Faculty of Mechanical Engineering

# FRICTION AND WEAR CHARACTERISTICS OF BIO-LUBRICANT ENHANCED WITH hBN AND PKAC ADDITIVES

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# DECLARATION

I declare that this report entitled "Friction and Wear Characteristics of Bio-lubricant Enhanced with hBN and PKAC Additives" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ............................................

Name : ............................................

Date : ...........................................

# APPROVAL

I hereby declare that I have read this dissertation/report and in my opinion this report is sufficient in terms of scope and quality as a partial fulfilment of Master of Mechanical Engineering (Energy Engineering).

Signature :………………………………...

Supervisor Name :………………………………..

Date :………........................................

# DEDICATION

I would like to give a very special appreciation to my beloved friends and family for always been there in the time of need. Thanks for giving me continuous support in order for me to fulfill the needs of my Master Project. To my beloved mother, father, family and friends, thank you all for this.

# ABSTRACT

In recent years, development of recycle, renewable and sustainable products to replace fossil products is an essential and crucial aspects to environment, industrial and academic perceptions. The bases of most lubricants nowadays are from petroleum oils. There has been increasing demand for green lubricants and lubricants additives. Previous study on vegetable oil is a good alternative to replace mineral oil in lubricant but the price is high. Thus due to waste vegetable cooking oil and fat have created serious problems for their disposal. Further study in managing waste cooking oil as a lubricant enhanced with different type of additives; hexagonal boron nitride (hBN) and palm kernel activated carbon (PKAC) have been study in this project. The purpose of this study is to investigate the effect of hBN and PKAC additives on tribological characteristics of waste cooking oil (WCO) at different temperature performance. Garcinia atroviridis and Zinngiber officinale were used as a natural adsorbent to treat and recover the waste cooking oil. To formulate the bio-lubricant by using 0.1 vol.%, 0.3 vol.% and 0.5 vol.% of 70 nm hBN and 63 µm PKAC additives separately dispersed with WCO, and then the properties of bio-lubricant in term of flash point and viscosity index were measured. The experimental test was conducted by using four ball tribometer at different temperature setting of 27°C, 50°C and 100°C. This experiment used the standard test method of ASTM D-4172 condition B under the applied load of 392.4N (40kg) at a spindle speed of 1200 revolution per minute (rpm) for one hour. In summary, at low temperature the WCO without any additives be the lowest value of COF compared to other sample; but at higher temperature 0.3 vol.%hBN and 0.3-0.5 vol.%PKAC addition to the WCO could effectively improve the anti-friction performance of waste cooking oil. However 0.3vol.%hBN and 0.1v.% PKAC was good enough to improve the anti-wear performance start from low to high temperature. Beside that, 0.5 vol.% of hBN additive have positively impact in lubricant's properties (flash point and viscosity index) while PKAC additive can increased the flash point value but reduced the viscosity index of WCO. Overall, this study have contributed to our knowledged about the effectiveness of hBN and PKAC additives on tribological characteristics of waste cooking oil (WCO) in three difference temperature performance. This research study also can assist in meeting both customer demand and green technology.

