

**EXPERIMENTAL INVESTIGATION OF FRICTION AND WEAR CHARACTERISTIC ON NATURAL  
OIL-BASED LUBRICANTS**

**YONG KAI FANG**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**EXPERIMENTAL INVESTIGATION OF FRICTION AND WEAR  
CHARACTERISTIC ON NATURAL OIL-BASED LUBRICANTS**

**YONG KAI FANG**

**B041210112**

**BMCT**

**Email: francisyong92@yahoo.com**

**Draft Final Report**

**Projek Sarjana Muda II**

**Supervisor: DR TEE BOON TUAN**

**2<sup>nd</sup> Examiner: EN. MD ISA BIN ALI**

**Faculty of Mechanical Engineering  
Universiti Teknikal Malaysia Melaka**

**JUNE 2016**

**EXPERIMENTAL INVESTIGATION OF FRICTION AND WEAR  
CHARACTERISTIC ON NATURAL OIL-BASED LUBRICANTS**

**YONG KAI FANG**

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

**Faculty of Mechanical Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2016**

## DECLARATION

I declare that this project report entitled “Experimental investigation of friction and wear characteristic on natural oil-based lubricants” is the result of my own work except as cited in the references.

Signature : .....

Name : YONG KAI FANG  
: .....

Date : 20/6/2016  
: .....

## APPROVAL

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

Signature	: .....
Name of Supervisor	: DR. TEE BOON TUAN .....
Date	: 20/6/2016 .....

## **DEDICATION**

To my beloved mother and father

## ABSTRACT

Friction and wear are one of the main factors that affect the efficiency, performance, quality and life span of machinery system. The purpose of this study is to determine the friction and wear properties of natural oil-based lubricant which consist of refined glycerin, crude glycerol and oleic methyl ester to compare with the friction and wear properties of commercial lubricant. Four ball tester experiments are carried out based on ASTM standard to evaluate the tribology properties of lubricants. The measurements of Coefficient of Friction and Wear Scar Diameter are taken at bearing ball for different types of lubricants. The difference in coefficient of friction and wear scar diameter for lubricant with and without additive and different temperature are being investigated. The results obtained from physical measurement and analysis is compared with coefficient of friction and wear scar diameter of commercial lubricants. The average coefficient of friction obtained from analysis for refined glycerin and crude glycerol with and without additive show lower reading compared to commercial lubricant. Lubricant with Carbon Nano Tube as additive show more preferred result compare to lubricant without additive in term of coefficient of friction. With the increase in temperature, the coefficient of friction for lubricant for both with and without additive increased. For wear scar diameter, performance of natural oil-based lubricant with and without additive, high and low temperature show better result compare to commercial lubricants. Overall, for coefficient of friction, at temperature of 75°C refined glycerin shows the most preferable result and at the temperature of 85°C, crude glycerol without additive shows the most preferable result. For wear scar diameter, at low and high temperature, refined glycerin without additive show the smallest reading compare to other. Based on the result, recommendations and suggestions are made to improve the accuracy of tribology test and tribology properties of lubricants.

## ABSTRAK

Geseran dan haus adalah salah satu faktor utama yang memberi kesan kepada kecekapan, prestasi, kualiti dan jangka hayat sistem jentera. Kajian ini dijalankan untuk menentukan sifat geseran dan haus yang berasaskan pelincir minyak semula jadi yang terdiri daripada gliserin ditapis, gliserol mentah dan oleik methyl ester untuk membandingkan sifat-sifat geseran dan haus dengan pelincir komersial. Eksperimen empat penguji bola dijalankan berdasarkan standard ASTM untuk menilai sifat-sifat tribologi pelincir. Pengukuran pekali geseran dan diameter haus parut diambil pada bearing bola untuk pelbagai jenis pelincir. Perbezaan dalam pekali geseran dan diameter haus parut untuk pelincir dengan dan tanpa bahan tambahan dan suhu yang berbeza turut dikaji. Keputusan yang diperolehi daripada pengukuran fizikal dan analisis dibandingkan dengan pekali geseran dan diameter haus parut pelincir komersial. Purata pekali geseran yang diperolehi daripada analisis untuk gliserin ditapis dan gliserol mentah dengan dan tanpa bahan tambahan menunjukkan bacaan yang lebih rendah berbanding dengan pelincir komersial. Dari segi pekali geseran, pelincir yang dicampurkan dengan Karbon Nano Tiub sebagai bahan tambahan menunjukkan hasil lebih memuaskan berbanding dengan pelincir tanpa bahan tambah. Dengan peningkatan suhu, pekali geseran untuk pelincir dengan dan tanpa bahan tambahan meningkat. Dari segi diameter haus parut, prestasi pelincir berasaskan minyak semula jadi dengan dan tanpa bahan tambahan, pada suhu tinggi dan rendah, semuanya menunjukkan keputusan yang lebih baik berbanding dengan pelincir komersial. Secara keseluruhan, untuk pekali geseran, pada suhu 75°C gliserin ditapis menunjukkan hasil yang paling baik dan pada suhu 85°C, gliserol mentah tanpa bahan tambahan menunjukkan hasil yang paling baik. Di suhu rendah, gliserin ditapis tanpa bahan tambahan menunjukkan bacaan yang paling rendah untuk diameter haus parut berbanding dengan yang lain. Berdasarkan keputusan yang diperolehi, penambahbaikan dicadangkan untuk meningkatkan ketepatan kajian tribologi dan sifat-sifat tribologi pelincir.



