Faculty of Mechanical Engineering

EXPERIMENTAL INVESTIGATION ON TRIBOLOGICAL PROPERTIES OF NATURAL OIL-BASED LUBRICANTS AS SUSTAINABLE BIO-LUBRICANTS

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A thesis submitted in fulfilment of the requirements for the degree of Master of mechanical Engineering (Energy Engineering)

Faculty of Mechanical Engineering

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DECLARATION

I declare that this thesis titled “Experimental Investigation on Tribological Properties of Natural Oil-Based Lubricants as Sustainable Bio-Lubricants” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not currently submitted in candidature of any other degree.

Signature : ……

Name : ……

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Mechanical Engineering (Energy Engineering).

Signature : ……

Name : ……

Date : ……

DEDICATION

I dedicate this works for my parents, my wife, my daughter and the entire world.

ABSTRACT

Nowadays the depleting of crude oil become an escalated global issue. Bio-based lubricant is seen as the alternative to the conventional petroleum based lubricant. The similarities between the properties of bio-based lubricant with conventional lubricant and greener system of bio-based lubricant are the strong point of bio based lubricant. This work investigates the tribological properties of natural oil-based lubricants and prospects of Hexagonal Boron Nitride (hBN) as additive for the lubricants in order to find a suitable alternative to the conventional lubricant. hBN is considered as a good candidate among other nanoparticles for the lubricant additives due to their roller-like shape, polishing property, extremely small particle size and unique mechanical properties. The experiment is conducted to obtain the friction and wear characteristics by using four-ball tester set-up. Based on the result, the pure bio-based lubricant shows better anti-wear property and lower value of coefficient of friction (COF). By adding 0.01wt% hBN additive to the bio-based lubricant, the wear scar for the bio-based lubricant is reduced by 99%. For refine glycerin (RG) the COF value is reduced significantly with the present of the additive but the oleic methyl ester (OME) has the opposite effect.

ABSTRAK

Dewasa kini isu kehabisan minyak mentah menjadi isu global. Pelincir berasaskan semula jadi dilihat sebagai alternatif kepada pelincir berasaskan petroleum konvensional. Persamaan antara sifat pelincir berasaskan semula jadi dan pelincir konvensional serta pelincir berasaskan semula jadi yang lebih hijau merupakan kelebihan pelincir berasaskan semula jadi. Kajian ini mengkaji sifat-sifat tribologi pelincir berasaskan minyak semula jadi dan prospek hBN sebagai penambah untuk pelincir. Eksperimen dijalankan untuk mendapatkan sifat geseran dan hakisan dengan menggunakan set penguji empat bola. Hexagonal Boron Nitride (hBN) dijangka menjadi calon yang baik di kalangan nano partikel lain sebagai bahan tambahan pelincir kerana bentuknya yang seperti pengguling, sifat penggilap, saiz zarah yang sangat kecil dan sifat mekanikal yang unik. Dari hasil ujian, pelincir berasaskan semula jadi tulen menunjukkan ciri anti-pakai yang lebih baik dan pekali geseran (COF) yang lebih rendah berbanding pelincir konvensional. Dengan menambahkan hBN 0.01wt% kepada minyak pelincir berasaskan semula jadi, parut haus untuk pelincir berasaskan semula jadi dikurangkan sebanyak 99%. Untuk gliserin halus (RG) nilai COF dikurangkan dengan ketara dengan bahan tambahan tetapi metil ester oleik (OME) memberi kesan yang sebaliknya.

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LIST OF ABBREVIATIONS

ABBREVIATION		MEANING
CNT	**-**	**Carbon Nano Tube**
COF	**-**	**Coefficient of Friction**
FP	**-**	**Flash Point**
GF	**-**	**Glass Fibre**
GHG	**-**	**Green House Gas**
hBN	**-**	**Hexagonal Boron Nitride**
HHT	**-**	**Carbon Nano Fibre**
OME	**-**	**Oleic Methyl Ester**
PAEK	**-**	**Polyaryletherketone**
PTFE	**-**	**Polytetrafluoroethylene**
RG	**-**	**Refined Glycerin**
TG	**-**	**Thermographite**
cPs	**-**	**Centipoise**

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter discusses on the general introduction of the overall project. The introduction covers the background, problem statement, objectives and the scopes of the study.

1.2 Background of Study

Bio-based lubricants are known to be environmentally safe and economic sustainable (Schneider, 2006), (Bremmer & Plonsker, 2008). Besides, it has infinite resource and properties like petroleum-based lubricants (Schneider, 2006). By infinite resource, it means that bio-based lubricants are easily reproduced and highly sustainable compare to petroleum-based lubricants (Bremmer & Plonsker, 2008). Additionally, the fact that they are from renewable raw materials result in any accidental spill of used and unused lubricants will pose minimal risk to environment and living things compare to conventional petroleum -based lubricants (Biresaw, et al., 2017), (Miller, 2013). In terms of greenhouse gas (GHG) contributions, bio-based lubricants are considered to be non-emitters of GHG (Miller, et al., 2007), (McManus, et al., 2004) as opposed to petroleum-based products which are well known to be major GHG emitters.

