DETERMINATION OF WEAR METALS IN AUTOMOTIVE LUBRICATING OILS USING UV SPECTROMETRY

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A report submitted
In fulfillment of the requirement for the degree of
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DECLARATION

I declare that this report entitled "Determination of Wear Metals in Automotive Lubricating Oils Using UV Spectrometry" is the result of my own work except as cited in the references.

Signature : ....

Name : ....

Date : ....

APPROVAL

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

Signature	:	……………………
Supervisor's Name	:	……………………..
Date	:	……………………..

DEDICATION

To my beloved mother and father

To a respected supervisor

To lecturers

&

To my friends

ABSTRACT

This Final Year Project outlines the background of the project "Determination of Wear Metals in Automotive Lubricating Oils Using UV Spectrometry". Wear metals exist when frictional wear occurs during the relative motion between lubricated surfaces. The ball bearings were immersed in two different lubricant condition; engine oil and nanoparticle-enhanced engine oil. Each tests were conducted under varying load and speed, with 100, 300, 500 N and 100, 300, 500 rpm respectively. The tests were undergone under different temperature which 27, 50, and 100˚C and the running time was approximately 60 minutes. The nano oil was prepared by dispersing a mixture of approximately composition 0.5 vol.% of 70nm hexagonal boron nitride, hBN with SAE 15W-40 engine oil as base oil. The mixing method used was sonication technique. The investigation was carried under different parameters in order to differentiate the stability of used oil with and without nanoparticle enhanced of hBN at different parameter by using UV spectrometry method and to propose standard range of wavelength for metals disperse in lubricating oils by using UV spectrometry method.

ABSTRAK

Projek Tahun Akhir menggariskan latar belakang projek "Penentuan Sisa Logam Terpakai Di Dalam Minyak Pelincir Automotif Menggunakan UV Spektrometri". Sisa logam terpakai wujud apabila geseran berlaku semasa gerakan relatif antara permukaan yang dilincirkan. Bola bearing telah ditenggelamkan dalam dua keadaan pelincir yang berbeza; minyak enjin dan minyak enjin yang ditambah zarah nano. Setiap ujian telah dijalankan di bawah beban yang berbeza-beza dan kelajuan, iaitu 100, 300, 500 N dan 100, 300, 500 rpm. Ujian telah dijalaninya di bawah suhu yang berbeza iaitu 27, 50, dan 100C dan masa yang berjalan adalah kira-kira 60 minit. Minyak nano telah disediakan oleh campuran kira-kira komposisi 0.5 vol.% Of heksagon boron nitrida 70nm, HBN dengan SAE 15W-40 minyak enjin minyak asas. Kaedah pencampuran yang digunakan adalah teknik sonication. Kajian telah dijalankan di bawah parameter yang berbeza untuk membezakan kestabilan minyak digunakan dengan dan tanpa nanoparticle yang dipertingkatkan daripada hBN pada parameter yang berbeza dengan menggunakan kaedah UV spektrometri dan untuk mencadangkan standard panjang gelombang bagi sisa logam yang terpakai dalam minyak pelincir dengan menggunakan kaedah UV spektrometri.

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LIST OF ABBEREVATIONS

OEMs	Original Equipment Manufacturers
FAAS	flame atomic absorption spectrometry
ICP-OES	inductively coupled plasma optical emission spectrometry
AAS	atomic absorption spectrometry
AES	atomic emission spectrometry
UV	ultraviolet
Vis	visible
SAE	Society of Automotive Engineer
hBN	Hexagonal boron nitride
VI	Viscosity Index
HDEO	Heavy duty engine oil
ATF	Automatic transmission fluid

LIST OF SYMBOL

A	=	Absorbance
I_0	=	intensity of light before passing through solution
I	=	intensity of light after passing through solution
cSt	=	centistokes

CHAPTER 1

INTRODUCTION

1.1 Background

In automotive industry, the selection of right material in each component of vehicle is very important. One of the reason is to maintain the structure and shape of the component. The wrong decision in choosing the right material for each component may shorting the life span of the component and cause failure. for example, if the engineers and manufacturers wrongly choose low melting point metal but want to be use in component that produce large amount of heat such as in the engine part may cause high wear and structure failure.

