in order to determine the actual lubricity behaviour of this vegetable oil in order to improve its performance. Thus, the findings of this study may contribute to the development of palm oil to be used extensively in many engineering applications, especially in the automotive industry. This new type of bio-lubricant is believed to be not only environmentally friendly, but is also expected to be cost-effective as it is available in abundance in Malaysia.

REFERENCES

Adhvaryu, A., Erhan, S., & Perez, J. (2004). Tribological studies of thermally and chemically modified vegetable oils for use as environmentally friendly lubricants. *Wear, 257*(3-4), 359-367.

Adhvaryu, A., Erhan, S. Z., Liu, Z. S., & Perez, J. M. (2000). Oxidation kinetic studies of oils derived from unmodified and genetically modified vegetables using pressurized differential scanning calorimetry and nuclear magnetic resonance spectroscopy. *Thermochimica Acta, 364*(1), 87-97.

Ahmed, D., Kasolang, S., Dwyer-Joyce, R., Sainan, K., & Roselina, N. (2014). Formulation and physico-chemical characteristics of biolubricant. *Jurnal Tribologi, 3*(unknown), 1-10.

Al-Araji, N., & Sarhan, H. (2011). Effect of temperature on sliding wear mechanism under lubrication conditions. *International Journal of Engineering, 5*, 176-184.

Alamu, O., Akintola, T., Enweremadu, C., & Adeleke, A. (2008). Characterization of palm-kernel oil biodiesel produced through NaOH-catalysed transesterification process. *Scientific Research and Essays, 3*(7), 308-311.

Ali, O. M., Mamat, R., Abdullah, N. R., & Abdullah, A. A. (2016). Analysis of blended fuel properties and engine performance with palm biodiesel–diesel blended fuel. *Renewable Energy, 86*, 59-67.

Alves, S., Barros, B., Trajano, M., Ribeiro, K., & Moura, E. (2013). Tribological behavior of vegetable oil-based lubricants with nanoparticles of oxides in boundary lubrication conditions. *Tribology International, 65*, 28-36.

Alves, S., Mello, V., Faria, E., & Camargo, A. (2016). Nanolubricants developed from tiny CuO nanoparticles. *Tribology International, 100*, 263-271.

Arumugam, S., & Sriram, G. (2013). Preliminary study of nano-and microscale TiO2 additives on tribological behavior of chemically modified rapeseed oil. *Tribology Transactions, 56*(5), 797-805.

Asadauskas, S., & Erhan, S. Z. (1999). Depression of pour points of vegetable oils by blending with diluents used for biodegradable lubricants. *Journal of the American Oil Chemists' Society, 76*(3), 313-316. doi:doi: 10.1007/s11746-999-0237-6

Asakuma, Y., Maeda, K., Kuramochi, H., & Fukui, K. (2009). Theoretical study of the transesterification of triglycerides to biodiesel fuel. *Fuel, 88*(5), 786-791.

Asaulyak, A., Rozhdestvenskii, Y., & Gavrilov, K. (2016). Elastohydrodynamic lubrication (EHL) of piston rings in the internal combustion engine. *Procedia Engineering, 150,* 536-540.

ASTM (1990) D1298-85: Standard Practice for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method. ASTM International, West Conshohocken, PA, USA.

ASTM (2010) D 2270-10: Standard practice for calculating viscosity index from kinematic viscosity at 40 and 100°C. ASTM International, West Conshohocken, PA, USA.

ASTM (2017) D97: Standard Practice for Calculating Viscosity Index from Kinematic Viscosity at 40 and 100°C. ASTM International, West Conshohocken, PA, USA.

ASTM (2018) D4172: Standard Test Method for Wear Preventive Characteristics of Lubricating Fluid (Four-Ball Method). ASTM International, West Conshohocken, PA, USA.

ASTM (2003) D2783: Standard Test Method for Measurement of Extreme-Pressure Properties of Lubricating Fluids (Four-Ball Method). ASTM International, West Conshohocken, PA, USA.

ASTM (2017) G99: Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus. ASTM International, West Conshohocken, PA, USA.

Azman, N. F., Samion, S., & Sot, M. N. H. M. (2018). Investigation of tribological properties of CuO/palm oil nanolubricant using pin-on-disc tribotester. *Green Materials, 6*(1), 30-37.