## **ACKNOWLEDGEMENT**

First of all, I would like to express my gratitude to my supervisor, Dr. Tee Boon Tuan, who has helped me so much by constantly imparting his knowledge and ideas so that I could complete my PSM project successfully. Sincere thanks to Mr. Md Isa Bin Ali and Dr. Yusmady Mohamed Arifin for evaluating my final year project. The ideas and suggestions given were valuable for me to complete this project.

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

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

## TABLE OF CONTENTS

<b>CHAPTER</b>	<b>TITLE</b>	<b>PAGE</b>
	<b>SUPERVISOR DECLARATION</b>	<b>ii</b>
	<b>APPROVAL</b>	<b>iii</b>
	<b>DEDICATION</b>	<b>iv</b>
	<b>ABSTRACT</b>	<b>v</b>
	<b>ABSTRAK</b>	<b>vi</b>
	<b>ACKNOWLEDGEMENT</b>	<b>vii</b>
	<b>TABLE OF CONTENTS</b>	<b>viii</b>
	<b>LIST OF TABLES</b>	<b>xiii</b>
	<b>LIST OF FIGURES</b>	<b>xv</b>
	<b>LIST OF SYMBOLS</b>	<b>xviii</b>
	<b>LIST OF APPENDICES</b>	<b>xix</b>
	<b>LIST OF ABBREVIATIONS</b>	<b>xx</b>
<b>CHAPTER 1</b>	<b>INTRODUCTION</b>	
1.1	Overview	1
1.2	Problem Statement	1
1.3	Objectives	2
1.4	Scopes	3
1.5	Expected Outcomes	3
1.6	Importances of this Project	3
<b>CHAPTER 2</b>	<b>THEORY</b>	
2.1	Overview	4
2.2	Tribology	4
2.3	Friction	4

<b>CHAPTER</b>	<b>TITLE</b>	<b>PAGE</b>
	2.3.1 Solid Surface Nature	5
	2.3.2 Surface Roughness	8
2.4	Wear	8
	2.4.1 Types of Wear	8
2.5	Lubricity	10
	2.5.1 Function of Lubricant	11
	2.5.2 Lubricant Characteristic-Viscosity	12
	2.5.3 Types of Lubricant	12
2.6	Additive	15
	2.6.1 Carbon Nanotubes, CNT	16
	2.6.2 Carbon Nanofiber, HHT	17
<b>CHAPTER 3 LITERATURE REVIEW</b>		
3.1	Overview	18
3.2	Wear Prevention Characteristic of Palm Oil-Based Trimthylolpropane TMP Ester by ZULKIFLI et al. (2013)	18
	3.2.1 Methodology	19
	3.2.2 Results And Discussion	22
	3.2.3 Conclusion	25
3.3	Friction Characteristic of RBD Palm Oleic using Four Ball Tribotester by S. SYAHRULLAIL et al. (2002)	26
	3.3.1 Methodology	26
	3.3.2 Results And Discussion	27
	3.3.3 Conclusion	28
3.4	Tribology Evaluation of Refined, Bleached and Deodorized Palm Stearin with Different Loads by TIONG et al. (2012)	28