A lubricating oil is made up from mineral oils or mixture of synthetic hydrocarbon. Original Equipment Manufacturers (OEMs) has set up the necessity and parameter of lubricating oil, so that the lubricant lack of their properties. So by adding effective additives, it can improve the function of lubricants. Some method to identify the optimum quantity of additives to be used are introducing anti-oxidation capability, tribological characteristics, and thermal properties. Nano-additives is improving their performance with help of nanotechnology (Shahnazar *et al*., 2016). The performance of engine oil by using different type of additives give different result. the As the lubricating oil contains many additives, it is difficult to choose the correct oil for each type of engine, so that American Petroleum Institute (API) has introduced the rating of service for this lubricating oil that is easy for us to select the right one (Erjavec, 2005).

Analysis on wear metals in lubricating oil has been used to evaluate the condition of engines and other part of automobile. It is a same concept to monitor the condition of patient by physician by running blood test. By running analysis on wear metals in lubricating oil, it can be a preventive maintenance before the wear can make bigger trouble and lastly can cause failure (Soutter, 2014). Lubricating oil are affected by engine operation in three factors that are complete destruction part of the oil, changes of oil's physical and chemical behaviour and oil contamination by outside matter.

1.2 Problem statement

The problem in determination of wear metals in lubricating oils are the method used are complicated. Most of method used by using other instruments such as flame atomic absorption spectrometry (FAAS) and inductively coupled plasma optical emission spectrometry (ICP-OES) need to used reagents that most of the reagents are hard to find. The standard of procedure and preparation of samples during conduct the experiment also taking time since need to prepare the reagent and solvents.

Furthermore, the method that has been mentioned include a high cost of foundation support and operating expense. Other than that, the presence of several emission lines or spectral interferences and the necessity of having samples dissolved in solutions making these method are complicated. Undeniable, the other method has more advantages compare to UV spectrometry but for education purpose of university, college or school, it burden the student as the complexity of the procedure and high cost to find the solvents. It just enough to use UV spectrometer to determine the wear metals since the procedure and test method is more simple.

1.3 Objectives

The objectives of this project are as follows:

1. To differentiate the stability of used oil with and without nanoparticle enhanced of hBN at different parameter by using UV spectrometry method.
2. To propose standard range of wavelength for metals disperse in lubricating oils by using UV spectrometry method.

1.4 Scope of project

The scope of this project are:

1. Data and result of lubricating oil's condition by using UV spectrometry method are presented in this report.
2. The wear test is performed by using 4-Ball Test method to obtain the used oil sample.
3. Only one type of lubricating oil is used for the experimental test that is Shell Rimula R2 Extra (SAE 15W-40) with and without nanoparticle enhanced of hBN and also one type of ball bearing that is SK11 as shown in Figure 1.1 and Figure 1.2.

Figure 1.3: Lubricant oil Rimula R2 Extra (15W-40)

Figure 1.4: ball bearing SK11

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Engine oil is functioning as lubricant to reduce the wear and friction between sliding parts in the engine parts. They additionally work as coolant by removing excessive heat away when the friction between moving parts occur. Typically, heat stored in greater part of the engine oil is larger than its thermal conductivity which brings out the development of oil sludge inside the engine at extreme conditions. Furthermore, this situation cause the engine oil getting burnt which production of large amount of smoke usually occur (Dinesh *et al.*, 2016). The checking of the wear metal concentration in the oil of moving parts inside the engine is an important guide of the internal condition of the engine. The main idea is that moving contact between oil-lubricated metallic components is followed by friction, which causes a conversion of the contact surface into small particles which are deposited in the lubricating oil (Zararsiz *et al.*, 1996). Determination of wear metals that deposited in lubricating oil can guide to the expectation of developed failure and need for machinery overhaul.

2.2 Wear testing by 4-ball test method

4–ball test is the method to study the wear and friction of metal covered with lubricating oil under certain load, temperature and speed. High wear lead to higher coefficient of friction for engine oil. The coefficient of friction is a value that shows the relationship between the force of friction between two objects and the normal reaction between the objects (Xue *et al.*, 1997). Wear testing is important to understand the wear properties of material and lead to determination whether it is suitable to be used in specific condition. Furthermore, wear testing is used to decide surface treatments and appropriate condition where the material suitable to be used. The friction and wear usually occur as shown in Figure

As been studied by Kuo *et al.* (1996), generally, wear increase with the increasing of load. The steady-state contact resistance decreases and the steady-state coefficient of friction increases with increasing of normal load. By using AISI 52100 steel ball and a paraffinic oil as lubricant, they differentiate the specific speed method according to ASTM 2596 with the standard test method according to ASTM D2783 that the sliding time is set to 10 seconds. For specific speed method, there are no wear occurs at 8 N of load while for standard test method, small wear occurs. The specific speed method is good at initial lubricating condition. But, at middle loading condition where the range from 80 N to 280 N, standard test method has better result as the friction coefficient is lower and wear scar is smaller compared to specific speed method. The regimes of lubrication mode can be classified into four regimes:

