

DEVELOP FUTURE BIO-BASED LUBRICANT BY UTILISING NAN0-PARTICLES



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Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours

DEVELOP FUTURE BIO-BASED LUBRICANT BY UTILISING NAN0-PARTICLES

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A thesis submitted in fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours



Faculty of Mechanical and Manufacturing Engineering Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2021

DECLARATION

I declare that this project entitled " Develop future bio-based lubricant by utilising nanoparticles" is the result of my own research except as cited in the references. The Choose an item. has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours



DEDICATION

I dedicate this works to my beloved parents and my supervisor Dr. Muhammad Ilman Hakimi Chua Bin Abdullah, who offered unconditional love and support and have always been there for me. Thank you so much for giving me strength to finish my Final Year Project.



ABSTRACT

Different kinds of lubricants are obtainable all around the worldwide including mineral oils, synthetic oils, re-filtered oils, and vegetable oils. Mostly the lubricants that obtainable in the wholesale place are mineral oil extrated from petroleum oil in which that is not acceptable with the environment because of toxicity and low biodegradability ability. The use of vegetable oil as a lubricant has stimulated the interest of academics due to diminishing petroleum sources and environmental concerns. In comparison to mineral-based oils, vegetable-based lubricants have better real properties, corrosivity, and are limitless and biodegradable. Virgin biological oil or refined agricultural wastes may be used as a resource of bio-based lubricants. This thesis examined the virgin vegetable oil follow by utilizing the nanoparticles that used as additives to obtain an excellent tribology properties that can improve bio-based lubricants. This research found the nanoparticle that meet the basic requirement types and concentrations, then examine and find out the most suitable that can enhance wear protection and reduce friction. Hexagonal boron nitride (hBN) nanoparticles in place of lubricant additive was added into the vegetable oil to improve its physical and tribology properties. Four-ball-wear tests were completed on the extraction of vegetable oil along with the addition of hexagonal boron nitrate nanoparticles lubricated to each of the contact surface. As a results, nanoparticles improved the physical properties along with the good anti-wear and anti-friction characteristics of the lubricant mixtures comparing to the mineral oil. Vegetable oil have meet the basic criteria as bio-based lubricant and can replace the mineral oil as a new advanced renewable bio-based lubricant for industrial activities that concern to the environment and save cost.

ABSTRAK

Pelbagai jenis pelincir terdapat di seluruh dunia termasuk minyak mineral, minyak sintetik, minyak penapis semula, dan minyak sayuran. Sebilangan besar pelincir yang terdapat di pasaran adalah minyak mineral yang berasal dari minyak petroleum yang tidak dapat disesuaikan dengan persekitaran kerana ketoksikan dan tidak terbiodegradasi. Oleh kerana penurunan cadangan minyak dan masalah alam sekitar, pendekatan menggunakan minyak sayuran sebagai pelincir telah menarik perhatian para penyelidik. Sebagai perbandingan dengan pelincir berasaskan mineral, pelincir berasaskan minyak berasaskan sayur mempunyai sifat fizikal yang lebih baik, pelinciran tinggi, boleh diperbaharui, dan terbiodegradasi. Sumber pelincir berasaskan bio boleh menjadi minyak asli dara, atau sisa buah yang diproses. Tesis ini meneliti ekstrak minyak sayuran ke minyak nabati, dan nanopartikel digunakan sebagai bahan tambahan untuk mendapatkan pelumas berasaskan bio yang ditingkatkan secara teologi. Jenis dan kepekatan nanopartikel yang sesuai kemudian dinilai untuk meningkatkan perlindungan keausan dan mengurangkan geseran. Nanopartikel boron nitrida heksagon (hBN) sebagai bahan tambahan pelincir ditambahkan ke dalam sisa minyak sayur untuk meningkatkan sifat fizikal dan tribologinya. Empat ujian penggunaan bola dilakukan pada pengekstrakan minyak sayur dengan penambahan partikel nanopartikel hBN yang dilumasi dengan setiap sampel pelincir. Hasil eksperimen menunjukkan sifat fizikal yang lebih baik serta prestasi anti-haus dan anti geseran campuran pelincir berbanding minyak mineral. Minyak sayur dilihat sesuai untuk digunakan sebagai pelincir berasaskan bio baru yang dapat diperbaharui untuk aktiviti pembuatan yang sesuai dengan faedah penjimatan tenaga dan masalah alam sekitar.

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LIST OF ABBBREVIATIONS

hBN	- Hexagonal boron nitride
Al ₂ O ₃	- Aluminium oxide
ASTM	- American society for testing and materials
AFM	- Atomic force microscopy
Cd	- Cadmium
СООН	- Carboxyl group
CMVOs	- Chemically modified vegetable oils
CoF	- Coefficient of friction
CuO	- Copper(II) oxide
DLVO	- Deryaguin–Landau–Verwey–Overbeek
EHC	- Engineered hard chrome
EOR	Enhanced oil recovery
FA	- Fatty acid
FAO	- Food and agriculture organization
GDS	- Glow discharge spectroscopy
Fe ₃ O ₄	- Iron(II,III) oxide
MWNT	- N Multi-surface materials AL MALAYSIA MELAKA
PAO	- Poly alpha olefin
RTILs	- Room temperature ionic liquids
SEM	- Scanning electron microscopy
SWCNT	- Single surface carbon monotubes
USDA	- The United States Department of Agriculture
TiO ₂	- Titanium dioxide
WSD	- Wear Scar Diameter
XRD	- X-ray diffraction
ZnO	- Zinc oxide
ZrO ₂	- Zirconium dioxide

CHAPTER 1

INTRODUCTION

1.1 Background

Vegetable oils are the collection of fats that are derived from food stuff cereal grains, nuts, seeds, fruits and even food waste. Based on the research, we need to understand that not all of these vegetable oils are liquid oils and at the range of surrounding temperatures or constant pressure (Hammond, 2013). The usage of vegetable oils and animal fats for lubrication resolutions already practiced for a few centuries. With the invention of petrol and thus the accessibility of economy oils, alternatives became unpleasant and were left by the roadside. (Fox and Stachowiak , 2007) found that selecting the correct waste vegetable oil added with nano-particles that can extract to bio-based lubricant will leading a way towards to sustainable future. The waste vegetable oil for example coconut, banana, papaya, corn, avocado, hemp oil palm, and soybean are the natural oil or pure organic elements that usually accustomed produce bio-based lubricant. There is no doubt that vegetable oils have excellent and outstanding properties such as high flash point, good lubricity, high viscosity index, high biodegradability, low evaporative loss and environmental friendly regarding to their use as feedstock and bio-based oil for lubricants (Madanhire & Mbohwa, 2016). "Today vegetable oil are gaining

popularity and safe to use in variety field because of the excellent performance to our mother earth as the vegetable oil is a renewability resource, biodegradability, and easily decompose in the environment" (Gawrilow, 2003).

Bio-lubricants is also defined generally as materials that are supported biodegradable and renewable-based feed stocks (Madanhire & Mbohwa, 2016). Bio-based lubricant involves the annually renewable raw material utilized to construct the lubricant's base stock. Some samples of these base stock materials would be soybean, palm, rapeseed and sunflower products. For instance banana oil was used as lubricant since 1650BC (Gawrilow, 2003). These base stocks offers good lubricity, flash point and viscosity index properties but often are inferior in regard to their oxidation stability. Different kinds of oil are used in all fields of various projects mostly to drag out a long period of the worked machines by diminishing the existing of wear and grinding. Besides, bio-based lubricant derived from vegetable oil offers important environmental advantages in terms of its non-toxicity, biodegradability, renewability, and satisfactory performance in a wide array of applications (Lovell et al., 2006).

Recently, nanoparticles act a crucial characters as lubricant additives for their potential in emission reduction and improving gasoline economy. Nanoparticle may be a small particle normally less than 100nm, that undetectable by the human eye in order that it can display essentially extraordinary physical and chemical properties to their bigger material (Laurent et al, 2010). Why nano-particles are important to extract waste vegetable oil to bio-based lubricant? (Emami et al., 2005)explored that with the best nanoparticle in the extraction of vegetable oil, it can advance the performance for many industrial such as increase the storage and thermal stability, enhance the availability for food usage, coloring strength and industry manufacturing. Furthermore, the nano-particles such as triglyceride in vegetable oil provides awesome lubricity that contact to the metal surface, minimizing specific energy and cutting force. The nano-particles inside the vegetable coolant contains a big heat transmission coefficient that accelerate heat transmission above the tool-work piece boundary, and accordingly advance the external feature follow by decrease in turning force (Sharma et al., 2005).



Figure 1.1. Example bio-based lubricant extraction by utilizing nanoparticles UNIVERSITI TEKNIKAL MALAYSIA MELAKA

1.2 Problem Statement

It is expected that, around 55 % of all mineral oil traded global result in the surroundings through spills, total loss applications, accidents or explosiveness. Over 96 % of these resources are mineral oil based such as petroleum. In view of their high eco-poisonousness and low biodegradability, mineral oil-based make up a considerable threat to the environment. (Gusain & Khatri, 2015)stated that roughly 3.5 billion gallons of lubricants are traded once a year in South African. Researches also additionally prove that much of this mixture (about 70%) is not accounted for and result in drain, ground water, rivers, lake and on the ground itself, causing uncountable danger to the ecosystem, agricultural and wildlife.

To overcome the problems that still using inorganic lubrication, the whole world attempt to substitute the synthetically and fuel based lubricants into the disposal, cost effective and environment approachable lubricants. To achieve a sustainable stability, it's the time now to use the lubricants that having minimum adverse outcome on the environment. Thus, waste vegetable oil plays an important role to extract itself to lubricant in their natural forms. Biobased lubricant so called vegetable oil have an awesome lubricity, beyond compared to petroleum. In reality, their lubricity is so useful in some applications, such as tractor conveying and transmissions that having the problem of friction within materials must be added to minimize the clutch slippage" (Mobarak et al., 2014). Bio-based lubricants that extract from waste vegetable oil will be the replacements of the minerals oil-based lubricants due to their original physical properties and easy to dispose. Another source proved that the bio-based lubricant are beneficial as fundamental purpose in mechanical and manufacturing field. Last but not least, when it compare to the mineral oils the degradation percentage of vegetable oils 20-30% higher and that they are 94% eco-friendly. In fact, the use of bio-based lubricants can help to maintain our mother earth and forget about the demand on mineral oils in the future (Sharma et al., 2005).

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1.3 Objective

The objective of this project are stated as below;

- 1. To examine suitable vegetable oil as based oil for developing bio-based oil.
- 2. To formulate new bio-based oil from vegetable oil with addition of hBN nanoparticles as additives.
- 3. To test and analyse the performance of new bio-based lubricant.