# ABSTRAK

Kebelakangan ini, pembangunan kitar semula, produk yang boleh diperbaharui dan mapan untuk menggantikan produk fosil adalah satu perkara yang penting dan penting dari alam sekitar, industri dan persepsi akademik. Sebahagian besar asas pelincir digunakan pada masa kini adalah dari minyak petroleum. Terdapat peningkatan permintaan untuk pelincir hijau dan bahan tambahan pelincir. Sebelum ini, minyak sayur-sayuran adalah alternatif yang baik untuk menggantikan sumber-sumber mineral dalam bidang minyak pelincir tetapi dengan dengan harga yang tinggi. Oleh kerana membuang minyak masak sayur-sayuran dan lemak telah mencipta masalah yang serius pada penguraian mereka, kajian lanjut mengenai pengurusan sisa minyak masak sebagai pelincir dipertingkatkan dengan pelbagai jenis bahan tambahan; boron nitrida heksagon (hBN) dan kelapa kernel diaktifkan karbon (PKAC) telah dikaji didalam project ini. Tujuan kajian ini adalah untuk mengkaji kesan hBN dan PKAC tambahan kepada ciri-ciri tribological sisa minyak masak (WCO) pada suhu yang berbeza. Atroviridis Garcinia dan Zinngiber Officinale digunakan sebagai penjerap semula jadi untuk merawat dan memulihkan sisa minyak masak. Penghasilan bio-pelincir dengan menggunakan 0.1 vol.%, 0.3 vol.% and 0.5 vol.% daripada hasil penambahan70nm hBN dan 63μm PKAC tersebar secara berasingan dengan WCO dan kemudian sifat-sifat bio-pelincir dari segi takat kilat dan indeks kelikatan diukur. kajian eksperimen telah dijalankan dengan menggunakan empat bola Tribometer pada tetapan suhu yang berbeza dari 27°C, 50°C dan 100°C. Eksperimen ini dijalankan mengikut ujian standard ASTM D-4172 keadaan B di bawah beban kenaan 392.4N (40kg) pada kelajuan gelendong 1200 revolusi per minit (rpm) selama satu jam. Ringkasnya, pada suhu rendah WCO tanpa sebarang bahan tambahan mempunyai nilai COF yang rendah berbanding dengan yang lain; tetapi pada suhu yang lebih tinggi 0.3 vol.% HBN dan 0,3-0,5 vol.% PKAC yang ditambah didalam WCO boleh meningkatkan prestasi anti-geseran sisa minyak masak. Walau bagaimanapun 0.3vol.% HBN dan 0.1V.% PKAC cukup baik untuk meningkatkan permulaan prestasi anti-haus dari rendah ke suhu yang tinggi. Di samping itu, 0.5 vol.% HBN tambahan telah memberi kesan positif dalam sifat-sifat pelincir ini (takat kilat dan indeks kelikatan) manakala PKAC tambahan boleh meningkatkan nilai takat kilat tetapi mengurangkan indeks kelikatan WCO. Keseluruhannya, kajian ini telah menyumbang kepada berpengetahuan tentang keberkesanan hBN dan PKAC tambahan kepada ciri-ciri tribological sisa minyak masak (WCO) dalam tiga perbezaan prestasi suhu. Kajian penyelidikan ini juga boleh membantu dengan memenuhi permintaan pelanggan dan teknologi hijau.

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## LIST OF ABBREVATIONS AND SYMBOLS

| | |
|---|---|
| WCO | Waste cooking oil |
| hBN | Hexagonal boron nitride |
| PKAC | Palm kernel activated carbon |
| OSHA | Occupational Safety and Health Administration |
| Vol.% | Volume percent |
| Wt.% | Weight percent |
| COF | Coefficient of friction |
| WSD | Wear scar diameter |

# CHAPTER 1

# INTRODUCTION

This chapter is about introducing the beginning of the proposed research. The title of this research is “Friction and Wear Characteristics of Bio-lubricant Enhanced with hBN and PKAC Additives”. This research study contribute to our knowledge about the friction and wear characteristics of waste cooking oil enhanced with hBN and PKAC additives. The content which will be discussed in this chapter is the background of study, problem statement, thesis outline and scope and limitation.

## 1.1 Background of Study

In recent years, development of recycle, renewable and sustainable products to replace fossil products is an essential and crucial matter from environment, industrial and academic perceptions. Increasing environment awareness and growing regulations over pollution and contamination have accelerated the development of renewable and biodegradable lubricants (Kalam et al., 2011). Thus with the demand for high performance yet environmentally friendly, a lots of work have been carried out to look for alternative of mineral oil lubricant to something more sustainable.

Vegetable oil have high potential to be a good alternative resources that used as a lubricant and additive to replace conventional lubricants and additives because of their readily biodegradable nature, non-toxic and environmental friendly (Shashidhara and jayaram, 2010). Table 1.1 shows a few type of vegetable oil that used as a lubricants in industry applications nowadays. The triacylglycerol structure with long fatty acid chains of vegetable oil, making them amphiphilic in character. These triacylglycerol molecules in vegetable oils orient themselves with the polar end at the solid surface making a closed packed monomolecular or multimolecular layer resulting in a surface film that provides desirable qualities in a lubricant. Besides that, the triacylglycerol molecules of vegetable oil also can significantly improve its resistance towards wear and extreme pressure. Furthermore, due to vegetable oil have very low volatility it's have excellent viscosity properties and high molecular weight of the triglyceride molecule (W. Liew Yun Hsein, 2015).

Table 1.1: A few type of vegetable oil as a lubricants in industry applications. (Shashidhara and jayaram, 2010)

| Type of vegetable oil | Industry application |
|---|---|
| Olive | Automotive lubricants (engine). |
| Palm | Grease and rolling lubricant. |
| Castor | Greases and gear lubricants. |
| Safflower | Resins, enamels and diesel fuel. |
| Coconut | Gas engine oils. |
| Jojoba | Grease and cosmetic industry. |
| Canola | Tractor transmission fluids, penetrating, hydraulic oils, metalworking fluids and oils food grade lubes |
| Tallow | Steam cylinder oils, cosmetics and lubricants |
| Rapeseed | Biodegradable greases and chain saw bar lubricants. |
| Crambe | Grease, intermediate chemicals and surfactants. |
| Linseed | Coating, paints, lacquers, varnishes and stains. |
| Soybean | Paints, hydraulic oil, soaps, disinfectants, pesticides, metal casting/working, plasticisers, biodiesel fuel, Lubricants, printing inks, detergents, and coatings. |
| Cuphea | motor oil and Cosmetics |
| Sunflower | Grease and diesel fuel substitutes. |