- Elastohydrodynamic lubrication (EHL)
- Partial EHL (P-EHL)
- Boundary lubrication (BL)
- Initial seizure (IS)

2.3 Properties of lubricating oil

As diesel engines operates at high temperature, the viscosity of lubricating oil increased because the evaporation of the light compounds, oil oxidation and contamination by smudge. The different viscosity of lubricating oil give different impact to the fuel consumption of diesel engine that operated under different load and speed condition. The adding of additives give little influence on lubricating oil viscosity (Carvalho *et al.,* 2010). The properties of lubricating oil of two different SAE grade is shown in Table 2.1.

Properties		Unit	HDEO	ATF
SAE grade			15W-40	10W-20
Viscosity, ASTM D 445	cSt @ 40°C	mm^2/s	104	34.08
	cSt @ 100°C	mm^2/s	14.3	7.19
Viscosity index, ASTM D 2270			140	180
Pour point, ASTM D 97		°C	-30	-45
Flash point, ASTM D 92		°C	215	202

Table 2.1: properties of lubricating oil for two different SAE grade (Abdullah *et al.*, 2013)

2.4 Additives in lubricating oil

As been investigated by Laad *et al.* (2016), nanoparticles as additives in lubricating oil confirms that the dispersion of nanoparticles have good stability and solubility in the lubricant and improve the properties of lubrication in lubricating oil. Stability means that the particles does not accumulate at important rate (Wang *et al.*, 2011). The lubrication with additives provide good friction-reduction and anti-wear properties. The study also conclude that absorption of nanoparticles increase with increase in ageing time by using UV spectroscopy method. The solution remain unchanged for several days at room temperature.

As what has been studied by Abdullah *et al.* (2014) that investigated the oil properties based on Viscocity Index (VI), additives with hBN nanoparticles improve the VI value roughly 3% compared to engine oil without additives and with Al_2O_3 nanoparticles additives. In the term of absorbance, they state that hBN nanoparticles has higher absorbance compared to Al_2O_3 nanoparticles. The higher absorbance, the better the dispersion of nanoparticles in lubricating oil, so more stability of the additives. But, the stability of hBN nanoparticles in lubricating oil is reduced as the reduction of absorbance against the period of time as shown in Figure 2.1 below.

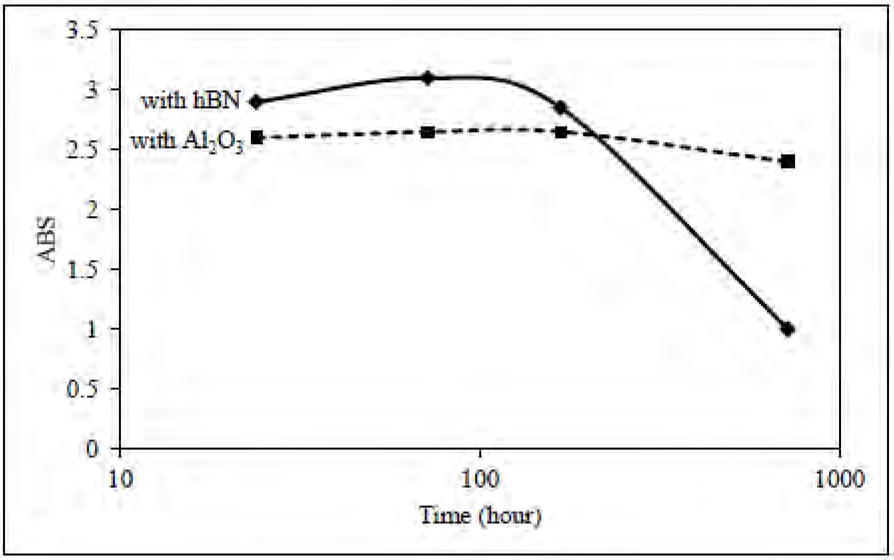


Figure 2.1: The absorbance of Nano-oil against time (Abdullah *et al.*, 2014)

2.5 Spectrophotometry

Spectrophotometry is a technique to gauge how much chemical matter absorbs light by measuring the intensity of light as a light emission goes through solution of sample. The measurement can be used to measure the amount of a known compound substance as the main principle is that every compound absorbs or transmits light over a specific scope of wavelength. Spectrophotometry is a standout amongst the most valuable techniques for quantitative examination in different fields. For example is used in physics, biochemistry, chemical engineering, material and clinical applications (Vo, 2015). There are likewise a few varieties of the spectrophotometry, for example, atomic absorption spectrophotometry (AAS) and atomic emission spectrophotometry (AES).