Barnes, A. M., Bartle, K. D., & Thibon, V. R. (2001). A review of zinc dialkyldithiophosphates (ZDDPS): characterisation and role in the lubricating oil. *Tribology International, 34*(6), 389-395.

Bart, J. C., Gucciardi, E., & Cavallaro, S. (2012). *Biolubricants: science and technology*: Elsevier.

Bartz, W. J. (1998). Lubricants and the environment. *Tribology International, 31*(1-3), 35-47.

Basiron, Y., & Weng, C. K. (2004). The oil palm and its sustainability. *Journal of Oil Palm Research, 16*(1).

Battez, A. H., González, R., Felgueroso, D., Fernández, J., del Rocío Fernández, M., García, M., & Penuelas, I. (2007). Wear prevention behaviour of nanoparticle suspension under extreme pressure conditions. *Wear, 263*(7-12), 1568-1574.

Benchaita, M., & Lockwood, F. (1993). Reliable model of lubricant-related friction in internal combustion engines. *Lubrication Science, 5*(4), 259-281.

Biberger, J., & Füßer, H.-J. (2017). Development of a test method for a realistic, single parameter-dependent analysis of piston ring versus cylinder liner contacts with a rotational tribometer. *Tribology International, 113,* 111-124.

Biresaw, G., Adhvaryu, A., & Erhan, S. (2003). Friction properties of vegetable oils. *Journal of the American Oil Chemists' Society, 80*(7), 697.

Blau, P. J. (2008). *Friction science and technology: from concepts to applications*: CRC press.

Bongfa, B., Atabor, P. A., Barnabas, A., & Adeoti, M. (2015). Comparison of lubricant properties of castor oil and commercial engine oil. *Jurnal Tribologi, 5*(1), 1-11.

Briant, J., Denis, J., & Parc, G. (1989). *Rheological properties of lubricants*: Editions Technip.

Carraher Jr, C. E. (2003). *Seymour/Carraher's polymer chemistry*: CRC Press.

Chan, C.-H., Tang, S. W., Mohd, N. K., Lim, W. H., Yeong, S. K., & Idris, Z. (2018). Tribological behavior of biolubricant base stocks and additives. *Renewable and Sustainable Energy Reviews, 93*, 145-157.

Chaudhari, T., & Sutaria, B. (2016). Investigation of friction characteristics in segmented piston ring liner assembly of IC engine. *Perspectives in Science, 8*, 599-602.

Che Man, Y., Haryati, T., Ghazali, H., & Asbi, B. (1999). Composition and thermal profile of crude palm oil and its products. *Journal of the American Oil Chemists' Society, 76*(2), 237-242.

Choi, U., Ahn, B., Kwon, O., & Chun, Y. (1997). Tribological behavior of some antiwear additives in vegetable oils. *Tribology International, 30*(9), 677-683.

Cosimbescu, L., Robinson, J. W., Zhou, Y., & Qu, J. (2016). Dual functional star polymers for lubricants. *RSC Advances, 6*(89), 86259-86268.

Covitch, M. J. (2003). Olefin copolymer viscosity modifiers. *CHEMICAL INDUSTRIES-NEW YORK-MARCEL DEKKER-*, 293-328.

Covitch, M. J., & Trickett, K. J. (2015). How polymers behave as viscosity index improvers in lubricating oils. *Advances in chemical engineering and science, 5*(02), 134.

De Almeida, S. C., Belchior, C. R., Nascimento, M. V., dos SR Vieira, L., & Fleury, G. (2002). Performance of a diesel generator fuelled with palm oil. *Fuel, 81*(16), 2097-2102.

De Carvalho, M. J. S., Seidl, P. R., Belchior, C. R. P., & Sodré, J. R. (2010). Lubricant viscosity and viscosity improver additive effects on diesel fuel economy. *Tribology International, 43*(12), 2298-2302.

Düzcükoğlu, H., & Acaroğlu, M. (2009). Lubrication properties of vegetable oils combined with boric acid and determination of their effects on wear. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 32*(3), 275-285.

Erhan, S. Z., & Asadauskas, S. (2000). Lubricant basestocks from vegetable oils. *Industrial Crops and Products, 11*(2-3), 277-282.

Fan, J., Müller, M., Stöhr, T., & Spikes, H. A. (2007). Reduction of friction by functionalised viscosity index improvers. *Tribology letters, 28*(3), 287-298.