1.4 Scope of Research

The scope of this research are as follows:

- 1. Developing the bio-based oil by using vegetable oil as a primary based oil.
- 2. Formulating pure bio-based oil accordingly to ASTM by addition of hBN nanoparticles. NIVERSITI TEKNIKAL MALAYSIA MELAKA
- 3. Testing the develop bio-based oil according to ASTM P417.
- 4. Analysing the surface petrology for develop bio-based oil.

CHAPTER 2

LITERATURE REVIEW

2.1 Problem of synthetic oil

Synthetic oils are delivered through cycles of the production of petrochemical industry crude products or in the hydro reactant interaction of hydrocarbon spine change after manufactured oil. On the planet, more than 85% of manufactured base-oils are delivered from three principle combination of materials that are poly-alpha-olefins (45%), esters, including dibasic esters, polyol esters (25%), and polyalkylene glycols (PAGs) (15%) (Schneider, 2006). Maximum majority completely manufactured oils are PAO oils. The reason is the way that oils of this sort get portrayed by a generally great productivity, yet additionally moderately exorbitant cost. Tragically, some engineered oils can likewise represent a danger to the climate. The reason is because the synthetic oil cause pollution toward the environment by contributing a massive amount of chemicals, waste and carbon emissions although the synthetic oils are cheap and easier to produce in large quantities.

Synthetic oil is produced into the surrounding as oil vapour and nano drops, representing a significant hazard to the surrounding (Guerra et al., 2018). Strength and impacts of connections of oil subsidiaries are firmly identified with the arrangement, discharge dimensions and recurrence at a given region, and characterisations of a gadget with an open cutting application. Mineral oils are a low biodegradability lubricant. Ferro and Smith wrote in 2007 that, "In the natural environment, oil of petroleum origin creates primary hazards for sawing operators, but also secondary hazards due to the accumulation of oils in plant, animal, and groundwater tissues." Lubricating oils created from raw petroleum are additionally a critical danger to oceanic environments.

As soil is a climate for an assortment of microorganisms and higher living organic entities, its defilement with oil based oils becomes risky and an adverse impact on natural life may happen. The legitimate working of the biological system might be upset. Mineral oil can stop up pores in the dirt, bringing about decreased air circulation and water penetration. Occurrence in the oil mixtures will lessen/restrict the penetrability of soils, thus, causing the disposal of soils because of O₂ deficiency. Throughout oil creation, store up and transportation, filtering and preparing, just as spills and releases of oil hydrocarbons regularly happen because of unexpected accident during oilfield progression, spillage from oil pipelines and capacity tanks, oil big hauler and big hauler spillage mishaps, oil well waxing, and during updates of treatment facilities and petrochemical creation gear (Chaerun et al., 2004).



2.1.1 Vegetable oil as a lubricant

The lubricity of the lubricant that extract from vegetable oil is well define as the feature that exhibits the characterisation of anti-wear and reduce friction. Bio-based lubricant performs when two, more moving metallic objects come into contact or sliding with each other and yet it will minimize the friction. Extracting vegetable oil as bio-based lubricant is common at this moment to support the resolution of 3R (Reuse, Reduce and Recycle). In modern decade, various type of vegetable oils such as jatropha oil, sunflower seed oil, palm oil, soy bean oil, and corn oil have been studied, and the findings show that they have the potential to be utilised as a substitute for mineral oil in a variety of applications. (Gunstone,1999) claimed that the vegetable oils have the properties of high melting point and proved that it is not contaminated organic compounds but mixtures, in which the sample could be fully solid, completely liquid, or commonly a combination of solid and liquid at any particular temperature.

Table 2.1 Typical Troperties of Conventional Transformer On and vegetable Ons					
Properties S	Conventional	Vegetable oil with	Vegetable oil with		
	mineral transformer	saturated fatty acid \geq	unsaturated fatty acid		
	oil	80%	$\geq 80\%$		
Breakdown strength	45	60	56		
(kv)					
Conductivity(S/m) at	(Mn 13 ⁻¹³	10-11	10-10		
20(°C)	کل ملیسیا ہ	ست, تكنع	اونتوم		
Density(kg/m ³) at	895	917	886		
20°C UNIV	ERSITI TEKNIK/	AL MALAYSIA M	ELAKA		
Flash Point (°C)	154	225	260		
Oxidation onset temp	207	282	192		
(°C)					
Pour Point (°C)	-40	20	-22		
Viscosity(cSt) at 40°C	13	29	37.6		

 Table 2.1 Typical Properties of Conventional Transformer Oil and Vegetable Oils

2.1.2 Types of vegetable oil

Vegetable oil have different characteristic and physical properties based on the source of waste generation. This can affect the quality of the product such as lubricant production. From this study, it shows that values of pour point, flash point, kinematic viscosity and so on as shown below Table 2.2. However, further investigation need to be done on more parameters to observe the suitability of waste vegetable oil for lubricant production.

Table 2.2 Physical Properties of Vegetable Oil						
Vegetable Oils	Iodine Value	Pour Point (°C)	Cloud Point (°C)	Kinematic Viscosity	Flash Point	Density at 15°C
				at 40 °C	(°C)	(g/cm ³)
Castor oil	83-86	-21	-18	(mm²/s)	229	0.960
Coconut oil	8-11	12.7	13.1	231	266	0.918
Cotton seed oil	90-119	-4 5	-0.5	34	234	0.918
Iatropha oil	82-98	SIA -6	11	34	225	0.94
Karanja oil	81-90	-4	2	38.8	212	0.9358
Linseed oil	168-204	-15	5	26-29	241	0.938
Mahua oil	58-70	11	20	37.18	238	0.945
Neem oil	81	7	13	35.8	200	0.918
Olive oil	75-94	-14	-11	39	177	0.918
Palm oil	48-58	23.6	25.2	39.4	252	0.919
Peanut/Ground	84-100	کا رحملس	4.5	u, 40,	2719	0.903
nut				. Q. V	and the second	
Rapeseed oil	98-105	TI 715 KN	KAL-2MAL	AYS5A ME	246	0.912
Rice bran oil	103	13	16	38.2	184	0.906
Rubber seed oil	104	18	25	33.89	228	0.928
Safflower oil	145	-7	-2	28.3	260	0.914
Sesame oil	104-116	-11	-8	36	260	0.918
Soybean oil	138-143	-12	-4	29	254	0.914
Sunflower oil	125-140	-15	-9.5	36	274	0.916

able 2.2 Physical Properties of Vegetable Oi

2.1.3 Physiochemical Properties of Vegetable Oil

Vegetable oil has numerous important and worthy physicochemical properties. They offer specialized benefits, dissimilar to the normal petrol based greases. It has high viscosity index, high lubricity, high flash point, and low evaporative losses. Generally, the vegetable oil-based illustrate a few amazing properties contrasted with mineral oils. Table 2.3 displays the effect of the relative of vegetable oils properties.

Table 2.5 Comparative analysis properties of vegetable ons		
Properties	Vegetable Oil	Mineral Oil
Density	940	880
Viscosity Index	100-200	100
Shear Stability	Good	Good
Pour Point, °C	-20+10	-15
Clod Flow Behaviour	Pour	Good
Miscibility with mineral oils	Good	
Solubility in water	Not miscible	Not miscible
Oxidation stability	Moderate	Good
Hydrolytic stability	Poor	Good
Sludge forming tendency	Poor	Good
Seal swelling tendency	Slight	Slight
4 ⁴ 4 ⁴	160° 61 61	V

 Table 2.3 Comparative analysis properties of vegetable oils

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2.2 Bio-Based lubricant

Bio-based lubricants can be defined as oil that are derived from a renewable source and biodegradable. Mostly will choose the vegetable waste or animal fat to extract as a bio-based lubricant. Any source can be extract as bio-based lubricant once the material meet the renewable and biodegradable requirements. Research showed that the bio-based lubricant are very useful to mechanical and industrial field due to their excellent physical properties. It is estimated that up to 60% of synthetic oil will be substitute to bio-based lubricant once the biodegradable oil release in the market. The reason why we choose bio-based lubricant compare to mineral oil because it has excellent lubricity, less toxic to environment, high viscosity index, renewable and eco-friendly, spill remediation and more safer.



Figure 2.1 A triglyceride molecule.

Plant oil also known as vegetable oil consists of two big parts of structural formula that are glycerol and fatty acids. Figure 2.1 shows the glycerol part consists of three linked hydroxyl groups follow by the fatty acids part in which formed from a long chain saturated FAs that attached to every hydroxyl group (COOH). Due to the long chain structure of vegetable oil, it is very easy to break or decompose and yet have a good biodegradable ability.

2.2.1 Tribological characteristics of bio-based lubricants

Based on (Syahir & Zulkifli, 2017) of the analysis of tribological characteristics, various types of testing techniques and application have been utilized in a few of study. Normally bio-based lubricant are renewability, low toxicity to environment and high biodegradability and result in as an excellent lubricating based oil. Usually bio-based lubricant at metallic surfaces exhibits a small coefficient of friction (COF) and high wear rate compared to mineral oils. And yet, these superior characteristics proved that vegetable oil suitable extract to bio-based lubricant or as a feedstock. Although bio-based lubricant is versatile, but there are also some factors that contribute and can affect the tribological analysis of the lubricant. Figure 2.2 showed the element that affecting tribological characteristics of bio-based lubricant.



Figure 2.2 Element that affecting the Tribological Characteristics of bio-based lubricant

2.2.2 Applications of bio-based lubricant

In 21st century, extract vegetable oil as bio-based lubricant in industrial become common because it can lead the whole world to the green future. Due to its excellent lubricity and low cost, many sector are looking for the most suitable vegetable waste or animal fats to extract as bio-based lubricant. The purity of vegetable oils must show common characteristics like thermal stability, lubricity and viscosity to fulfil the requirement of those sector. In addition, the vegetable waste help the sector increase the environmental concern to the application and have a high biodegradable ability so that the sector can meet the environmental regulation. And yet, bio-based lubricant sold in worldwide to replace the use of mineral oil.

Physical and chemical properties during a lubricant should have differs relying on the planned application. Normally, every lubricants must display the subsequent characteristics that are good thermal stability, high viscosity index, high boiling point, high freezing point, great resistance to oxidation, and excellent corrosion prevention capability so as to accomplish its full performance (Mobarak et al., 2014).



Figure 2.3 Application of bio-based lubricant in 2019

2.2.3 Potential of vegetable oil

Almost all advanced equipment relies on lubricants in some form or another. Oils used to lubricate surfaces that come into touch with one other, such as grease, oil, or hydraulic fluid, help move parts around more easily while also reducing friction and wear. Lubricants may be utilised for a wide range of reasons. Choosing the right lubricant for the job may boost the efficiency and dependability of equipment and its components by extending their lifetime and reducing wear and tear. Lubricants may be utilised in both open and closed systems. The environment is polluted when lubricants like saw chain grease and drilling fluids are released into open systems. Lubricants in closed systems aren't in contact with the outside world. Through leaks, broken pipes, and human mistake, lubricants are released into the environment, (Rudnick, 2013). Most lubricants used across the globe contribute to environmental contamination because of total-loss lubrication, leakage, or evaporation. Annually, lubricants are projected to be consumed at 50% and large amounts are discarded as waste, (Willing, 2001). As a result, biodegradable lubricants derived from sustainable and renewable resources are greatly sought after. As seen in Figure 2, a good lubricant should have a high viscosity index (VI), a high flash point, a low pour point, strong corrosion resistance, and a high oxidation stability.