<b>CHAPTER</b>	<b>TITLE</b>	<b>PAGE</b>
	3.4.1 Methodology	28
	3.4.2 Results And Discussion	29
	3.4.3 Conclusion	30
3.5	Investigation of Anti Wear Characteristic of Palm Oil Methyl Ester by H.H. MASJUKI AND M.A. MALEQUE (2006)	30
	3.5.1 Methodology	30
	3.5.2 Results And Discussion	31
	3.5.3 Conclusion	35
3.6	The Effect of Temperature on the Tribology Behavior of RBD Palm Stearin by A.K MOHAMMED RAFIQ (2012)	35
	3.6.1 Methodology	35
	3.6.2 Results And Discussion	36
	3.6.3 Conclusion	40
3.7	Comparison of Previous Studies	40
3.8	Coefficient of Friction, (COF) of Engine Oil and Amber Technology Concentration 4128 at Temperature 75°C	44
3.7	Wear Scar Diameter, (WSD) of Engine Oil and Amber Technology Concentration 4128 at Temperature 75°C	44
 <b>CHAPTER 4 METHODOLOGY</b>		
4.1	Overview	46
4.2	Introduction	46
4.3	Flow chart	46
4.4	General Flow of Methodology	48
	4.4.1 Apparatus and Standard Setting	48
	4.4.2 Experiments Conducted	50

<b>CHAPTER</b>	<b>TITLE</b>	<b>PAGE</b>
	4.4.3 Result Analysis	51
4.5	ASTM D-4172	52
4.6	Experimental Procedures	52
	4.6.1 Experiment 1	53
	4.6.2 Experiment 2	54
	4.6.3 Experiment 3	56
	4.6.4 Experiment 4	57
	4.6.5 Experiment 5	57
<b>CHAPTER 5</b>	<b>RESULT AND ANALYSIS</b>	
5.1	Overview	59
5.2	Experimental Results and Analysis	59
	5.2.1 Viscosity	60
	5.2.2 Coefficient of Friction, (COF)	62
	5.2.3 Wear Scar Diameter, (WSD)	74
5.3	Comparison of COF and WSD for CG, RG and OME Lubricant with Commonly Used Lubricant	85
	5.3.1 Comparison for COF Between Commonly Used Lubricant with Natural Oil-Based Lubricant	85
	5.3.2 Comparison for WSD between Commonly Used Lubricant With Natural Oil-Based Lubricant	86
<b>CHAPTER 6</b>	<b>CONCLUSION AND RECOMMENDATIONS</b>	88
	<b>REFERENCES</b>	91
	<b>APPENDIX A:</b> Flow Chart	95
	<b>APPENDIX B:</b> Gantt Chart	96
	<b>APPENDIX C:</b> Frictional Force Plot	97

<b>CHAPTER</b>	<b>TITLE</b>	<b>PAGE</b>
	<b>APPENDIX D:</b> Friction coefficient vs load for different % of POME	97
	<b>APPENDIX E:</b> Wear Scar of ball specimen	98
	<b>APPENDIX F:</b> Wear worn surface observed using CCD camera	99
	<b>APPENDIX G:</b> Digital Microscope	100
	<b>APPENDIX H:</b> Wear Scar of ball specimen	101

## LIST OF TABLES

NO.	TITLE	PAGE
2.1	General information for Refined glycerin	13
2.2	General information for Crude glycerol	14
2.3	General information for Oleic Methyl Ester	15
2.4	General information for Carbon nanotube CNT	16
2.5	General information for Carbon nanofiber HHT	17
3.1	Percentages of the palm oil based TMP ester and OL in each sample	19
3.2	Experiment data and calculation result for lubricant SAE20	23
3.3	Chemical composition (wt%) and hardness of EN31 steel ball material	31
3.4	Comparison of Previous study	41
3.5	COF of Engine oil, Cottonseed oil and Amber technology concentration-4128	44
3.6	WSD of Engine oil, Cottonseed oil and Amber technology concentration-4128	45
4.1	Types of experiment with its Standard and material	50
4.2	Types of ASTM 4172 and their parameter	52
5.1	Different types of experiment with different parameter	59
5.2	Viscosity of lubricants in unit of $\frac{m^2}{s}$	60
5.3	Time taken for each type's lubricant to form 2 layers	62
5.4	Averages of Coefficient of friction for different Lubricant under 75C° in unit $\mu m$	67
5.5	Averages of Coefficient of friction for different Lubricant under 85C° in unit $\mu m$	71