Farhanah, A., & Syahrullail, S. (2016). Evaluation of lubrication performance of RBD palm stearin and its formulation under different applied loads. *Jurnal Tribologi, 10*, 1-15.

Fox, N., Tyrer, B., & Stachowiak, G. (2004). Boundary lubrication performance of free fatty acids in sunflower oil. *Tribology letters, 16*(4), 275-281.

Georges, E., Georges, J.-M., & Diraison, C. (1996). Rheology of olefinic copolymer layers adsorbed on solid surfaces. *Tribology Transactions, 39*(3), 563-570.

Ghanbarzadeh, A., Wilson, M., Morina, A., Dowson, D., & Neville, A. (2016). Development of a new mechano-chemical model in boundary lubrication. *Tribology International, 93*, 573-582.

Ghazi, T. I. M., Resul, M. F. G., & Idris, A. (2009). Bioenergy II: production of biodegradable lubricant from jatropha curcas and trimethylolpropane. *International Journal of Chemical Reactor Engineering, 7*(1).

Girotti, G., Raimondi, A., Blengini, G. A., & Fino, D. (2011). The contribution of lube additives to the life cycle impacts of fully formulated petroleum-based lubricants. *American Journal of Applied Sciences, 8*(11), 1232.

Golshokouh, I., Syahrullail, S., Ani, F., & Masjuki, H. (2013). *Investigation of palm fatty acid distillate as an alternative lubricant of petrochemical based lubricants, tested at various speeds.* Paper presented at the Extracted By ICOME 2012 Virtual Forum–3rd International Conference On Mechanical Engineering.

Gryglewicz, S., Piechocki, W., & Gryglewicz, G. (2003). Preparation of polyol esters based on vegetable and animal fats. *Bioresource Technology, 87*(1), 35-39.

Gunsel, S., Smeeth, M., & Spikes, H. (1996). *Friction and wear reduction by boundary film-forming viscosity index improvers* (0148-7191).

Hamrock, B. J., Schmid, S. R., & Jacobson, B. O. (2004). *Fundamentals of fluid film lubrication*. CRC press.

Hamrock, B. J., & Dowson, D. (1981). Ball bearing lubrication: the elastohydrodynamics of elliptical contacts.

Haumann, B. F. (1994). Tools: hydrogenation, interesterification Hydrogenation and interesterifi. *Inform, 5*(6).

Holmberg, K., Andersson, P., & Erdemir, A. (2012). Global energy consumption due to friction in passenger cars. *Tribology International, 47*, 221-234.

Hutton, J., Jackson, K., & Williamson, B. (1986). The effects of lubricant rheology on the performance of journal bearings. *ASLE transactions, 29*(1), 52-60.

Hwang, H.-S., & Erhan, S. Z. (2006). Synthetic lubricant basestocks from epoxidized soybean oil and Guerbet alcohols. *Industrial Crops and Products, 23*(3), 311-317.

Ing, T. C., Mohammed Rafiq, A., Azli, Y., & Syahrullail, S. (2012). The effect of temperature on the tribological behavior of RBD palm stearin. *Tribology Transactions, 55*(5), 539-548.

Jatti, V. S., & Singh, T. (2015). Copper oxide nano-particles as friction-reduction and anti-wear additives in lubricating oil. *Journal of Mechanical Science and Technology, 29*(2), 793-798.

Jayadas, N., & Nair, K. P. (2006). Coconut oil as base oil for industrial lubricants—evaluation and modification of thermal, oxidative and low temperature properties. *Tribology International, 39*(9), 873-878.

Jayadas, N., Nair, K. P., & Ajithkumar, G. (2007). Tribological evaluation of coconut oil as an environment-friendly lubricant. *Tribology International, 40*(2), 350-354.

Jitputti, J., Kitiyanan, B., Rangsunvigit, P., Bunyakiat, K., Attanatho, L., & Jenvanitpanjakul, P. (2006). Transesterification of crude palm kernel oil and crude coconut oil by different solid catalysts. *Chemical Engineering Journal, 116*(1), 61-66.

Johansson, S., Nilsson, P. H., Ohlsson, R., & Rosén, B.-G. (2011). Experimental friction evaluation of cylinder liner/piston ring contact. *Wear, 271*(3-4), 625-633.

Kabir, M., Higgs, C. F., & Lovell, M. R. (2008). A pin-on-disk experimental study on a green particulate-fluid lubricant. *Journal of Tribology, 130*(4), 041801.