Bio-based lubricants are materials that are free from toxic and have great biodegradability. Bio-based lubricants are not always made from vegetable-based oils, although they are often made from them. Because plants may be regrown, it can be classified as renewable. Synthesized triglycerides, which are partly sourced from high biodiversity sources such as animal fats, waste products, and glycerin, may also be used as bio-based lubricants. 'A commercial or industrial product (other than feedstuffs) that is comprised, in whole or in considerable part, of biological products or sustainable domestic agricultural resources (including animals and plants) or forestry materials,' according to the (United States Secretary of Agriculture, 2010). Because bio-based lubricants are made from renewable raw resources, they are considered sustainable. According to (Andreas Willing, 2012), the longterm viability of raw material applications may be divided into two categories: the source of the resources as well as the contamination created by them. When bio-based products (oleochemicals) reach the end of their useful life, they are discharged through different routes, with the organic molecules disintegrating into water and carbon dioxide. Because the quantity of carbon dioxide emitted matches the quantity of carbon dioxide taken up by plants from the environment, the greenhouse effect of oleochemicals is closed. As a result, it has no impact on the carbon dioxide equilibrium in the atmosphere. Mineral oil-based goods, on the other hand, increase carbon dioxide in the atmosphere and hence cause climate change, which is known to as indirect pollution. Figure 2.4 depicts the life span of lubricating obtained from renewable fuels.



Figure 2.4 Life cycle of bio-based lubricants. (Moukaddam H et.al., 2007)

2.3 Nanoparticles

Nanoparticles is an extremely tiny particles that measured in nanometres and their ranges are between 1 to 100nm in size. Nanoparticles are particles that undetectable or invisible by human eyes. It can be visible through microscope such as scanning electron microscope (SEM) to determine their physical properties such as size, shape and concentration. The development of nanotechnology nowadays boost the growth of nanoparticles unintentionally. Nanoparticles acts as a catalyst or additive to improve the lubricant performance under any condition. To meet the requirements of the excellent nanoparticles, it need to achieve three criteria that are able to dissolve through the body well, can interact with biomolecules on the surface of cell and high surface area to volume ratio.

Due to their sub-microscopic size, they already have necessary sensible attributes, and made nanoparticles may discover down to earth utilizes in an assortment of parts, including, designing, catalysis, medication and natural remediation.



Figure 2.5 3D structure of individual nanoparticles

2.3.1 Properties of nanoparticles

The characteristics of nanoparticles can be identified by using the reference of physical and chemical properties. The physical properties are agglomeration or aggregation state, size distribution, size, shape, specific diameter and surface area, aspect ratio, solubility, structure including crystallinity and flaw structure and the surface morphology or topography. While the chemical properties consists of phase identity, composition of nanomaterial including known additive and catalyst, structural formula or molecular structure, hydrophilicity or lipophilicity, and surface chemistry.

Besides, there are three important fact properties of nanoparticles that are co-related to huge explicit surface regions for example a 5nm width boron nitrate under a standard silver spoon approximately 7ml has a big surface region than twelve badminton courts and 25% of the relative mass of molecules in each nanosphere will be located at the surface. Next is the exceptionally multipurpose in the Free State for example a 5nm dimension nanosphere of boron nitrate takes a deposition level under gravity of 0.001 mm per day without some other additional influence. Lastly is to display what are known as quantum effects. Hence, nanoparticles have an enormous variety of arrangements, depend to the use of the merchandise.

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2.3.2 Nanoparticles to industrial field

The use of nanoparticles in Enhanced Oil Recovery (EOR) is likely one of the most common applications since it produces larger amounts of oil during recovery, resulting in a faster return from prediction. Various nanotechnology-based treatments are being considered, the most promising of which seems to be the use of nano-robots for continuous knowledge into the well cushion. Lately, (Ogolo et al., 2012)implemented some EOR experiments by utilizing various type of nanoparticles such as MgO, Al₂O₃, ZnO, ZrO₂, SnO₂, FeO, NiO and SiO₂ penetrated with silane to proof that the nanoparticles enhanced recovery and increased hydrocarbon production.

Next will be the improvement in equipment reliability. The obvious problem in the oil and gas industry is the utilization of materials fit for withstanding exceptionally destructive conditions. The utilization of sharp rough is featuring this issue, lessening the gear lifetimes, especially for pipes and warmth exchangers. The requirement to tackle these issues has prompted research in the field of nanotechnology, to create nanostructured coatings ready to build the corrosion resistance. The point is consequently to foster the production ready to diminish the erosion harm and the downtime because of preservation.

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Lastly, the use of nanoparticles for high-performance lubricant oils. The utilization of nanoparticles as additive to specific mixtures is conveying improvement in different industrial field, permitting the improvement of new superior items which will decidedly impact the connected industry. Another crucial revolution is presented by the utilization of a new era of anti-wear lubricant oils. The lubrication impact the various type of nanoparticles used as additives upon on material group and basically concerns the properties of typical nanoparticle materials.
2.4 Lubricant additives

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"The world of lubrication is one of diversity: Each machine, application and set of operating conditions demands a particular combination of lubricant properties and functions" (Abdullah, 2009). These requirements generate the necessity for a wide range of lubricant formulations, and base oils alone are not enough to deliver the necessary performance levels machines demand in most situations. To perform its intended functions, a lubricant must be carefully and precisely blended with the appropriate additives. Each additive in a lubricant formulation either enhances the base oil's innate properties or introduces additional properties.

Lubricant additive can act as antiwear agents. Antiwear agents go through with metallic surfaces, forming a sacrificial film layer to help prevent metal-on-metal contact. By reducing friction and wear, anti-wear agents may help prolong component life. These additives generally are suitable for moderate-temperature, moderate-load applications, especially if excessive sliding or rolling may occur. Besides, lubricant additive can prevent rust and corrosion. Rust and corrosion damage metal parts, often resulting in costs for repairs or replacement. Rust and corrosion inhibitors can help protect against this damage in one of two ways: Some of these additives are absorbed on metal surfaces, forming a protective film to guard against oxygen, acids and other corrosive substances. Other additives in this category are designed to neutralize the harmful substances, rendering them innocuous.

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2.4.1 Nanoparticles as lubricant additives



Figure 2.6 Basic role of lubricant additives

To be consider that nanoparticles are potential to eco-friendly as lubricant additives. Nanoparticles exist numerous benefits compared to organic molecules normally utilized as lubricant additives. Nanoparticles as additives can assist to reduce friction, dampening vibrations, enhance load bearing ability thus conserve energy, increase lubricity, improve the productivity of conveying system, reducing noise and anti-wear.

The main benefits of nanoparticles that have been used as lubricant additives in order to advance the production of lubricants due to their nanoscale effects, insensitivity to temperature, and excellent tribology characteristics.

2.4.2 Boron-based nanoparticles

Many researches has the interest on boron-based nanoparticles because of its load carrying and antiwear behaviours. Boron-based nanoparticles can be a reliable candidate for lubricant oil additive due to environmental friendly and thermally stable properties. Table 2.4 showed the summary researches on the properties of boron-based nanoparticles as lubricant additives.

Nanoparticle	Effect
Potassium borate (Adams et al., 1981)	Extreme pressure additive
Calcium borate overbased salicylate (Norman et al., 1998)	Antiwear
Nano-cerium borate (Hu et al., 2002)	Friction modifier
Titanium borate (Hu and Dong, 1998)	Antiwear
Hexagonal boron nitride (Hutchinson and Reid, 2007)	Boron nitride can
	withstand extremely high
	temperatures and high
	loads, it is also non-
Sanna	reactive, thermally
shi lila in in	conductive, electrically
يتي يتصليك متيسيا مارك	insulating, and is white in
UNIVERSITI TEKNIKAL MALAYSIA	appearance.
Hexagonal boron nitride (Mosleh et al., 2009)	Friction modifier, anti-
	wear
Hexagonal boron nitride (Abdullah et al. 2013)	Reducing coefficient of
	friction and scar diameter

 Table 2.4 Summary of publications about boron-based nanoparticles being used as lubricant oil additive.

Hexagonal boron nitride (hBN) has remarkable qualities, make it as an appealing exhibition upgrading option in contrast to inorganic strong lubricants, for example, charcoal and molybdenum (IV) sulfide.

2.4.3 Friction modifiers and anti-wear additives

The addition of nanoparticles into lubricant obviously decreases the coefficient of friction (COF) and increases the load-bearing capacity of the friction parts in manufacturing systems. There are variety of techniques and mechanisms such as mending effect, polishing effect, four ball testing, protective film and so on to determine the lubrication development of the nanoparticle that added in lubricating oil (Maharaja K et al., 2016). These mechanisms can be mainly classified into 2 groups, as shown in Fig. 2.7 In the beginning, rolling effect connected with nanoparticles on the lubricant surface to enrich and follow by nanoparticles suspended in lubricating oil play the part of ball bearings between the friction surfaces. Additionally, they provide a protective coating on the rough friction surfaces to some degree. The next impact of the presence of nanoparticles on surface improvement is the secondary effect. "The nanoparticles deposit on the friction surface and compensate for the loss of mass, which is known as mending effect follow by the polishing effect in which the roughness of the lubricating surface is reduced by nanoparticle assisted abrasion." (Zhang, Z. et al., 1997).



mending effect

polishing effect

Fig. 2.7 Possible lubrication mechanisms by the application of nano-oil between the frictional surfaces (Hwang, 2009).

To check the friction and anti-wear characteristics, it has been used different types of surface analysis techniques, such as scanning electron microscopy/energy dispersive spectrometer (SEM/EDS), atomic force microscopy (AFM), X-ray photoelectron spectroscopy (XPS), glow discharge spectroscopy (GDS) and X-ray diffraction (XRD) for the lubrication mechanisms to examine the friction on the surfaces under a series of standard friction test (Hwang, 2009).

2.4.4 HBN nanoparticles as additives

Several resources have been carried out lately on the properties of different types of organic and inorganic nanoparticles as lubricating oil additives on wear and friction (Xu Bin-Shi, 2004). Because of the outstanding tribo properties of nanoparticles, collected with their best environmental-friendly property and excellent self-repair ability to the damaged surface (Liu Wei-Min, 2003), nanoparticles have been chosen for an excellent substitution for traditional lubricant additives, especially at severe frictional conditions, such as high temperature, high load and high sliding speed. When the nanoparticles were added into any lubricant, hexagonal boron nitrate, hBN nanoparticles have absorbed much consideration and exhibited brilliant applications for their wear resistance properties and good friction reduction (Xue Qun-ji et al., 1997). Several influencing issues have to be consider and the tribo behaviours of hBN nanoparticles as catalyst was examined, for example sliding speed.