The production of useful products or energy production is the latest approach for efficient waste management and utilisation of waste products across the globe. Waste vegetable cooking oil can be considered as a potential waste which can be utilized as energy source and raw material for chemical or biological processes (Panadare and Rathod, 2015). Huge quantities of waste vegetable cooking oils is available throughout the world, especially in the developed countries. Management of such oils pose a significant challenge because of their disposal problems and possible contamination of the water and land resources. Even though some of this waste vegetable cooking oil is used for soap production, a major part of it is discharged into the environment (Jasenka Petran et al., 2008).

Thin film coating by using nanolubricants have been proved to be a great variety of advanced in lubrication technologies (Gschwender et al, 2001). There is an increasing demand for nanotechnology in solid lubricant coatings that allow contacting surfaces to rub against one another with reduced friction and wear, as cost associated with disposal increase and environmental regulation regarding the use of lubricants begin tighter (Victor and W. Wong, 2012). Since 1950, the scientists and researchers are looking for environmental friendly additives that could help to maintain the key lubrication properties; thus by selected 70nm hexagonal boron nitride (hBN) and 63µm palm kernel activated carbon (PKAC) which is an natural carbon structures as an additives in this research study could help in gain our knowledge about their tribology. To study the tribological performance of waste cooking oil (WCO) as a lubricant; and the effect of hexagonal boron nitride (hBN) and palm kernel activated carbon (PKAC) additives on tribological performance of waste cooking oil (WCO) can help on finding the alternative way or a solution to minimize the used of mineral oil. This research study develop in order to meet both customer demand and green technology.

## 1.2 Problem Statement

The inflationary pressure and environmental, and toxicity issue of conventional lubricants caused the higher interest in the development of environmental friendly lubricants as it is related to a global shortage as well as poor biodegradability. The use of mineral oil-based lubricant and environmental-harmful additives has been discouraged by environmental legislation by OSHA and other international regulation authorities.

Increasing population leads to increase in the demand of food items such as grains, vegetables, milk and milk products, cooking oil which also leads to generation of kitchen waste. Among these kitchen generated wastes, waste cooking oil and fat have created serious problems for their disposal due to its slow degradation. Waste cooking oil disposed incorrectly into the kitchen sinks can solidify and hence block the sewer pipes. Further degradation of WCO in pipes may also cause corrosion of metal and concrete elements. However removal of WCO from sewer streams at sewage treatment plant adds extra cost to it. Due to waste cooking oil (WCO) is being generated large scale all over the world; hence it has devised serious problems of its waste management (Qingming, 2015).

Further study about managing waste cooking oil as a lubricant enhanced with different type of additives; hexagonal boron nitride (hBN) and palm kernel activated carbon (PKAC) could help to meet green technology demand and reducing cost of lubrication by increasing reliability with high performance lubricants.

## 1.3 Objective

1) To investigate the effect of hexagonal boron nitride (hBN) and palm kernel activated carbon (PKAC) additives on tribological characteristics of waste cooking oil.
2) To investigate the effect of tribological characteristics of waste cooking oil enhanced with hBN and PKAC additives in different operating temperature performance.

## 1.4 Scope and Limitation

This research focus on the tribological performance of waste cooking oil with different type of additives as a lubricant oil by using natural adsorbent; garcinia atroviridis and zinngiber officinale. This natural adsorbent were used to treat and recover the waste cooking oil. Then, the sample solution were prepare with different percent of waste cooking oil with hBN and PKAC additives. Blend all the sample with ultrasonic homogenizer and the flash point and viscosity index (VI) for each sample solution were identified. Next, run friction and wear test by using four ball tester machines with different temperature setting. The last scope for this project is to study and analyse the WCO with their additives on lubrications performance; in terms of coefficient of friction and wear scar diameter. However dealing with hBN and PKAC powder is a complicated issue and very difficult one, mainly because of their toxicity and propensity to agglomeration as a result of their high surface area. Even through the stability of powder is the key issue for its application; the limitation of this investigation includes the weakness to stabiliz e the powder-oil solution.