Kapsiz, M., Durat, M., & Ficici, F. (2011). Friction and wear studies between cylinder liner and piston ring pair using Taguchi design method. *Advances in Engineering Software, 42*(8), 595-603.

Kassfeldt, E., & Dave, G. (1997). Environmentally adapted hydraulic oils. *Wear, 207*(1-2), 41-45. doi:doi: 10.1016/S0043-1648(96)07466-2

Kecheng, G., Boshui, C., & Yong, C. (2013). Preparation and tribological properties of lanthanum-doped TiO2 nanoparticles in rapeseed oil. *Journal of Rare Earths, 31*(6), 589-594.

Kim, B., Jiang, J. C., & Aswath, P. B. (2011). Mechanism of wear at extreme load and boundary conditions with ashless anti-wear additives: Analysis of wear surfaces and wear debris. *Wear, 270*(3-4), 181-194.

Kinker, B. G. (2009). 11 Polymethacrylate Viscosity Modifiers and Pour Point Depressants. *Lubricant Additives*, 315.

Knothe, G., & Steidley, K. R. (2005). Kinematic viscosity of biodiesel fuel components and related compounds. Influence of compound structure and comparison to petrodiesel fuel components. *Fuel, 84*(9), 1059-1065.

Koh, M. Y., Ghazi, T. I. M., & Idris, A. (2014). Synthesis of palm based biolubricant in an oscillatory flow reactor (OFR). *Industrial Crops and Products, 52*, 567-574.

Koshy, C. P., Rajendrakumar, P. K., & Thottackkad, M. V. (2015). Evaluation of the tribological and thermo-physical properties of coconut oil added with MoS2 nanoparticles at elevated temperatures. *Wear, 330*, 288-308.

Kouzu, M., & Hidaka, J.-s. (2012). Transesterification of vegetable oil into biodiesel catalyzed by CaO: a review. *Fuel, 93*, 1-12.

Kržan, B., & Vižintin, J. (2003). Tribological properties of an environmentally adopted universal tractor transmission oil based on vegetable oil. *Tribology International, 36*(11), 827-833.

Kumar, D., Chibber, V. K., & Singh, A. (2017). Review of Vegetable Seeds Oils as Biolubricants. *Energy and Environment Focus, 6*(2), 103-113. doi:10.1166/eef.2017.1251

Leung, D. Y., Wu, X., & Leung, M. (2010). A review on biodiesel production using catalyzed transesterification. *Applied Energy, 87*(4), 1083-1095.

Li, Y.-R., Pereira, G., Kasrai, M., & Norton, P. R. (2007). Studies on ZDDP anti-wear films formed under different conditions by XANES spectroscopy, atomic force microscopy and 31P NMR. *Tribology letters, 28*(3), 319.

Liu, K., & Brown, E. A. (1996). Enhancing vegetable oil quality through plant breeding and genetic engineering. *Food technology (USA).*

Loehle, S. (2014). *Understanding of adsorption mechanism and tribological behaviors of C18 fatty acids on iron-based surfaces: a molecular simulation approach.* Ecully, Ecole centrale de Lyon,

Lomège, J., Negrell, C., Robin, J.-J., Lapinte, V., & Caillol, S. (2018). Fatty acid-Based Methacrylate Polymers as Viscosity Modifiers for Mineral Oils. *Green Materials*, 1-46.

Maleque, M., Masjuki, H., & Ishak, M. (1998). Bio-fuel-contaminated lubricant and hardening effects on the friction and wear of AISI 1045 steel. *Tribology Transactions, 41*(1), 155-159.

Maleque, M. A., Masjuki, H. H., & Haseeb, A. S. M. A. (2000). Effect of mechanical factors on tribological properties of palm oil methyl ester blended lubricant. *Wear, 239*(1), 117-125. doi:doi: org/10.1016/S0043-1648(00)00319-7

Maleque, M. A., Masjuki, H. H., & Sapuan, S. M. (2003). Vegetable-based biodegradable lubricating oil additives. *Industrial Lubrication and Tribology, 55*(3), 137-143. doi:doi:10.1108/00368790310470976

Mannekote, J. K., & Kailas, S. V. (2012). The effect of oxidation on the tribological performance of few vegetable oils. *Journal of materials research and technology, 1*(2), 91-95.