Moreover, in mechanical applications, friction lost is one of numerous components in energy utilization (Holmberg & Erdemi, 2017). To lessen grinding and wear, nanoparticles have been concentrated to be utilized as additive to benefit the automobile field. Nanoparticles of different combinations and sizes have shown specific levels of grating adjusting and aggressive to wear impacts that as of late detailed in the limit oil district, the expansion of nanoparticles can decrease the CoF up to 72%, and wear volume as great as 77%. The capability to lubricate the contact area will get restricted because of the separation of nanoparticles. So, hBN nanoparticle acts an important role to reduce the friction up to 70% during the combination with lubricant oil. The reduction of friction was completed by using ultrasonic dispersion directly before experiment. Because of the reduction of "shear" effect, the friction will increase with the separation of nanoparticles. And yet, nano-particles are suitable as lubricant additives.



Figure 2.8 Sample of Hexagonal Boron Nitrate

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter contains about the explanation of the methodology process that will be carried out in the experiment. The reason is to make sure that the aim of this research can be successfully accomplished. In this chapter I will discussed the tribological characterisation and properties such as antiwear, antifriction, viscosity index and etc of the banana peel with utilizing the hBN nanoparticle by using different types of method.

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Next, the sample will be used for characterization testing. The results of the characterisation testing will be analysed by using SEM. This project process for product was significant character in the product improvement. Lastly, the samples that meet requirements will be used as an addictive or catalyst to extract the waste vegetable oil. Insure all the necessary steps and levels are being done systematically and can be achieved at the desired time.

3.1.1 Flow chart

This research has several parts of process. In this project study will takes about 2 semesters, the project process is shown in Figure 3.1. The flow chart was described all the process to analyse the results of bio-based lubricant by utilizing nano-particles from the beginning until the end of the process.



Figure 3.1 Flow Chart

3.2 Material Selection

A large portion of lubricant utilized today still depend to the mineral oil in which extricated from petrol oil. Indicating to the measurement, around 38.9 billion huge loads of oils were applied in 2006 worldwide. Since the oil is valuable and broadly utilized, it is additionally turning into a natural hazard because of their harmfulness and non-biodegradability. Due to developing regard for the ecological issues, many industrial has been attempting to form biodegradable lubricant which can be utilized to substitute the use of mineral oil to bio-based lubricant. According to lately investigation, waste vegetable oils have the prospective to be extract as alternative lubricants for engineering and manufacturing applications because of their eco- friendly characteristics. Bio-based lubricant, specifically palm oil is one of the potential material that might be cultivate to substitute the petroleum based- oil as an alternative lubricant in the new era. Why choose palm oil? A stem of the oil palm fruit is the source of palm oil, an edible oil. With an average annual rainfall of between 1600 and 2200 millimetres, hot, humid tropical climates are ideal for agriculture. There must be never over than four months of rain in order for oil palms to thrive. 6 to 8 hours of direct sunshine each day in a temperature range of 27-33 degrees Celsius is ideal. Because of its high yield, one hectare of oil palm produces approximately 10 times more oil than a typical vegetable oil. The need for vegetable oil-based lubricants may be met by palm oil, which has significant potential. Over the last several decades, many studies have investigated palm oil's potential for usage in engine additives (S. Sapuan, 1995), as a lubricant for cool forward extruded, and in minimum quantity lubrication.

Other than palm oil, sunflower seed oil also a potential bio-based lubricant. Sunflowers thrive on soils that are rich, wet, and well-drained, with enough of mulch. Sunflower oil is derived from sunflower seeds and is widely used in cooking, as well as in the manufacture of margarine and biofuels. Sunflower oil is less expensive than olive oil (Sarquis, 2020). Sunflower variations differ in terms of fatty acid content (Carson, 1969), with some "high oleic" variants containing more unsaturated fatty acids than olive oil. Sunflower oils with a high oleic content have a number of properties that make them appropriate for lubricants, including oxidation stability and lubricity (Minami, 1999). According to one research, high oleic sunflower oil (HOSO) may be utilised to replace mineral oils in fabric and leather applications without causing technical issues or requiring facility modifications (Giovannelli

et al., 2006). Sunflower oil, when correctly prepared, is equivalent to mineral oil and hence a suitable alternative lubricant for chain saws.

Another option will be corn oil. Corn oil is a rapeseed cultivar that had undergone genetic modification to improve its nutritive value (low-erucic acid and low-glucosinolate rapeseed oil). Although animal fats make up the majority of both corn and sunflower oils, the level of methyl ester in corn oil is very low (less than 1 percent).



3.2.1 Vegetable oil as bio-based lubricant

3.2.2

To have a respond or responsibility to environmental protection, many researchers start to test on the performance of vegetable oil as lubricants and result in that it have the capabilities to be a good lubricant since its give a low coefficient of friction. Vegetable oil has been tested by several researches for different engineering application. Not only are vegetable oil renewable raw materials, but they are also biodegradable and non-toxic, making them suitable mineral oil alternatives. Based on research, the researchers investigated the characteristic of vegetable oil as a bio-based oil forming lubricant. Besides, vegetable oil such as palm oil has the potential to be substitute as biodiesel engine and hydraulic fluid as projected by the data and flow chart. In the future, the lubrication from the extraction of vegetable oil will be widely use in engineering and mechanical application due to its satisfactory results from the data. Result that provided showed banana peel has a great performance in term of lubrication and has the potential that can minimize the reliable on mineral oil.



A nanoparticle (or nanopowder or nanocluster or nanocrystal) is an insignificant molecule with at any rate one measurement under 100 nm. Nanoparticle investigation is at present a space of extreme logical examination, due to a widespread variety of expected applications in mechanical field, biomedical, manufacture field, and electronic fields. The construction even structure of nanoparticles are awesome because their structure consists of an extension between mass materials and nuclear or atomic. It is choose as additive because of their fine particles characteristics and other excellent properties.

3.3 Development of bio-based nanolubricants

Many researchers found that the development of bio-based lubricant become more important with the addition of nanoparticles. Scientists investigated different sustainable raw material like coffee pulp, proteins, vegetable oils, paper mill sludge, tree leaves, seaweeds, lignocellulose and other wastages, for the construction of bio-based were bioethanol, stimulants, adsorbent, lubricant, diesel and plastic. These bio-based nanolubricant are currently being utilized effectively at business level in many industrial country.

On the off chance that one considers oil today, the basic thing that glimmers at the top of the priority list is the petrol oil. Oil segments keep on framing the significant extent of oils. The fundamental establishment of practically all oil is the lube division which is procured from essential petrol. Wide usage of petro put together oils is with respect to the grounds that they have the longest channel stretch for instance the functioning presence of an oil, which decreases the replication of breakdown period of the machine as absolutely changing the oil takes a great deal of time.

Nowadays, there are significant quota of lubricants being use globally and result in polluting our mother earth, and yet many hard work needed to reduce greenhouse effect and climate change. These kind of lubricant will vaporise into the surrounding and the hazard will speed up turn out with endanger human life. Many researches trust that petroleum soon may no longer be use, thus they are examining for a cheap and renewable source of lubricant instead of petroleum. As we realize that non-edible vegetable oils were in used during the last couple of centuries. Even though some industries have been manufactured vegetable oil based on oriented items, there are still many kind scopes that can manufactured vegetable oils. Numerous countries like China, Japan, Bangladesh, India etc. have great potential of manufacturing edible and non-edible nanolubricants because those countries full of natural source. Several of environmental society and health management have pressured some of the heavy manufacturing industry to utilize bio-based oil instead of petroleum in these situation.

3.3.1 Extraction process to obtain based oil

In this research, there are two extraction process to obtain based oil that are traditional extraction method and soxhlet extraction method.

3.3.1.1 Traditional extraction method

The process was drawn on a lubricant sample extracted from banana peels sighting many reasons. The banana is a naturally occurring substance and is farmed in large scales for consumption. However, the peels left behind have not had many apparent uses. The said procedure allows for potential in uses for extracting products for commercial uses from it. As discussed above, many scholars have acknowledged the potential in banana skin for the selection of lubricant. To analyse the potential of banana peels as a lubricant, an extract within the sort of banana peel was created for more straightforward analysis. The banana peel was extracted manually without the usage of any expensive equipment. Use of any sort of chemical was also avoided for the sake of reducing the cost of extraction and restricting any harmful chemical usage. The method of banana peel extraction was kept simple with minimum steps involved to permit the emulation of the method easy. The process requires many banana peels, restricting its usage to places with a big number of banana peels. The formulation process as follows:

- At first, a significant number of banana peels were collected for the extraction. It's to be noted that fresh banana peels are considered favourable for the process; however, just in case of unavailability of such, other banana peels also can be used.
- From the collected banana peels, inside a part of the peels were scratched off and picked up separately and mixed. The scratched-off product was blended, employing a motorized blender.
- The remainder of the part of the banana peel left was then crushed, then the extract from that was collected. The skin residue which is then left-off are often used as a fertilizer or are often fed to the biomass plant.
- The extract collected from the left-off banana peel was then added to the scratched-off product then mixed with small quantity of water and was blended.
- Blended residue was then heated to thicken into a paste. This paste was left off to chill. Continuous stirring of the mixture while heating is required to stay the mixture from burning and allowing the gases produced to exit.

3.3.1.2 Soxhlet extraction method

Soxhlet extraction exists as a helpful apparatus for multi-purposes where the analyte is determined from the framework all in all or isolated from specific meddling substances. Test readiness of ecological examples has been produced for quite a long time utilizing a wide assortment of procedures. Dissolvable extraction of strong examples, which is regularly known as strong fluid extraction (likewise alluded to as draining or Lixiviation in a more right utilization of the physicochemical phrasing), is probably the most established technique for strong example pre-treatment. Traditional Soxhlet extraction stays as perhaps the most applicable methods in the natural extraction field. This statement is upheld by the twofold utilization of traditional Soxhlet that are as an extraction procedure in a given technique and become a grounded sample for examination of different extraction options.

Figure 3.2 shows a schematic diagram of a conventional Soxhlet device. Soxhlet extraction is a very simple technique and yet soxhlet extraction always the first choice for extract a new bio-based oil.



Figure 3.2 Soxhlet extraction apparatus. (Reproduced from Reeves RN (1994) Environmental Analysis. New York: John Wiley).

3.3.2 Formulation Process

The samples were processed to acquire just the hBN particles with the adsorption of a dispersion agent on the surface in order to determine the presence of a surface modification for hBN particles. The dispersed hBN sample was centrifuged at 50, 70 and 90 rpm for 10, 20 and 30 minutes at 75 °C to separate the particles from suspension, then any leftover vegetable oil was put in a bottle as references.