As lubricant are initially used to assist in reducing the effect from wear and friction in systems (Shahnazar, et al., 2016). And since the science of controlling and managing wear, friction, and lubrication are known ad Tribology (Blau, 2008),(Bartz, 1978). Thus, tribological properties of a certain oil are the most accurate way to evaluate the value of the oil to act as a lubricant. The tribological properties gauge and mark the ability of the certain oil to act as lubricant and reducing wear and friction in a system. In short, the bio-based lubricant need to have tribological characteristic on par or above of the conventional lubricant in order to act as alternative to the conventional lubricant.

While tribological is an important aspect, flash point (FP) of a bio-lubricant is second to none in term of importance. The flash point is used to characterize the ignition and explosion hazards of these lubricants (Carareto, et al., 2012). Thus, the lubricants can be handled accordingly to FP of the lubricant.

Table1.1: Research gap in this field

Hexagonal Boron Nitride		(Talib & Rahim, 2018)			This study	
Carbon Nano Tube					(Tee, et al., 2017), (Fang, 2016)	
Carbon Nano Fibre						
Thermographite						
	Rapeseed (Arumugam, et al., 2014)	Jatropha (Ruggiero, et al., 2016)	Castor (Suhane, et al., 2017)	Canola (Reeves, et al., 2015)	Oleic Methyl Ester	Refined Glycerin

Table 1.1 shows several bio-based oil and additive that had been tested available. The red column is the area of study that is covered in this study. This study investigates Oleic

methyl ester (OME) and refine glycerin (RG) as alternative to the conventional petroleum-based lubricant.

1.3 Problem Statement

With the environmental awareness concern and initiative to preserve the environment, action must be taken to find feasible alternative to traditional petroleum-based lubricants. Thus, bio-based lubricant is seen as a potential alternative to the current conventional petroleum-based lubricant. Previous works find that bio-based lubricant has similar tribological properties to petroleum-based lubricant. Bio-based lubricant also a greener alternative which can be reproduce in short amount of time and more sustainable. This similarities and benefits drive this the study on looking the prospects of bio-based lubricant as alternative to petroleum-based lubricant.

Additive recorded have the ability to boost the performance of bio-based lubricant. Hexagonal boron nitride (hBN) specifically had improve numbers of lubricant (Shahnazar, et al., 2016). Thus, this study also studies the effect of hBN on the tribological properties of bio lubricant.

1.4 Objective

1) To investigate a potential of eco-friendly bio-lubricants, derived from renewable resources and provide feasible alternatives to conventional petroleum-based lubricants.
2) To investigate upon the tribological properties of natural oils by combining with solid powder additive.

1.5 Scope of Study

1) This study focuses on two types of natural oil-based lubricant: Oleic Methyl Ester & Refined Glycerin
2) The solid powder additive that is used in this study is Hexagonal Boron Nitride (hBN).
3) This study focuses on Tribological Properties such as coefficient of friction (COF) and wear test.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

More than 95% of these materials are currently mineral oil based. In view of their high ecotoxicity and low biodegradability, petroleum-based lubricants constitute a considerable threat to the environment (Schneider, 2006). In contrast, most lubricants and hydraulic fluids based on plant oils are completely biodegradable and low ecotoxicity. Moreover, bio-based lubricants oils display excellent tribological properties and generally have very high viscosity indices and flashpoints (Schneider, 2006). Thus, there are many study on the potential of bio-based oil as lubricants had been carry out, in chapter 2, discussion on previous study on the matter had been done. From the previous studies, some pre-experiment information can be obtained such as research gap and related past results. The information then can be used as the foundation during the process of planning the study.

2.2 Lubricant Properties

In the previous studies on lubricant properties, they are several properties that deem to be important which are flash point (FP), viscosity, tribology and additive. Each property is explained in the following sub-sections.

2.2.1 Flash Point

The Flash Point (FP) is related to the lowest temperature where a flammable liquid produces enough vapor pressure to start an ignition with just by the presence of heat and air (Crowl & Joseph, 2002). As temperature increases, the vapor pressure increases and the amount of evaporated flammable liquid in equilibrium with the air also increases. When the FP is reached, a simple ignition source can combust the mixture (Carareto, et al., 2012). Carareto (2012) also highlighting the importance of the experimental FP data in ensuring safe storage of flammable materials and appropriate application can be assigned. Below are the available previous studies on the FP of the lubricant.