Maru, M. M., & Tanaka, D. K. (2007). Consideration of stribeck diagram parameters in the investigation on wear and friction behavior in lubricated sliding. *Journal of the Brazilian Society of Mechanical Sciences and Engineering, 29*(1), 55-62.

Masjuki, H., & Maleque, M. (1997). Investigation of the anti-wear characteristics of palm oil methyl ester using a four-ball tribometer test. *Wear, 206*(1-2), 179-186. doi:doi: 10.1016/S0043-1648(96)07351-6

Masjuki, H., Maleque, M., Kubo, A., & Nonaka, T. (1999). Palm oil and mineral oil based lubricants—their tribological and emission performance. *Tribology International, 32*(6), 305-314.

McNutt, J. (2016). Development of biolubricants from vegetable oils via chemical modification. *Journal of industrial and Engineering Chemistry, 36*, 1-12.

Ming, K. K., & Chandramohan, D. (2002). Malaysian palm oil industry at crossroads and its future direction. *Oil Palm Industry Economic Journal, 2*(2), 10-15.

Misbah, F. (2016). *Development of palm kernel oil as a lubricant under extreme pressure.* (Master Dissertation), Universiti Teknologi Malaysia,

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

Müller, M., Topolovec-Miklozic, K., Dardin, A., & Spikes, H. A. (2006). The design of boundary film-forming PMA viscosity modifiers. *Tribology Transactions, 49*(2), 225-232.

Nagendramma, P., & Kaul, S. (2012). Development of ecofriendly/biodegradable lubricants: An overview. *Renewable and Sustainable Energy Reviews, 16*(1), 764-774.

Neff, W., Mounts, T., Rinsch, W., Konishi, H., & El-Agaimy, M. (1994). Oxidative stability of purified canola oil triacylglycerols with altered fatty acid compositions as affected by triacylglycerol composition and structure. *Journal of the American Oil Chemists' Society, 71*(10), 1101-1109.

Nigeria, M. (2009). Evaluation of the lubricating properties of palm kernel oil. *Leonardo electronic journal of practices and technologies, 14*, 107-114.

Norizzah, A., Chong, C., Cheow, C., & Zaliha, O. (2004). Effects of chemical interesterification on physicochemical properties of palm stearin and palm kernel olein blends. *Food Chemistry, 86*(2), 229-235.

Oğuz, H., Acaroğlu, M., Öğüt, H., & İlban, B. (2009). Determination of performance of the soybean oil in farm tractors as hydraulic fluid. *Energy Sources, Part A, 31*(16), 1487-1493.

Padgurskas, J., Rukuiza, R., Prosyčevas, I., & Kreivaitis, R. (2013). Tribological properties of lubricant additives of Fe, Cu and Co nanoparticles. *Tribology International, 60,* 224-232.

Panchal, T. M., Patel, A., Chauhan, D., Thomas, M., & Patel, J. V. (2017). A methodological review on bio-lubricants from vegetable oil based resources. *Renewable and Sustainable Energy Reviews, 70,* 65-70.

Parthasarathi, N., Borah, U., & Albert, S. K. (2013). Correlation between coefficient of friction and surface roughness in dry sliding wear of AISI 316 L (N) stainless steel at elevated temperatures. *Computer Modelling and New Technologies, 17*(1), 51-63.

Peña-Parás, L., Taha-Tijerina, J., García, A., Maldonado, D., González, J. A., Molina, D., . . . Cantú, P. (2014). Antiwear and extreme pressure properties of nanofluids for industrial applications. *Tribology Transactions, 57*(6), 1072-1076.

Quinchia, L., Delgado, M., Franco, J., Spikes, H., & Gallegos, C. (2012). Low-temperature flow behaviour of vegetable oil-based lubricants. *Industrial Crops and Products, 37*(1), 383-388. doi:doi: 10.1016/j.indcrop.2011.12.021

Quinchia, L., Delgado, M., Valencia, C., Franco, J., & Gallegos, C. (2009). Viscosity modification of high-oleic sunflower oil with polymeric additives for the design of new biolubricant formulations. *Environmental science & technology, 43*(6), 2060-2065.

Quinchia, L., Delgado, M., Valencia, C., Franco, J., & Gallegos, C. (2010). Viscosity modification of different vegetable oils with EVA copolymer for lubricant applications. *Industrial Crops and Products, 32*(3), 607-612.