<b>NO.</b>	<b>TITLE</b>	<b>PAGE</b>
5.6	Comparison of COF between lubricant with and without lubricant at 75°C and 85 °C	74
5.7	WSD of bearing ball by using Crude Glycerol as lubricant at temperature 75°C	75
5.8	WSD of bearing ball by using Refined Glycerin as lubricant at temperature 75°C	76
5.9	WSD of bearing ball by using Oleic Methyl Ester as lubricant at temperature 75°C	78
5.10	Averages of wear scar diameter for different lubricant under temperature 75C° in unit μm	79
5.11	WSD of bearing ball by using Crude Glycerol as lubricant at temperature 85°C	80
5.12	WSD of bearing ball by using Refined Glycerin as lubricant at temperature 85°C	81
5.13	WSD of bearing ball by using Oleic Methyl Ester as lubricant at temperature 85°C	82
5.14	Averages of wear scar diameter for different lubricant under temperature 85C° in unit μm	83
5.15	Comparison of COF between lubricant with and without additive at 75°C and 85 °C	84
5.16	Comparison of COF between commonly used lubricant with Palm oil-based lubricant at 75°C	86
5.17	Comparison of WSD between commonly used lubricant with Palm oil-based lubricant at 75°C	87



## LIST OF FIGURES

NO.	TITLE	PAGE
2.1	Solid surface layers	6
2.2	Mechanisms of abrasive wear	9
3.1	Synthesis of palm oil based TMP ester	20
3.2	Preparation of palm oil based TMP ester	20
3.3	A schematic of the four ball test machine	21
3.4	A schematic diagram of HFRR wear test	22
3.5	Wear scar diameter (WSD) and Coefficient of friction (COF) for different percentages of palm oil based TMP ester in OL	23
3.6	SEM micrograph from the stationary ball of different percentages palm oil-based TMP ester in OL	24
3.7	Relationship of friction with time under hydrodynamic lubricant	25
3.8	Schematic diagram of four ball tester apparatus	26
3.9	Effect of different loads on the wear scar diameter for different percentages of POME	32
3.10	Effect of different percentages of Pome on the wear scar diameter for different load.	32
3.11	Graph of POME percentages against flash temperature parameter for different wear loads.	33
3.12	Distribution of coefficient of friction	37
3.13	Wear scar diameter	38
3.14	Flash temperature parameter for RBD palm stearin and paraffinic mineral oil	39

<b>NO.</b>	<b>TITLE</b>	<b>PAGE</b>
4.1	Flow chat of the methodology	47
4.2	Summary of common ASTM Standard	48
4.3	Four Ball Tester	49
4.3	Sartorius Stedim Homogenizer	50
4.4	Four Ball Tester Apparatus and Digital Mass Measurement Instrument	53
	(a) Four Ball Tester	53
	(b) Internal Component of Ball Cup Assembly	53
	(c) Ball Cup Assembly with bearing ball	53
	(d) Digital Mass Measurement Instrument with Lubricants	53
4.5	Beaker with addictive and lubricant.	55
4.6	Basin with beaker	56
5.1	Graph of COF against Time for crude glycerin with and without additive under temperature 75°C	63
5.2	Graph of COF against Time for Refined Glycerin with and without additive under temperature 75°C	64
5.3	Graph of COF against Time for Oleic Methyl Ester with and without additive under temperature 75°C	65
5.4	Graph of COF against Time for all natural oil-based lubricant with and without additive under temperature 75°C	66
5.5	Graph of COF against Time for crude glycerin with and without additive under temperature 85°C	67
5.6	Graph of COF against Time for Refined Glycerin with and without additive under temperature 85°C	68
5.7	Graph of COF against Time for Oleic Methyl Ester with and without additive under temperature 85°C	69
5.8	Graph of COF against Time for all natural oil-based lubricant with and without additive under temperature 85°C	70
5.9	Wear scar of bearing ball by using Crude Glycerol as lubricant under temperature of 75 °C	75
5.10	Wear scar of bearing ball by using Refined Glycerin lubricants under temperature of 75 °C	76

<b>NO.</b>	<b>TITLE</b>	<b>PAGE</b>
5.11	Additive cut off the metal surface 1	77
5.12	Additive cut off the metal surface 2	77
5.13	Wear scar of bearing ball by using Oleic Methyl Ester lubricant under temperature of 75 °C	78
5.14	Wear scar of bearing ball by using Crude Glycerol as lubricant under temperature of 85 °C	80
5.15	Wear scar of bearing ball by using Refined Glycerin lubricants under temperature of 85 °C	81
5.16	Wear scar of bearing ball by using Oleic Methyl Ester as lubricant under temperature of 85 °C	82
5.17	Black messy area of wear	83