Table 2.1: Previous Study on Flash Point

No.	Title	Author	Sample	Flash Point °C
1	Flash Point of Lubricating Oil	(Lab, n.d.)	Mineral oils	187.78-198.89
			Automotive and Diesel engine oil	218.33-237.78
2	Flash point for binary mixtures of methylcyclohexane, n heptane and p-xylene	(In, 2015)	Binary mixture	(-4.5)-25.3
3	Lubrication capabilities of amino acid based ionic liquids as green bio-lubricant additives	(Nagendramma, et al., 2017)	Amino acid derived ionic liquids	246
4	Flammability characteristics of pure hydrocarbons	(Albahri, 2003)	Hydrocarbon	216-417
5	Determination of flash point in air and pure oxygen using an equilibrium closed bomb apparatus	(Kong, et al., 2003)	dichloromethane	10.7

Conventional lubricants have flash point varies from 187.78°C – 198.89°C. Functioning as motion assistance, the longer the lubricant can retain the form and functioning as the lubricant the better the lubricant is. Thus, lubricant with higher the flash point is better as it can still be functioning at respective temperature and not ignite and cause malfunction to the system that supposed to be assisted. As the alternative to the conventional petroleum-based lubricants, the bio-based lubricants are expected to have equal or higher flash point than 187.78ºC as it is the minimum FP for conventional lubricant (Lab, n.d.).

2.2.2 Viscosity

Viscosity is a measure of resistance to flow of liquid due to internal friction of one part of a fluid moving over another (Hoekmana, et al., 2012). According to Ting and Chen (2011) viscosity of lubricant is a very important property in choosing a lubricant for hydrodynamic lubrication. Large viscosity of lubricant also requires large force against its own intermolecular forces in sliding motion between devices (Ting & Chen, 2011). If viscosity of lubricant is too small, it will cause surfaces between the devices to be rubbed directly and further damage the devices (Symon, 1971).

The viscosity of bio-based product is typically higher than that of petroleum-based product (Su & Liu, 2011). Thus, in this study the viscosity of selected bio-based lubricant and 5 types of conventional petroleum-based lubricant are measured.

2.2.3 Tribological Properties

Tribology is made up of two Greek words; “tribos” and “logos”, Which means “rubbing” and “word” respectively (Blau, 2008). As stated in section 1.2, tribology involves the science of controlling and managing wear, friction, and lubrication. There are many

disadvantages with the present of wear and friction in systems. Some of the major disadvantages are:

1. Failure of machineries: Occurs in engines, gears, bearings, etc. All of which are vital for the smooth operation of mechanical systems in various industries, including machinery, automotive, robotic, factories and etc (Demydov, et al., 2010).
2. Energy loss: Due to high frictions this tribological issue arise (Ferguson & Kirkpatrick, 2001). In a study conducted by Holmberg (2012), it was concluded that up to one third of energy from fuel is wasted due to frictional losses from engines and other moving parts such as the transmission, brakes, and tires. Their calculations also revealed that if a new friction reduction technology could be applied to passenger cars, friction loss would decrease by 18% in 5-10 years (results in saving 174,000 million euros globally), and by 61% in 15-25 years (results in saving EUR 576,000 million globally) (Holmberg, et al., 2012). Holmberg (2014) analysed trucks and buses and proved that 33% of fuel energy is spent on friction loss in their engines. Moreover, they showed that globally, 180,000 million L of fuel was consumed to overcome friction in heavy duty vehicles in 2012 (Holmberg, et al., 2014).

Table 2.2 shown below summarizes the studies that had been carried out on some bio-based and conventional lubricants.

Table 2.2: Previous research on tribological properties of substances

No.	Author	Sample	Wear test	COF test
1.	(Talib & Rahim, 2018)	Jatropha oil + Hexagonal Boron Nitride (hBN)	/	X
2.	(Biresaw, et al., 2017)	Soya Bean Oil	/	X
3.	(Suhane, et al., 2017)	Castor oil	/	X
4.	(Podgornik, et al., 2017)	Industrial grease + (Hexagonal Boron Nitride (hBN) / graphite)	/	/
5.	(Nehme, 2017)	Molybdenum Disulfide Grease	/	/
6.	(Gangwani, et al., 2017)	Group III Oil + Hexagonal Boron Nitride (hBN) and Polytetrafluoroethylene(PTFE)	/	X
7.	(Nagendramma, et al., 2017)	Polyol ester + Amino acid based ionic liquid	/	/
8.	(Panda, et al., 2017)	Polyarylether ketone(PAEK) + short glass fibers (GF) + [Hexagonal Boron Nitride (hBN) and/or Thermographite]	/	X
9.	(Chen, et al., 2017)	Si_3N_4 + Hexagonal Boron Nitride (hBN)	/	/
10.	(Tee, et al., 2017)	natural oil + Carbon nanotubes (CNT)	/	/