Quinchia, L. A., Delgado, M. A., Reddyhoff, T., Gallegos, C., & Spikes, H. A. (2014). Tribological studies of potential vegetable oil-based lubricants containing environmentally friendly viscosity modifiers. *Tribology International, 69*, 110-117.

Rabaso, P., Ville, F., Dassenoy, F., Diaby, M., Afanasiev, P., Cavoret, J., . . . Le Mogne, T. (2014). Boundary lubrication: Influence of the size and structure of inorganic fullerene-like MoS2 nanoparticles on friction and wear reduction. *Wear, 320*, 161-178.

Rabelo, S. N., Ferraz, V. P., Oliveira, L. S., & Franca, A. S. (2015). FTIR analysis for quantification of fatty acid methyl esters in biodiesel produced by microwave-assisted transesterification. *International Journal of Environmental Science and Development, 6*(12), 964.

Reyes, M., & Neville, A. (2003). The effect of anti-wear additives, detergents and friction modifiers in boundary lubrication of traditional Fe-base materials. In *Tribology Series* (Vol. 41, pp. 57-65): Elsevier.

Rhee, I.-S., Velez, C., & Von Bernewitz, K. (1995). *Evaluation of Environmentally Acceptable Hydraulic Fluids*. Retrieved from

Robinson, J. W., Zhou, Y., Qu, J., Bays, J. T., & Cosimbescu, L. (2016). Highly branched polyethylenes as lubricant viscosity and friction modifiers. *Reactive and Functional Polymers, 109,* 52-55.

Roegiers, M., & Zhmud, B. (2009). Tribological performance of ionised vegetable oils as lubricity and fatty oiliness additives in lubricants and fuels. *Lubrication Science, 21*(5), 169-182.

Roïz, J., “Biolubricants: technical and market survey,” 2009.

Ronkainen, H., Elomaa, O., Varjus, S., Kilpi, L., Jaatinen, T., & Koskinen, J. (2016). The influence of carbon based coatings and surface finish on the tribological performance in high-load contacts. *Tribology International, 96,* 402-409.

Rudnick, L. R. (2017). *Lubricant additives: chemistry and applications*: CRC press.

Rymuza, Z. (2007). Tribology of polymers. *Archives of civil and mechanical engineering, 7*(4), 177-184.

Salimon, J., Salih, N., & Yousif, E. (2010). Biolubricants: Raw materials, chemical modifications and environmental benefits. *European Journal of Lipid Science and Technology, 112*(5), 519-530.

Sapawe, N., Syahrullail, S., & Izhan, M. (2014). Evaluation on the tribological properties of palm olein in different loads applied using pin-on-disk tribotester. *Jurnal Tribologi, 3*(unknown), 11-29.

Shahabuddin, M., Masjuki, H., Kalam, M., Bhuiya, M., & Mehat, H. (2013). Comparative tribological investigation of bio-lubricant formulated from a non-edible oil source (Jatropha oil). *Industrial Crops and Products, 47,* 323-330.

Shahnazar, S., Bagheri, S., & Hamid, S. B. A. (2016). Enhancing lubricant properties by nanoparticle additives. *International journal of hydrogen energy, 41*(4), 3153-3170.

Shashidhara, Y., & Jayaram, S. (2010). Vegetable oils as a potential cutting fluid—an evolution. *Tribology International, 43*(5-6), 1073-1081.

Sherrington, I., & Hayhurst, P. (2001). Simultaneous observation of the evolution of debris density and friction coefficient in dry sliding steel contacts. *Wear, 249*(3-4), 182-187.

Siniawski, M. T., Saniei, N., & Stoyanov, P. (2011). Influence of humidity on the tribological performance of unmodified soybean and sunflower oils. *Lubrication Science, 23*(7), 301-311.

Sklepic, V. M., Podobnik, M., & Bambic, J. (2008). Engine oil viscosity index improver behaviour at extended shear stability test. *Goriva i Maziva, 47*(2), 118.

Smeeth, M., Spikes, H., & Gunsel, S. (1996). Boundary film formation by viscosity index improvers. *Tribology Transactions, 39*(3), 726-734.

Soares, I. P., Rezende, T. F., Silva, R. C., Castro, E. V. R., & Fortes, I. C. (2008). Multivariate calibration by variable selection for blends of raw soybean oil/biodiesel from different sources using fourier transform infrared spectroscopy (FTIR) spectra data. *Energy & fuels, 22*(3), 2079-2083.