## LIST OF SYMBOLS

°	=	degree
°C	=	degree Celcius
%	=	percentage
$\mu$	=	friction coefficient
F	=	friction force
W	=	normal load
rpm	=	revolutions per minute
<i>mm</i>	=	milimeter
R <sub>c</sub>	=	Rockwell
ml	=	mililiter
kg	=	kilogram
K	=	Kelvin
g	=	gram
m	=	meter
Hz	=	Hertz
N	=	Newton
T	=	temperature, °C
wt	=	chemical composition, %
PS	=	palm stearin
sec	=	second
$\mu\text{m}$	=	micrometer

## LIST OF APPENDICES

<b>NO.</b>	<b>TITLE</b>	<b>PAGE</b>
A	Flow Chart	98
B	Gantt Chart	99
C	Frictional Force Plot	100
D	Frictional coefficient vs load for different % of POME	100
E	Wear Scar of ball Specimen	101
F	Wear worn surface observed using CCD camera	102
E	Digital Microscope	103
F	Oil-View Model 52DV Digital Viscometer	104

## LIST OF ABBREVIATIONS

HFRR	=	High frequency reciprocating rig
ASTM	=	American Society for Testing and Materials
COF	=	Coefficient of Friction
WSD	=	Wear Scar Diameter
VI	=	Viscosity index
POME	=	Palm oil methyl ester
TMP	=	Trimethylolpropane
OL	=	Pure lube oil
ANSI	=	American National Standards Institute
SAE	=	Society of Automotive Engineers
FSL	=	Final seizure load
SEM	=	Scanning electron microscope
RBD	=	Refined Bleached Deodorised
CCD	=	Charge-coupled device
PMO	=	Paraffinic mineral oil
PS	=	Palm stearin
FTP	=	Flash Temperature Parameter
EN	=	Chrome Steel Ball Standard
MWSD	=	Mean Wear Scar Diameter
CNT	=	Carbon Nano Tube
HHT	=	Carbon Nano Fiber

# CHAPTER 1

## INTRODUCTION

### 1.1 Overview

The tribology study of metal processing has been emphasized nowadays due to the trend of era is directed toward the machinery world. To increase the life span of machinery system, lubricant is needed. Global environmental awareness encouraged the replacement of mineral or synthetic lubricant with renewable, high biodegradability, sustainability and eco-friendly lubricant. Palm oil based lubricant constitute as one of the natural oil-based lubricant has the potential to replace the mineral lubricant as alternative lubricant for industrial processes. The performance of lubricants is mainly depends on the friction and wear characteristic.

A great friction and wear control for machining process can prevent rapid, wear and failure of machine, hence lubrication of machinery system can considered as vital part of any of the working parts in a machine. In order to reduce the usage of mineral oil, and relieve the amount of the demand on chemical or mineral oils in future, natural oil-based lubricant which is biodegradable source is chosen as study material to provide an alternative to replace mineral oils as lubricant. This project will focus on analyzing the friction and wear characteristic of natural oil-based lubricant – Palm Oil lubricant by conducting four-ball tester ( You Bai. 2011).

### 1.2 Problem Statement

When two or more surfaces have to move in contact or interacting with each other in relative motion, there will have some resistance to movement exit between both surfaces which is friction. Friction will reduce the effectiveness of the equipment itself and at the

same time will reduce the life span of equipment through the heat, wear and scar produce during friction occur between surfaces. The amount of friction between surfaces will change according to the various roughness of the surfaces. Friction between two interacting surface can be reduce by using lubricant. But the uses of petroleum based lubricants or mineral oil lubricants can pollute the environment either during or after use. Hence natural oil-based lubricant which has high biodegradability compared to mineral oil is applied to provide an alternative to replace the mineral oil as lubricant.

The tribology properties and effectiveness of the natural oil-based lubricant can be evaluated by using Four Ball Tester equipment by test the friction and wear characteristic for different types of lubricants. Based on the proposed, this project is aimed to investigate the friction and wear characteristic of selected natural oil-based lubricants and make a comparison with the commercial lubricants. Measuring of friction, wear, scar and viscosity of lubricants can be done by using bearings under different lubricants by using Four Ball tester equipment.

### **1.3 Objectives**

The objectives of this project are as follows:

- i. To obtain friction and wear characteristics of natural oil-based lubricants which consist of refined glycerin, crude glycerol and oleic methyl ester by conducting four-ball tester experiment.
- ii. To compare the friction and wear characteristics between the selected lubricants with commercial lubricants.