3.3.2.1 Ultrasonic dispersion

The application of ultrasonic dispersion usually is to disperse the nanosized particles into liquids form. It dispersed or segregate the nanosized of materials in liquids in order to break the particle completely.



Experimental Setup

The samples composition was prepared according to Table 3.1 and Table 3.2 shows the L9 orthogonal arrays for testing condition.

Table 3.1 Sample Preparation						
Types of nanoparticles	Concentration of nanoparticles	Vol.% SN-0W20	Concentration of surfactant agent (oleic acid)			
Hexagonal boron nitride (hBN)	0.3 vol% (1.15g)	9.2	0.3 vol%			
	0.5 vol% (0.115g)	99.65				
	0.7 vol% (0.23g)	99.6				

Loval	Parameter				
Level	hBn (vol.%)	Time (min)	Amplitude (rpm)		
1	0.3	10	50		
2	0.3	20	70		
3	0.3	30	90		
4	0.5	10	50		
5	0.5	20	70		
6	0.5	30	90		
7	0.7	10	50		
8	0.7	20	70		
9	0.7	30	90		

Table 3.2 L9 Orthogonal arrays Taguchi Method

The additive nano particles (figure 3.4), have the following characteristics that the average particle size is in the reading of 500 ± 100 nm with the purity > 98.5% while the Nitrogen content > 55%. The size full range is in the measurement of 100-1000nm and lastly the specific surface is approximately $23 \pm 3 \text{ m}^2/\text{g}$.



Figure 3.4 hBN before added vegetable oil

3.3.2.2 Dispersion of stability analysis

This methodology is to formulating a two phase for examples (solid-liquid) and (liquid-liquid) ready to disperse in order to achieve the stability of the product. Noted that the particle size will affect the stability. To make sure that the potential of dispersion is always in the stable state, electrophoretic light scattering (ELS) is used to monitor the condition of stability.



3.4 Bio-based lubricant characterization

Bio-based lubricants are materials that are relatively non - toxic or have great degradation rate. Bio-based lubricants are not always made from vegetable-based oils, although they are often made from them. Because vegetables may be regrown, it can be classified as renewable. Synthesized esters, which are partly sourced from diverse natural resources such as unsaturated fat, waste products, and glycerin, may have been used as bio-based lubricants. Because biobased lubricants are made from renewable raw resources, they are considered sustainable.

3.4.1 Viscosity index

The most significant of bio-based lubricant is viscosity. Viscosity requires the resistance to move and straight correlated to pressure, temperature, and film formation. VI was established by Dean and Davis in 1929 for purpose ASTM D 2270. It is empirically derived with a non-unit number. The greater the viscosity index, the more steady the viscosity across a range of temperatures, which is more desired. Normally the temperatures that measure the viscosity index are more likely at 40 °C to 100 °C. Table 3.3 shows the properties of vegetable oils compared to mineral oils.

5 Malu	Viscosity	Viscosity	Viscosity	Pour	Flash
2)0-000	40°C (cSt)	100°C (cSt)	Index	point, °C	point, °C
Coconut oil/ERSI	TI T27.7NIK	CAL 16.1 LAY	SIA 175ELA	KA 24	600
350 Neutral mineral oil	65.6	8.4	97	-18	252
Low erucic rapeseed oil	36.2	8.2	211	-18	346
High oleic sunflower oil	39.9	8.6	206	-12	252
Conventional soybean oil	28.9	7.6	246	-9	325
Banana oil	24.3	7.5	150	0	250
Palm oil	38.9	9.0	190	N/A	N/A

Table 3.3 Properties of vegetable oils compared to mineral oil (I. Gawrilow, 2004)

3.4.2 Flash Point

Flashpoint is the most minimal temperature where lubricant should be warmed before it vaporizes. Table 3.4 shows the flashpoint test of vegetable oils using the ASTM D92 method (Annu.B. ASTM Stand. I, 2007).

Table 3.4 Flash points of vegetable oils	s (A. Adhvaryu & S. Z. Erhan, 2002)
Oils	Flash Point (°C)
Soybean	240
Sunflower	252
Rapseed	240
Banana	250
Jojoba	248
Jatropha carcass	240
Corn	280
Frank Marina	JIEM Si in muni al
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3.4.3 Oxidation stability

(Erhan et al., 2006), have done oxidation stability analysis of vegetable oil lubricant. The used of Pressure Differential Scanning Calorimetry (PDSC) help obtained corrosion or oxidation properties. These properties are based on fatty acid structure. Composition of FA of soybean, banana and sunflower oil are presenting in Figure 3.6(a), 1(b) and 1(c), respectively. Unsaturated number banana is the highest compared to soybean and sunflower. This suggests that banana have more comparative quantities of saturated, monounsaturated and polyunsaturated FAs in the vegetable oils compared to soybean and sunflower.



Figure 3.6 The fatty acid composition on three types of vegetable oils bio-based lubricant (a) Soybean, (b) Banana and (c) Sunflower.

3.4.4 Rotating Disk Electrode (RDE)

The RDE strategy as of now has such wide spread use in business, military and modern research facilities. The RDE method has encountered a new resurrection because of instrumentation upgrades and improved abilities. The significant traits of the RDE method, i.e., no example readiness, quick and simultaneous analysis, effortlessness, versatility of the spectrometer and promptly accessible consumables keep on extending its utilization. Since the RDE strategy for oil examination has been in need for more than 40 years, an undeniable inquiry may be "the reason do you need a standard technique?" The appropriate response is straightforward, there is no perceived standard system for RDE spectrometers that is all around applied or perceived. The requirement for a standard test strategy has been shopper driven and mentioned by various oil investigation research facilities. In these long stretches of value cognizant shoppers and ISO certificate, standard test strategies are a way to guarantee a purchaser that testing is performed by an acknowledged and recognizable technique. In spite of the fact that it is a set up procedure, there is no standard test strategy that everything research facilities can hold fast to. The proposed test strategy for utilized oil examination by the RDE method is well headed to endorsement by ASTM. In the course of recent years, a few drafts have been composed and the necessary between research centre investigation has been effectively finished.





3.5 Friction and wear performance test

A four ball tester with rotational speeds 1200 rpm will be used to evaluate the friction and wear properties of vegetable oil as a bio-lubricant for a period of half an hour. The loads will be 40N. Base reference lubricants in this investigation were palm oil, sunflower seed oil and corn oil with the addition of hBN.

3.5.1 Four ball test

Four ball testing is known as worldwide because it can determine wear scar properties and coefficient of friction some more extreme pressure. This testing is widely used for evaluating the tribological properties because of its high accuracy. Coefficient of friction, antiwear along with the load carrying capacity of lubricating oils can be measured under standard working situation. The wear scar that display on the three static balls will minimize if a better lubricant is used to prevent wear.



Figure 3.8 Graphic drawing of a four ball tester (Abdullah et al. 2013)

3.5.1.1 Coefficient of friction

The coefficient of friction (COF) can be calculated using the formula of $f = \mu N$ after the four ball testing. COF is the maximum value of the frictional force divided by the normal force. COF calculation is used to determine the banana peel surface. In this testing, it also check the ability of the extraction banana peel whether it is performing under extreme condition. Thus, the result in the frictional characteristics of a material is reported systematically. The smaller the value of COF, the smoother the surface of the material.

3.5.1.2 Wear scar diameter (WSD)

The banana peel which was prepared was tested on a high temperature rotary tribometer for analyzing the tribological properties of the lubricant. The lubricant was subjected to variable loads and speeds for understanding the nature of the lubricant under different working conditions. Different observations were recorded for different conditions and are plotted to find out its nature. The quantities that were put under observations were wear and coefficient of friction experienced. All the results were measured digitally by the high-temperature rotary tribometer. The results were measured about change in time.

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3.5.2 Surface analysis

3.5.2.1 SEM

Scanning electron microscopy with energy dispersive X-ray analysis (SEM–EDX) is a well- known surface analysis method. It is a digital testing to let the surface become visible and more clearly. SEM can detect the surface fractures, flaws or corrosion. SEM is used in this research paper to investigate or explore the surface of banana peel is suitable for extracting as a bio-based lubricant. Hitachi S2300 Scanning Electron Microscope with 25 kV of accelerating voltage use to examine the morphologies of the specimen surface areas. The high magnification of the result enables to detect any flaws easily. Lastly, result on the banana peel with the addition of hBN was acquired by using SEM analysis. A microporous structure in Figure 3.9 was observed at a resolution of 1500× with the scan of the material and yet the image of banana peel was magnified that showed the particle size of 10 μ m.



Figure 3.9 Scanning electrode microscopic (SEM) analysis of banana peel.

3.5.2.2 Profilometer

Profilometer is another type of technique that obtain data based on the surface analysis. It can be used to measure the wear scar of the surfaces, waviness, roughness, and other finish parameters. Profilometer is a direct measurement technique easy that can be easily done using a physical analysis or by using light to get the accurate result.



Figure 3.10 Schematic diagram of a Profilometer

3.6 Sample preparation for utilization process

There are 27 types of sample has been produced by using the ultrasonic homogenizer for the dispersion of hBN which shown in Figure 3.11. The virgin oil was then fully utilized with the different volume of percentage according to different parameter that were 0.3%, 0.5% and 0.7%. The time was set in 10, 20 and 30 minutes respectively while the amplitude were in 50amp, 70amp and 90amp which shown in Figure 3.14. The reason of using ultrasonic homogenizer is to make sure that the sample of oil fully disperse the nanosized particles into liquids form and can proceed to the four ball test.





Figure 3.11 Palm oil with the additional of hBN



Figure 3.12 Sunflower Seed oil with the additional of hBN



Figure 3.13 Corn oil with the additional of hBN





Figure 3.14 Ultrasonic Homogenizer with different amplitude



CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This section focus and discuss on the overall result obtained from tribology test. The tribological testing result is represented in term of table, graph and scanning electron microscopy (SEM). The optimization process and explanation is elaborated in details in this chapter. The significant factor and parameter involved will be further explained.

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4.2 L9 Taguchi Method Orthogonal Array Optimization

In order to get an optimization result, L9 orthogonal array by Taguchi Method was designed to discuss on the element that affect the performance of the vegetable oil. The parameter that being analyse were hBN composition, time, amplitude response to wear scar diameter and coefficient of friction. The result was discuss in section 4.2.1.

4.2.1 Optimization for Coefficient of Friction (CoF)

Figure 4.1, 4.2 and 4.3 shows the mean of S/N ratio graph for three types of optimization on the CoF. Figure 4.1 shows the optimize value for palm oil with indicate by 0.70 vol. % (level 3) for hBN nanoparticles, 20 minutes (level 2) for time and 50 rpm (level 1) for amplitude respectively. Figure 4.2 shows the optimum value for sunflower seed oil indicate by 0.50 vol. % (level 2) for hBN nanoparticles, 20 minutes (level 2) for time and follow by 70 rpm for amplitude. Last but not least, Figure 4.3 also display the optimum value indicate by 0.3 vol. % (level 1) for hBN nanoparticles, 10 minutes (level 1) for time and 70 rpm for amplitude.