Sodamade, A., Oyedepo, T., & Bolaji, O. (2013). Fatty acids composition of three different vegetable oils (soybean oil, groundnut oil and coconut oil) by high-performance liquid chromatography. *Extraction, 3*(7).

Söderfjäll, M., Almqvist, A., & Larsson, R. (2016). Component test for simulation of piston ring–Cylinder liner friction at realistic speeds. *Tribology International, 104*, 57-63.

Sripada, P. K., Sharma, R. V., & Dalai, A. K. (2013). Comparative study of tribological properties of trimethylolpropane-based biolubricants derived from methyl oleate and canola biodiesel. *Industrial Crops and Products, 50*, 95-103.

Stachowiak, G., & Batchelor, A. (2006). Chapter 14—Fatigue Wear. *Engineering Tribology, 3rd ed., Butterworth-Heinemann, Oxford, UK*, 595-619.

Stachowiak, G., & Batchelor, A. W. (2013). *Engineering tribology*: Butterworth-Heinemann.

Stöhr, T., Eisenberg, B., & Müller, M. (2009). A new generation of high performance viscosity modifiers based on comb polymers. *SAE International Journal of Fuels and Lubricants, 1*(1), 1511-1516.

Stojilković, M., Golubović, D., & Ješić, D. (2014). *Ecotribology aspects in the lubricants application.* Paper presented at the 6th International Symposium on Exploitation of Renewable Energy Sources “EXPRES.

Stuart, M. C., Waajen, F. H., Cosgrove, T., Vincent, B., & Crowley, T. L. (1984). Hydrodynamic thickness of adsorbed polymer layers. *Macromolecules, 17*(9), 1825-1830.

Sulek, M., Kulczycki, A., & Malysa, A. (2010). Assessment of lubricity of compositions of fuel oil with biocomponents derived from rape-seed. *Wear, 268*(1-2), 104-108.

Syahir, A., Zulkifli, N., Masjuki, H., Kalam, M., Alabdulkarem, A., Gulzar, M., . . . Harith, M. (2017). A review on bio-based lubricants and their applications. *Journal of Cleaner Production, 168*, 997-1016.

Syahrullail, S., Azwadi, C., & Ing, T. C. (2011a). The metal flow evaluation of billet extruded with RBD palm stearin. *International Review of Mechanical Engineering, 5*(1), 21-27.

Syahrullail, S., Hariz, M., Hamid, M. A., & Bakar, A. A. (2013a). Friction characteristic of mineral oil containing palm fatty acid distillate using four ball tribo-tester. *Procedia Engineering, 68*, 166-171.

Syahrullail, S., Wira, J. Y., Wan Nik, W., & Fawwaz, W. (2013b). *Friction characteristics of RBD palm olein using four-ball tribotester.* Paper presented at the Applied Mechanics and materials.

Syahrullail, S., Zubil, B., Azwadi, C., & Ridzuan, M. (2011b). Experimental evaluation of palm oil as lubricant in cold forward extrusion process. *International journal of mechanical sciences, 53*(7), 549-555. doi:doi: 10.1016/j.ijmecsci.2011.05.002

Szterk, A., Roszko, M., Sosińska, E., Derewiaka, D., & Lewicki, P. (2010). Chemical composition and oxidative stability of selected plant oils. *Journal of the American Oil Chemists' Society, 87*(6), 637-645.

Tan, C.-H., Ghazali, H. M., Kuntom, A., Tan, C.-P., & Ariffin, A. A. (2009). Extraction and physicochemical properties of low free fatty acid crude palm oil. *Food Chemistry, 113*(2), 645-650.

Tang, Z., & Li, S. (2014). A review of recent developments of friction modifiers for liquid lubricants (2007–present). *Current opinion in solid state and materials science, 18*(3), 119-139.

Teoh, C. H. (2002). The palm oil industry in Malaysia. From seed to frying pan.

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), 111-116.

Ting, C.-C., & Chen, C.-C. (2011). Viscosity and working efficiency analysis of soybean oil based bio-lubricants. *Measurement, 44*(8), 1337-1341.

Tiong, C. I., Azli, Y., Kadir, M. R. A., & Syahrullail, S. (2012). Tribological evaluation of refined, bleached and deodorized palm stearin using four-ball tribotester with different normal loads. *Journal of Zhejiang University Science A, 13*(8), 633-640. doi:doi: 10.1631/jzus.A1200021

Trajano, M. F., Moura, E. I. F., Ribeiro, K. S. B., & Alves, S. M. (2014). Study of oxide nanoparticles as additives for vegetable lubricants. *Materials Research, 17*(5), 1124-1128.