## 1.5 Thesis Outline

The project background, problem statement, objectives and scope of this research have been discussed in this chapter. Due to WCO and fat have created serious problems for their disposal. This research was conducted in managing waste cooking oil as a base oil of lubricant enhanced with different type of additives; hBN and PKAC. Carbon additive could reduce friction and wear between contacting surfaces; hBN and PKAC was selected as an additives in this project to act as an antiwear boundary film to decrease the wear rate and also to reduce the frictional force between the contacting surfaces (Abdullah et al., 2014). This project was run by using different percent of waste cooking oil, type of additives and temperature setting of four ball tester machines; this research to study more about the tribological characteristics of waste cooking oil enhanced hBN and PKAC additives.

## 1.6 Thesis Structure

For this report writing, total number of five chapters written. The chapters are introduction, literature review, methodology, results with discussion and finally conclusion together with few suggestions. In Introduction, there are total of four subtopics will be presented. The first part is to study the background of this bio-lubricant. From the background, the problem statements are summarized and explain in detail in a paragraph. Next, a few objectives will be set. However, to make it short, few research scopes and limitation of this research study will be addressed so that it will only cover few portions rather than carried out with broad research area.

Next chapter basically is the literature review. By having the objective from the previous chapter and scopes, the journal or other resources are searched thoroughly according to the set objective and limited by the scope. Personal argument will be presented in order to have better understanding to follow or amend the guideline from previous research.

As for Chapter 3, the methods to carry out this project are determined in a flow chart. From the literature review, some material and guidelines on the do and don’t is being mentioned clearly. Therefore for methodology, a correlation between the concept mentioned and steps to be carried out must be simultaneous. However, the crucial chapter to be carried out is Chapter 4. This chapter is to testify according to the objective. When the research is carried out, it is the best form to obtain an outcome which satisfies the objectives. The steps are to be followed as shown from the overall flow chart from Chapter 3 which is the methodology.

Finally, the last chapter is to give conclusion based on the overall project from problems answered by objective, methods to be carried out and research outcome. Conclusion obtained should be declared either it satisfies all objectives from the first chapter. In the same chapter also, few recommendation will be added so that the next researcher can carry out the same experiment with a better step and result accuracy.

# CHAPTER 2

# LITERATURE REVIEW

In this chapter, the research resources and literature review in the related field will be discussed thoroughly as it is an important step in this project to be done. It is an important method in order to get more understanding of this project and to gain ideas and improvements of the project. The research on various lubricants has been extensively carried out due to present of friction and wear in industrial applications that cannot be avoided. Hence, in this work, biolubricant was prepared from waste vegetable cooking oil with hBN and PKAC additives.

## 2.1 Tribology

Tribology is defined as the science and engineering of surface phenomena such as friction, wear, lubrication, adhesion, surface fatigue and erosion. Tribological design and materials selection play vital roles in the performance, operation and durability of all mechanical machines. Even our body faces tribological issues and problems especially in joints.

If friction and wear may be considered as the problems then lubrication is one of the solutions. About 2600 years, ancient Eygiptians used water to lubricate the soil over which they dragged the colossus and heavy stones to build pyramids. Later people used animal fats to lubricate chariot wheels. These inventions, though very simple in nature, have given birth to may later inventions and the industrial revolution. It is one thing to design a car, it is another to run it without a lubricant. In today's context lubricants are all natural or synthetic long chain organic materials (Jackson, 1987). They provide lubrication by virtue of their viscosity and ability to withstand high bearing essure and frictional heat.

Lubricants simply separate two solid surfaces from intimate contact when in relative motion against each other. This ability to separate surfaces and thus bear the load applied increases with the relative speed if there is a converging gap between the solid surfaces and the motion forces the lubricant to flow into this flow constraint. As a result, the rise in the hydrodynamic pressure will be sufficient to take the bearing pressure or the load applied between the two surfaces. Surfaces can also be protected by coatings and some surfaces modifications and treatment. This area of knowledge is known as surface engineering in tribology.

## 2.2 Lubricant

The major function of lubricant is to keep the moving/sliding surfaces apart as it can reduce friction and consequent destruction of material. The introduction of lubricants in between sliding/moving surfaces to reduce friction between them is called lubrication. Modern equipment need to be lubricated in order to extend their lifespan. Lubricant performs a number of major functions like lubrication, cooling, cleaning and suspending and protecting metal surfaces against corrosive deterioration (Ahmed and Nassar, 2011). Lubricants composed a base fluid and an additive package. The main function of the base fluid is to lubricate and act as a carrier of additives. The purpose of the additives is neither to enhance an already-existing property of the base fluid nor to add a new property. Viscosity, viscosity index, pour point, and oxidation resistance is the examples of already-existing properties meanwhile cleaning and suspending ability, anti-wear performance, and corrosion control is the examples of new properties (Obasi et al., 2014).