Figure 4.1 Optimization CoF of Palm Oil



Figure 4.3 Optimization CoF of Corn Oil

4.2.2 Optimization for Wear Scar Diameter (WSD)

Figure 4.4, 4.5 and 4.6 shows the main effect plots for S/N ratios for optimal value of wear scar diameter (WSD) for the vegetable oil which defined by the parameters. Based on the analysis in Figure 4.4, the highest S/N ratio obtained was 0.5 vol. % (level 1) for hBN nanoparticles, 10 minutes (level 1) for time and 50 rpm (level 1) for amplitude recpectively. Meanwhile, Figure 4.5 shows the optimum WSD for sunflower seed oil indicate by 0.7 vol. % (level 3) for hBN nanoparticles, 30 minutes (level 3) for time follow by 70 rpm for amplitude. Figure 4.6 shows the optimum WSD for corn oil indicate by 0.3 vol. % (level 1) for hBN nanoparticles, 10 minutes (level 1) for time and 70 rpm for the amplitude.



Figure 4.4 Optimisation WSD of Palm Oil



Figure 4.6 Optimisation WSD of Corn Oil

4.2.3 L9 orthogonal array used in Palm oil, Sunflower Seed oil and Corn oil

In this section, by using mean and S/N ratio, the influence of tribology factors such as volume percentage (vol. %) of hBN, duration, and amplitude on different reactions such as CoF and WSD is determined. To investigate the CoF and WSD of vegetal oil with the addition of hBN, Taguchi's "smaller the better" and "bigger the better" characteristics were chosen. To identify the statistically significant factors, the data collected were translated into mean and S/N ratio. The table below shows the S/N ratios for CoF and WSD. Finding the average S/N ratio for tests 1-3, 4-6, and 7-9, respectively, determines the S/N ratio of CoF for various vegetable oils with the addition of hBN at levels 1, 2, and 3.

The S/N ratio for CoF and WSD of palm oil with hBN is presented in Table 4.1. The average S/N ratio response table for CoF and WSD is shown in Table 4.1 as well. From the response plot for CoF and WSD (Figure 4.1 and Figure 4.4), the optimum volume percentage of hBN are at level 3, time at level 2 and amplitude of ultrasonic homogenizer at level 1 for minimizing CoF and WSD. And yet, the optimized result of palm oil that suitable replace the mineral oil is in level 8, which are 0.7 vol. % of hBN, 20 minutes and 50 rpm.

Table 4.1 Respond table of mean S/N ratio for CoF and WSD in Palm Oil (with hBN)						
	leiner min Parameter					
Level		COF	-10	- Q.	WSD	
	A, vol%	B , mins	C, rpm	A, vol%	B, mins	C, rpm
1	22.44	22.23	22.03	6.664	6.670	6.192
2	22.32	22.73	22.97	5.423	5.714	5.783
3	22.75	22.55	22.51	5.680	5.383	5.792
Delta	0.43	0.50	0.94	1.241	1.287	0.410
Rank	3	2	1	3	2	1

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The average S/N ratio of CoF and WSD for all the parameters at all values is calculated using the same approach. Table 4.2 shows the average S/N ratio response table for CoF and WSD. The optimal S/N ratio was determined using the S/N ratio analysis that the volume percentage of hBN in CoF are at level 2, time in minutes at level 1 and the amplitude at level 3. Similarly, the optimum volume percentage of hBN for WSD are at level 1, time in minutes at level 2 and amplitude at level 1. In the end, the optimized result of sunflower seed oil that suitable replace the mineral oil is in level 5, which are 0.5 vol% of hBN, 10 minutes and 90 rpm.

 Table 4.2 Respond table of mean S/N ratio for CoF and WSD in Seed Oil (with hBN)
 Parameter

Level		COF			WSD	
	A, vol%	B, mins	C, rpm	A, vol%	B, mins	C, rpm
1	20.80	20.79	20.78	-2.25804	0.07460	0.31703
2	21.40	21.48	21.24	-0.27558	0.55769	1.10614
3	20.98	20.91	21.16	1.88859	0.72268	-0.06820
Delta	0.60	0.69	0.45	2.16417	0.64809	1.17434
Rank	2	n 1	3	2	1	3
اويبؤم سيتى نيكنيكل مليسيا ملاك						

The S/N ratio for CoF and WSD of palm oil with hBN is presented in Table 4.3. The average S/N ratio response table for CoF and WSD is shown in Table 4.3 as well. From the response plot for CoF and WSD (Figure 4.3 and Figure 4.6), the optimum volume percentage of hBN are at level 1, time at level 3 and amplitude of ultrasonic homogenizer at level 2 for minimizing CoF and WSD. And yet, the optimized result of corn oil that suitable replace the mineral oil is in level 4, which are 0.3 vol% of hBN, 30 minutes and 50 rpm.
			Para	ameter			
Level	COF			WSD			
	A, vol%	B, mins	C, rpm	A, vol%	B, mins	C, rpm	
1	25.01	24.35	23.28	3.9183	1.2291	0.4258	
2	23.78	23.58	24.71	-0.4965	-0.9785	1.0942	
3	22.09	22.95	22.89	-3.6155	-0.4443	-1.7137	
Delta	2.92	1.40	1.82	7.5337	2.2076	2.8078	
Rank	1	3	2	1	3	2	

 Table 4.3 Respond table of mean S/N ratio for CoF and WSD in Corn Oil (with hBN)

 Parameter



4.3 Effect of Vegetable Oil before additional of hBN

Three types of vegetable oil which was prepared and tested on a fixed temperature four ball tester for analyzing the tribological properties of the lubricant. (Guglea et al. 2020), hBN was added to low-viscosity liquids to improve the wear resistance of bodies in contact, as full film creation to separate them is difficult to sustain in real situation. The lubricant was subjected to variable loads and speeds for understanding the nature of the lubricant under different working conditions. Different observations were recorded for different conditions and are plotted to find out its lubricity. The parameters that were put under observations were wear scar diameter and coefficient of friction. All the results were measured by the 75°C fixed temperature with 1200 rpm four ball tester. The results was measured under half an hour.

Lubricant	Applied	Load	Speed	WSD	WSD	WSD	Average	COF
Туре	Load	(N)	(Nm)	of Ball	of Ball	of Ball	of WSD	
• 1	(kg)		5	1	2	3		
	-			(mm)	(mm)	(mm)		
Palm Oil	40	392.4	1200	0.472	0.450	0.516	0.479	0.0750
Sunflower	40	392.4	1200	0.340	0.326	0.306	0.324	0.0705
Seed Oil	- All	Vn .						
Corn Oil	40	392.4	1200	0.352	0.360	0.362	0.358	0.1224
	ملاك	mar	A, 1	-	20,0	n per	اوىيۇ	
		10 March 10	"Annal"	10.75	at here	1. L. 1. 19 19 19 19 19 19 19 19 19 19 19 19 19	ALC: NAME: NO.	

Table 4.4 Result of vegetable oil before adding hBN



Figure 4.7 Comparison CoF between vegetable oil before adding hBN



Figure 4.8 Comparison WSD between vegetable oil before adding hBN



4.3.1 Image of Four Ball Tester

After each four ball-test of vegetable oil before the additional of hBN nanoparticles, wear scar was produced on the surface of the steel balls. Under an optical microscope connected to a computer, the wear scar left on each used ball was examined. The picture of the wear was recorded using dimension software, and its circumference was determined as illustrated in Figure 4.9. The wear scar is evaluated in a single direction in the four-ball test, with the average measurement of wear scar diameters created at every ball computed and documented. Based on the research in (Petro Industry News, 2021), the microscope can clearly observe the radius of the scars produced on the three statonary balls to an accuracy of 0.01mm. In Figure 4.9, ball A have the scar with the radius of 0.236mm, while ball B have the scar with the radius of 0.225mm and follow by the ball C with the radius of 0.258mm.



Figure 4.9 WSD of Ball A, B and C of Palm oil before the additional of hBN nanoparticles

In Figure 4.10, ball A have the scar with the radius of 0.170mm, while ball B have the scar with the radius of 0.163mm and follow by the ball C with the radius of 0.153mm. Compare to palm oil, the average of wear scar diameter in sunflower seed oil has the smallest radius after the observation from the optical microscopy.



Figure 4.10 WSD of Ball A, B and C of Sunflower Seed oil before the additional of hBN nanoparticles

In Figure 4.11, ball A have the scar with the radius of 0.344mm, while ball B have the scar with the radius of 0.348mm and follow by the ball C with the radius of 0.440mm. Compare to others vegetable oil, the average of wear scar diameter in corn oil has the largest radius after the observation from the optical microscopy.



Figure 4.11 WSD of Ball A, B and C of Corn oil before the additional of hBN nanoparticles

4.3.2 Scanning Electron Microscopy (SEM) before utilization

The morphologies of the worn ball surfaces were analysed by scanning electron microscopy (SEM). The SEM micrographs in Figure 4.12, 4.13, 4.14 correspond to center of worn scar on the disks (1000x magnification) under various lubricating conditions and the value of WSD (wear scar diameter) of ball. With these images, it is possible to evaluate the anti-wear ability of oil base. Worn surface for vegetable pure oils (Figure 4.12, 4.13, 4.14) shows almost no sign of severe scuffing and it is smoother and flatter than worn surface for vegetable oils with the addition of hBN nanoparticles.

The wear scar of palm oil before the addition of hBN is shown in Figure 4.12, which was scanned at 100 m by SEM. SEM measurements revealed a wear scar diameter of 479.0 m. As may be seen in Figure 4.12, it seems that apparent wear is classified as adhesive wear. Adhesive wear occurs when a high load is applied between the contacts of two ball bearings, causing the ball bearings to deform and adhere to one another, resulting in a friction effect (Abdullah et al. 2013). In this scenario, the friction created at the ball bearing's surface created a rolling motion that later became a sliding motion.



Figure 4.12: Wear scar diameter of Palm oil at 100 µm (a) and SEM microscope of worn surface on a ball (b).

Figure 4.13 shows the wear scar of sunflower seed oil before the additional of hBN scanned at 100 μ m by SEM. The wear scar diameter obtained from SEM is 324.0 μ m. According to Figure 4.13, there are almost no wear scar in the image. Based on (Nikiforidis et al 2013), this happened might due to sunflower seeds oil contain double the amount of water compared with other vegetable oil and this may explain the denser sunflower seed oil structure. Inside the Figure 4.13 also shows the oxide layer. The oxide layer is used to protect the surface of the metal to avoid further corrosion.



Figure 4.13: Wear scar diameter of Sunflower Seed oil at 100 µm (a) and SEM microscope of worn surface on a ball (b).