Warner, K., & Knowlton, S. (1997). Frying quality and oxidative stability of high-oleic corn oils. *Journal of the American Oil Chemists' Society, 74*(10), 1317-1322.

Wu, X., Zhang, X., Yang, S., Chen, H., & Wang, D. (2000). The study of epoxidized rapeseed oil used as a potential biodegradable lubricant. *Journal of the American Oil Chemists' Society, 77*(5), 561-563.

Xie, H., Jiang, B., He, J., Xia, X., Jiang, Z., Dai, J., & Pan, F. (2015). Effect of SiO2 nanoparticles as lubricating oil additives on the cold-rolling of AZ31 magnesium alloy sheet. *Materials Research Innovations, 19*(sup4), S127-S132.

Yunus, R., Fakhru'l-Razi, A., Ooi, T. L., Omar, R., & Idris, A. (2005). Synthesis of palm oil based trimethylolpropane esters with improved pour points. *Industrial & engineering chemistry research, 44*(22), 8178-8183.

Yunus, R., Fakhru'l-Razi, A., Ooi, T. L., Iyuke, S. E., & Perez, J. M. (2004). Lubrication properties of trimethylolpropane esters based on palm oil and palm kernel oils. *European Journal of Lipid Science and Technology, 106*(1), 52-60.

Zainal, N., Zulkifli, N., Gulzar, M., & Masjuki, H. (2018). A review on the chemistry, production, and technological potential of bio-based lubricants. *Renewable and Sustainable Energy Reviews, 82*, 80-102.

Zhang, B.-S., Xu, B.-S., Xu, Y., Gao, F., Shi, P.-J., & Wu, Y.-X. (2011). Cu nanoparticles effect on the tribological properties of hydrosilicate powders as lubricant additive for steel–steel contacts. *Tribology International, 44*(7-8), 878-886.

Zhang, X., Xuan, F., Tu, S., Xu, B., & Wu, Y. (2011). Durability of plasma-sprayed Cr 3 C 2-NiCr coatings under rolling contact conditions. *Frontiers of Mechanical Engineering, 6*(1), 118-135.

Zhao, G., Zhao, Q., Li, W., Wang, X., & Liu, W. (2014). Tribological properties of nano-calcium borate as lithium grease additive. *Lubrication Science, 26*(1), 43-53.

Zulkifli, N., Kalam, M., Masjuki, 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. doi:doi: 10.1016/j.energy.2013.01.038

Zulkifli, N., Masjuki, H., Kalam, M., Yunus, R., & Azman, S. (2014). Lubricity of bio-based lubricant derived from chemically modified jatropha methyl ester. *Jurnal Tribologi*, *1*, 18-39. doi:doi: 10.1016/j.energy.2013.01.038.

APPENDIX B

List of Publications

Journal with Impact Factor

1. **Dandan, M. A**., & Samion, S. (2019). Tribological Analysis of Palm Kernel Methyl Ester Containing Polymeric Viscosity Improver. *Green Materials*, 1-9. https://doi.org/10.1680/jgrma.18.00067. **(Q3, IF:1.344)**

2. **Dandan, M. A.**, Samion, S., Azman, N. F., Zawawi, F. M., Hamid, M. K. A., & Musa, M. N. (2019). Performance of polymeric viscosity improver as bio-lubricant additives. *International Journal of Structural Integrity* **(Q3,ISI)**..

Indexed Journal

1. **Dandan, M. A**., Aiman Wan Yahaya, W. M., Samion, S., & Musa, M. N. (2018). A comprehensive review on palm oil and the challenges using vegetable oil as lubricant base-stock. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences,* 52(2), 182-197. **(Indexed by SCOPUS)**

2. **Dandan, M. A**., Yahaya, W. M. A. W., & Samion, S. (2018). The effect of fluidity of palm kernel oil with pour point depressant on coefficient of friction using fourball tribotester. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences,* 50(2), 97-107. **(Indexed by SCOPUS).**

3. The Effect of the Different Percentage of Pour Point Depressant (PPD) On the Tribological Properties of Palm Kernel Oil. *Tribology in Industry* **(Indexed by SCOPUS).**