Figure 4.14 shows the wear scar of corn oil before the additional of hBN scanned at 100 μ m by SEM. The wear scar diameter obtained from SEM is 358.0 μ m. From the observation, the wear scar is produced outside the diameter. This might due to human error. It is not placed in a proper position. And yet, the wear scar diameter outside is more obvious than the scar inside. It also have a normal sliding direction that show adhesive wear with a little debris. It can conclude that corn oil still can improve it's tribology characteristics through additional of nanoparticles.



Figure 4.14: Wear scar diameter of Corn oil at 100 μ m (a) and SEM microscope of worn surface on a ball (b).



4.4 Effect of hBN nanoparticle on the COF

The results can be compared to standard values and additional of the nanoparticle between the three types of vegetable oil that are palm oil, sunflower seed oil and corn oil. The standard value of the coefficient of friction between the virgin oil is expected to be close compare to the condition with the additional of hBN. As evident from table and figure below, the observed coefficient of friction of virgin oil is less than the vegetable oil with the additional of hBN. (Zhao et al. 2019), the values of the coefficient of friction between the vegetable oil with the additional of hBN are always more than the standard value and follow a pattern of increase and then stable with the increase in time.

4.4.1 Result for Palm Oil with an addition of hBN

Table 4.5 illustrates the results of palm oil studies employing L9 orthogonal arrays, which were carried out using an ultrasonic homogenizer, four ball tester, and a scanning electron microscope (SEM). There were nine samples done based on various compositions produced by the Taguchi technique, each of which effects the coefficient of friction in distinct ways (CoF) After the observation of the L9 orthogonal array result, the optimization composition is generated. It can be clearly observe in Figure 4.15 that the optimized CoF is in level 8, which are 0.7 vol. % of hBN, 20mins of time and 70 rpm of amplitude. The medium level will be in level 3, which are 0.3 vol. % of hBN, 30 mins of time and 90 rpm of amplitude. The worst CoF level is level 9 that have the biggest average value of CoF, 0.0912 µm with the 0.7 vol. % of hBN, 30 mins of time and 90 rpm of amplitude.

rusic the Result Cor of I and On With IDI										
L9	hBN, vol%	Time, mins	Amplitude	CoF						
1	0.3	10	50	0.0782						
2	0.3	20	70	0.0702						
3	0.3	30	90	0.0682						
4	0.5	10	50	0.0783						
5	0.5	20	70	0.0708						
6	0.5	30	90	0.0810						
7	0.7	10	50	0.0756						
8	0.7	20	70	0.0832						
9	0.7	30	90	0.0912						

Table 4.5 Result CoF of Palm oil with hBN



Figure 4.15 Graph CoF Palm Oil with hBN

4.4.2 Result for Sunflower Seed Oil with an addition of hBN

The same procedure of data aquisition were recorded directly using the four ball test machine. Below the Table 4.6, it shows 9 different samples composition of hBN. The optimized sample will be in level 5, which have 0.079 µm of CoF. The optimisation value in level 5 consists of 0.5 vol. % of hBN, 20 mins for time and 70 rpm of amplitude. The medium value of CoF will be in level 1. There is a little bit different compare to level 5 because in Figure 4.16, it showed unstable in 450 seconds and end up with 0.0878 µm of CoF. An obvious fluctuation displayed below the Figure 4.16 is level 9. Level 9 is the worst resistant to CoF that have 0.7 vol. % of hBN, 30 mins of time and 90 rpm of amplitude.

Table 4.0 Result Cor of Sunflower Seed off with nBN										
L9	hBN, vol%	Time, mins	Amplitude	CoF						
1	0.3	10	50	0.0878						
2	0.3	20	70	0.0852						
3	0.3	30	90	0.0931						
4	0.5	10	50	0.0872						
5	0.5	20	70	0.0789						
6	0.5	30	90	0.0895						
7	0.7	10	50	0.0912						
8	0.7	20	70	0.0891						
9	0.7	30	90	0.0957						



Figure 4.16 Graph CoF Sunflower Seed Oil with hBN

4.4.3 Result for Corn Oil with an addition of hBN

Table 4.7 shows the results of corn oil after the addiitional of hBN. From Table 4.7 below, it displays the average range of CoF from 0.0537 μ m to 0.0848 μ m. The optimized value in corn oil is in level 2, which took 0.3 vol. % of hBN, 20 mins of time and 70 rpm of amplitude. Below the graph of Figure 4.17, the result is under control and not much fluctuation happened in corn oil after 200 seconds. It can conclude that level 2 is in medium condition and level 7 is in the worst CoF. In the worst level of sample 7, it took 0.7 vol. % of hBN, 10 mins of time and 50 rpm of amplitude.

Table 4.7 Result CoF of Corn oil with hBN									
L9	hBN, vol%	Time, mins	Amplitude	CoF					
1	0.3	10	50	0.0603					
2	0.3	20	70	0.0537					
3	0.3	30	90	0.0547					
4	0.5	10	50	0.0435					
5	0.5	20	70	0.0794					
6	0.5	30	90	0.0784					
7	0.7	10	50	0.0848					
8	0.7	20	70	0.0681					
9	0.7	30	90	0.0841					



Figure 4.17 Graph CoF of Corn Oil with hBN

4.5 Effect of hBN nanoparticle on the WSD

A comparison result of wear between vegetable oil before and after the additional of hBN nanoparticles was conducted in this experiment to determine the effects of percentage volume of the additive, time, and speed on the wear scar diameter. Figures 4.16, 4.17 and 4.18 shows the wear scar diameters at different conditions. The wear data were analyzed by the L9 orthogonal array using the best Taguchi method. (Kraipat, 2013) state that the criterions for choosing the right sample was the 'small is better'. Time (mins), speed (rpm), temperature (°C), the addition of hBN additive, and the interconnections among such components all impact the wear scar diameter (mm).

4.5.1 Result for Palm Oil with an addition of hBN

Table 4.8 clearly shows that the time and the relationship between additive and speed are the factors that substantially impact wear scar for additive hBN in palm oils. As previously indicated, the hBN additive provides a protective coating on the surface, reducing direct contact between surfaces and resulting in a smaller wear scar diameter (Kraipat, 2013). Because the rubbing balls have been in touch for a longer distance throughout the same testing time, speed has an effect on the wear scar. And yet in the Figure 4.18, palm oil with the addition of 0.3 vol. % hBN, 30 mins of time and 90 rpm of amplitude marked as the optimized WSD. Meanwhile, level 8 and level 9 are in the medium and worst categories of WSD respectively with the same volume percentage of hBN but different time and amplitude.

τo	1 DM	ALAYS/A	A 1'	MICD C	MICD C	MUCD C	
L9	hBN, 🕚	Time,	Amplitu	WSD of	WSD of	WSD of	Average
	vol%	mins	💡 de	Ball 1	Ball 2	Ball 3	of WSD
	E.		3	(mm)	(mm)	(mm)	
1	0.3	10	> 50	0.472	0.454	0.450	0.459
2	0.3	20	70	0.456	0.474	0.452	0.461
3	0.3	30	90	0.470	0.492	0.456	0.473
4	0.5	10	50	0.468	0.468	-0.478	0.471
5	0.5	20	70	0.624	0.626	0.608	0.619
6	0.5	30	90	0.518	0.510	0.552	0.527
7	0.7	10	50	0.478	0.456	0.452	0.462
8	0.7	20	70	0.516	0.494	0.450	0.487
9	0.7	30	EK90KA	0.620	0.620	0.634	0.625

Table 4.8 Result WSD of Palm oil



Figure 4.18 WSD of Palm oil with hBN

4.5.2 Result for Sunflower Seed Oil with an addition of hBN

Table 4.9 shows the result of the additon of hBN nanoparticles into sunflower seed oil using ultrasonic homogenizer. From the table, the wear scar diameter shows the less amount of hBN in the sunflower seed oil, the smaller the wear scar diameter produced. In Figure 4.19, the optimum WSD were in level 4 that took 0.5 vol% of hBN, 10 mins of time and 50 rpm of amplitude. This result proved that even a little amount of nanoparticle added in the based-oil is already enough to enhance the properties of lubricant, (Shahnazar et al. 2016). Level 8 will be in the medium range of WSD. It took 0.7 vol. % of hBN, 20 mins of time and 70 rpm of amplitude. The worst WSD is in level 1 which took 0.3 vol% of hBN, 10 mins of time and 50 rpm of amplitude.

L9	hBN,	Time,	Amplitu	WSD of	WSD of	WSD of	Average
	vol%	mins	de	Ball 1	Ball 2	Ball 3	of WSD
	A.	X	-	(mm)	(mm)	(mm)	
1	0.3	10	5 50	1.258	1.128	1.198	1.195
2	0.3	20	70	0.880	0.984	0.876	0.913
3	0.3	30	90	1.010	0.978	1.018	1.002
4	0.5	10	50	0.846	1.024	0.964	0.945
5	0.5	20	70	1.090	1.292	1.170	1.184
6	0.5	30	90	0.958	0.966	1.024	0.983
7	0.7	10	50	0.908	0.826	0.856	0.863
8	0.7	20	70	0.732	0.796	0.760	0.763
9	0.7	30	90	0.848	0.746	0.778	0.791
	LININ/	COOLT I TR	-IZNIIIZA	L BEAL AN	VOLA ME	1. 8.17.8	

Table 4.9 Result WSD of Seed Oil

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Figure 4.19 WSD of Sunflower Seed oil with hBN

4.5.3 Result for Corn Oil with an addition of hBN

The dispersion of hBN nanoparticles into the corn oil are expressing that the various data of wear scar diameter (WSD) that influenced by the volume percentage. From Figure 4.20, the volume percentage of level 4 and 6 contained the same amount of hBN but still the level 4 had the lowest WSD by 0.611 mm. This is due to the difference time and amplitude which level 4 was in 10 mins and 50 rpm. This can proved that the previous research (Abdullah et al. 2013) state the effect of the volume percentage of hBN is affecting the base-oil in terms of CoF and WSD obtained.

		=					
L9	hBN,	Time,	Amplitu	WSD of	WSD of	WSD of	Average
	vol%	mins	de	Ball 1	Ball 2	Ball 3	of WSD
				(mm)	(mm)	(mm)	
1	0.3	10	50	0.672	0.688	0.582	0.647
2	0.3	20	70	0.630	0.696	0.618	0.648
3	0.3	30	90	0.616	0.634	0.598	0.616
4	0.5	10	50	0.594	0.626	0.614	0.611
5	0.5	20	70	1.864	1.644	1.818	1.775
6	0.5	30	90	1.072	1.078	1.132	1.094
7	0.7	10	50	1.518	1.658	1.784	1.653
8	0.7	20	70	1.160	1.246	1.250	1.219
9	0.7	30	90	1.806	1.786	1.598	1.730

Table 4.10 Result WSD of Corn Oil



Figure 4.20 WSD of Corn oil with hBN

4.6 Effect of hBN nanoparticle on the Scanning Electron Microscopy (SEM)

After the experiment was finished, the wear characteristics of the steel ball bearings were measured and studied using an optical and scanning electron microscope (high resolution) at a high magnification (100 μ m) (half an hour run time). The wear scar diameters were measured using micrographs, and the average value of the diameters was calculated using the ASTM D4172-B standard.

4.6.1 Result for Palm Oil with an addition of hBN nanoparticle

Figure 4.21, 4.22, 4.23 shows the comparison of WSDs between the optimum, medium and worst after the additional of hBN nanoparticles. . From the figures, it can be seen that the wear scar diameter increased with increase in the applied load. Under different volume percentage of hBN (0.3 vol. %, 0.5 vol. % and 0.7 vol. %), the wear scar diameters using 0.7 vol% of hBN nanoparticle (397 µm) was smaller than using 0.5 vol. % and 0.7 vol. % (473 and 625 µm). Different tribological behaviour is verified to before and after the additional hBN nanoparticles. The worn surfaces after tests with additional of hBN are a little rough with grooves in comparison to pure palm oils. In Figure 4.23, it shows an obvious abrasion wear on the image. (Chetan et al. 2015) reported a similar observation in their finding, and mentioned that, inadequate lubrication and coolant could render the surface prone to abrasion wear mechanism. Tool material is scraped off by hard particles that can be free, between the toolchip interfaces, or issuing from the work piece or cutting tool material, causing abrasion wear. Due to an insufficient lubricating action of hBN, the abrasion wear mechanism contributes to friction coefficient. Oxidation process also have been go through and form oxide layer in Figure 4.23 due to hBN nanoparticles weak reactivity and short carbon chain, the surface protected was reduced.



Figure 4.21 Palm oil 0.7hBN, 20mins, 70amp (Optimized)



Figure 4.22 Palm oil 0.7hBN, 30mins, 90amp (Medium)



Figure 4.23 Palm oil 0.3hBN, 30mins, 90amp (Worst)

4.6.2 Result for Sunflower Seed Oil with an addition of hBN nanoparticle

Figure 4.24, 4.25, 4.26 shows the SEM image accordingly to optimum, medium and worst WSD. In the optimum WSD of seed oil, it can clearly see that there is smooth surface with a little of debris presence. Sunflower seed oil with the optimum value (0.5 hBN, 20 mins and 70 rpm) has the potential to be an alternative bio-lubricant on the basis of biodegradability, well wear phenomena, and lubricating performance. Meanwhile, the seed oil with the composition of 0.7 vol. % of hBN, 20 mins and 70 rpm contained a lot of oxide layer that caused by the sliding motion. At the worn surface in Figure 4.25 and 4.26, there is formation of groove and debris. It is clearly enough that formation of those asperities is due to sliding friction. The spot debris that found in Figure 4.25 and 4.26 might due to the unclean filtering oil or during the four ball test. As a result, plastic deformation will occur through this phenomenon. Adhesion and abrasion wear will be occur and form cold weld junction as shown in the figure below between the contacting asperities. (Jabal et al. 2018) state that the strength of the junction is determined by the surface structure and by the mutual solubility of two contact metals. This is due to the presence of unsaturated fatty acids in sunflower oil, which react with bare metal surfaces to generate a thin metallic soap coating. The adsorption layers are responsible for the compounds' improved lubricating properties. As a result, sunflower oil with the additional of hBN exceeded pure sunflower seed oil in terms of anti-wear performance.

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Figure 4.24 Seed Oil 0.5hBN, 20mins, 70amp (Optimized)



Figure 4.25 Seed oil 0.7hBN, 20mins, 70amp (Medium)



Figure 4.26 Seed Oil 0.3hBN, 10mins, 50amp (Worst)

4.6.3 Result for Corn Oil with an addition of hBN nanoparticle

The corn oil with the addition of hBN's appearance of the surface damage in the wear scar on the ball specimens is shown in Figure 4.27, 4.28 and 4.29. Surface examination of the worn samples was done by SEM once again. Figures below show that mild abrasion, pitting adhesive, and severe delamination of the specimen surface increased significantly when run at higher volume percentage of hBN and higher amplitude. Individual specimen displayed the above wear mechanisms in different forms and intensities. In Figure 4.27, it can be observed that the surface is more smooth compare to Figure 4.28 and 4.29. It took 0.5 vol. % of hBN, 10 mins and 50 rpm of amplitude to take over the optimum of WSD. On the worn surface of the ball specimens, tested at same parameters (Figure 4.28) debris, groove, and oxide layer were observed. A lot of debris occurred in Figure 4.28 might due to unclean filtration process or unmatched composition itself. The medium sample was composed with 0.3 vol. % of hBN, 20 mins and 70 rpm of amplitude. The major wear mechanisms was in Figure 4.29 that showed abrasive wear, oxide layer, debris and/or smoothing, groove and corrosion. Oxidation layer occurs in situations where the environment surrounding a sliding surface interacts chemically with it. In this case, the hBN nanoparticles additive reacted with the corn oil at higher percentage of hBN and the reaction products were worn off from the surface (Figure 4.29) leading to higher wear and friction.

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Figure 4.27 Corn oil 0.5hBN, 10mins, 50amp (Optimized)



Figure 4.28 Corn oil 0.3hBN, 20mins, 70amp (Medium)



Figure 4.29 Corn oil 0.7hBN, 10mins, 50amp (Worst)

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study was conducted to formulate new bio-based oil from vegetable oil with addition of hBN nanoparticles as additives. Each vegetable oil was added with different volume percentage of hBN were then set up based on selected parameters with accordance of Taguchi method (L9 Orthogonal arrays) which performed during the homogenization process by using ultrasonic homogenizer. The tribological performance of nano-oil was determined by using four-ball tester and scanning electron microscope (SEM). The presence of coefficient of friction (CoF) and wear scar diameter (WSD) on the bearing was identified and analysed.

The study successfully applied the Taguchi method to determine optimal vegetable oil conditions for low coefficient of friction (CoF) and wear scar diameter (WSD) will then validated by running a two factors, three-level experimental design. The coefficient of friction (CoF) and wear scar diameter (WSD) during the ultrasonic homogenizer process were all observed. Meanwhile, the optimal parameter were identified and obtained by using signal noise ratio which functioning to determine the optimal sample based on the tribological performance of nano-oil which are average CoF and WSD. The signal noise ratio will then clarified the accurate design of each parameter and yet produce an ultimate result based on the experiment conducted. Therefore, Taguchi method is essential to assess design parameter in terms of to get

an optimum result. Nine samples were tested out three of the results (optimal, medium and worst) by using scanning electron microscope (SEM).

After being experimented, it can be concluded that the presence of hBN nanoparticles added in each vegetable oil significantly enhanced the tribological properties of nano-oil. The combination of 0.7 vol. % hBN nanoparticles into the palm oil is effectively reduce the coefficient of friction (CoF) and wear scar diameter (WSD) after being homogenized at 20 minutes with the speed 70 rpm of amplitude. It can be conclude that hBN nanoparticles used to have a ball bearing effect by transforming the sliding friction between the frictional pairs to sliding friction, causing a reduction in the contact region. Hence the surface performance in SEM of palm oil with 0.7 vol. % have the smooth surface compare to virgin palm oil.

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The results of the table indicate that the percentages of sunflower seed oil and additives had a substantial impact on tribological behaviour. A complicated boundary lubrication layer might be produced by combining 0.5 vol. % hBN nanoparticles with a mixture of acceptable parameters to enhance wear and friction. As a result, a low coefficient of friction and a small wear scar diameter were possible. Generally, the wear mechanism that appear on the worn surface of the ball bearing was an adhesive wear. The adhesive and abrasive wear happened because of debris and sliding friction caused by the ball bearing. Due to the sliding movement, it produced a groove, debris and oxide layer at the ball bearing surface. And yet, with the appropriate amount of hBN nanoparticles will produce a lower friction of lubricant.

The most significant findings from the corn oil with the additional of hBN nanoparticles can be concluded after the experiment based on the results shown above. Properties of corn oil decrease with the hBN nanoparticles helps reducing the friction between the components and the lubricating oil amplitude. The combination of 0.3 vol. % hBN nanoparticles into the corn oil is effectively reduce the coefficient of friction (CoF) and wear scar diameter (WSD) after being homogenized at 20 minutes with the speed 70 rpm of amplitude. This prove that with a little amount of hBN nanoparticles have the ability to be anti-friction additive.

In conclusion, addition of hBN into vegetable oil showed improvement in tribological properties by reducing friction coefficient and wear scar diameter. The results showed that a little amount of hBN nanoparticles can reduce CoF and WSD as compared to pure vegetable oil. This can be further study due to its ability to be an anti-wear additive.

5.2 Recommendation

The multi-parameter characterization and bio-lubricant base oil with the addition of hBN nanoparticles has not yet been developed. As a recommendation for improvement of this study, the hBN nanoparticles should be deeply investigate into different type of bio-based lubricant. The characteristics model of oxidation stability, viscosity index, flash point, anti-wear, and anti-friction properties of nano-oil also requires further investigation. With the achievement of surface smoothness or the tribological properties of the bio-based lubricant as the goal, it is necessary to explore more scale of the parameter value under the influence of multiple factors of nano-oil characteristics (volume percentage, vol. %, time and amplitude). In the end, the repeatability and reproducibility of the four ball test machine also need to take as consideration in the experiment to avoid bias and inaccuracy.

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5.3 Future prospect of bio-based lubricant

Environmental issues are becoming increasingly important in our culture. Given the fact that the ecosystem is constantly polluted with many types of pollutants, any small reduction is desirable. During or after use, a substantial volume of petroleum-based lubricants damaged the environment, usually as a result of spills and industrial activities. Various governments have imposed restrictions on the use of petroleum-based lubricants in situations where they may come into contact with soil or water. In comparison to other mineral oils, the potential of vegetables oil as an additives and bio-lubricant for industry is now greater due to their lower cost and biodegradability.

Vegetable oils are generally suited as lubricant base oils to improve their physicochemical and tribological characteristics, with vegetable oils performing as well as or better than mineral and synthetic oils. Lower toxicity, good lubricating properties, good anti-wear character, excellent coefficient of friction and rapid biodegradation are some of the capabilities of vegetable oils as additives and bio-lubricants as an alternative lubricant for industrial and maintenance applications. By switching to bio-lubricants, industries may save money on tools and enhance product quality while also protecting the environment. The use of a bio-lubricant lowers costs and improves competitiveness.

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APPENDICES

APPENDIX A



APPENDIX C



APPENDIX E





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BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA

TAJUK: DEVELOP FUTURE BIO-BASED LUBRICANT BY UTILISING NAN0-PARTICLES

SESI PENGAJIAN: 2020/21 Semester 1

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Nama pelajar: YIP YUN YU (B091810391) Tajuk Tesis: DEVELOP FUTURE BIO-BASED LUBRICANT BY UTILISING NANO-PARTICLES

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Sekian, terima kasih.

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Saya yang menjalankan amanah,

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