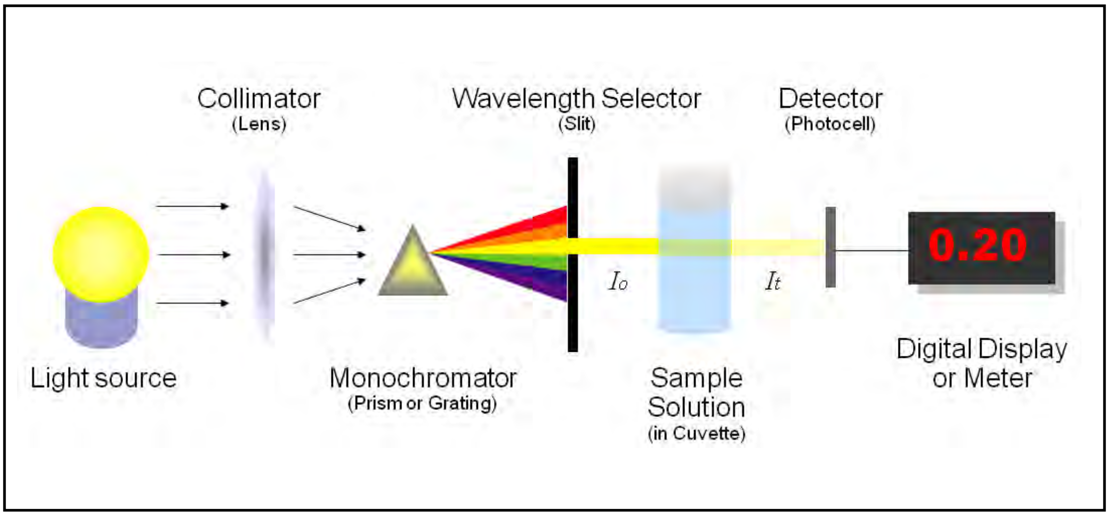


Figure 2.2: Basic structure of spectrophotometers (illustrated by Heesung Shim)

According to Lambert-Beer law, the absorbance (*A*) or (ABS) is related to the intensity if light before (I_0) and after (I) pass through the solution and the absorbance is depends linearly on concentration (Schmid, 2001)

$$A = -\log_{10}\left(\frac{I}{I_0}\right) \qquad (2.1)$$

2.6 Ultraviolet and visible absorption spectroscopy

Ultraviolet and visible absorption spectroscopy is used widely in research to characterise materials and examine their behaviour. Spectroscopy is a system that measures the association of particles with electromagnetic radiation. Light in ultraviolet (UV) and visible (vis) range of the electromagnetic spectrum has energy around 150-400kJ mol^{-1}. In order to promote electron from ground state to excited state, the energy of light is used. A spectrum acquired when the absorption of light is measured as an element of its frequency or wavelength. Absorption spectroscopy in equation (2.1) is normally performed with particles dissolved in a transparent solvent. Spectroscopic measurements are very precise and only slight amount of sample required for the analysis (Schmid, 2001). The mass division of additives in lubricating oil can be reflect by UV absorbance by measuring absorbance of lubricating oil for unused and used oil which before and after the experiment.(Feng *et al*., 2011).

Ultraviolet-visible spectrophotometry absorbance measurement are used as a method of spectral absorbency to know the stability of nanoparticle additives in lubricating oil. It used to describe the stability of dispersion. This method is easy and suitable method to figure out the dispersion stability as the nanoparticles dispersed in lubricating oil have characteristic absorption bands in the range of wavelength between 190-100 nm (Gulzar *et al*., 2016).

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the methodology used in this project to obtain data output for UV spectrophotometer. This project start by studying the stability of used oil with and without additives of hBN. The function of UV spectrophotometer are being study to choose the correct way to obtain correct and valid measurement data. The experiment will be carried by preparing the sample of SAE 15W40 diesel engine oil with and without nanoparticles enhanced. The preparation of oil sample also conducted by 4-Ball Tester under several condition which are different speed of rotation, load and temperature applied on 12.7mm diameter steel balls (SK11) made of AISI E52100 that covered by lubricant. UV spectrophotometer is used once before and after the oil sample is applied in 4-ball Tester to analyse the wear. The flow chart for general methodology of the project is shown in Figure 3.1.

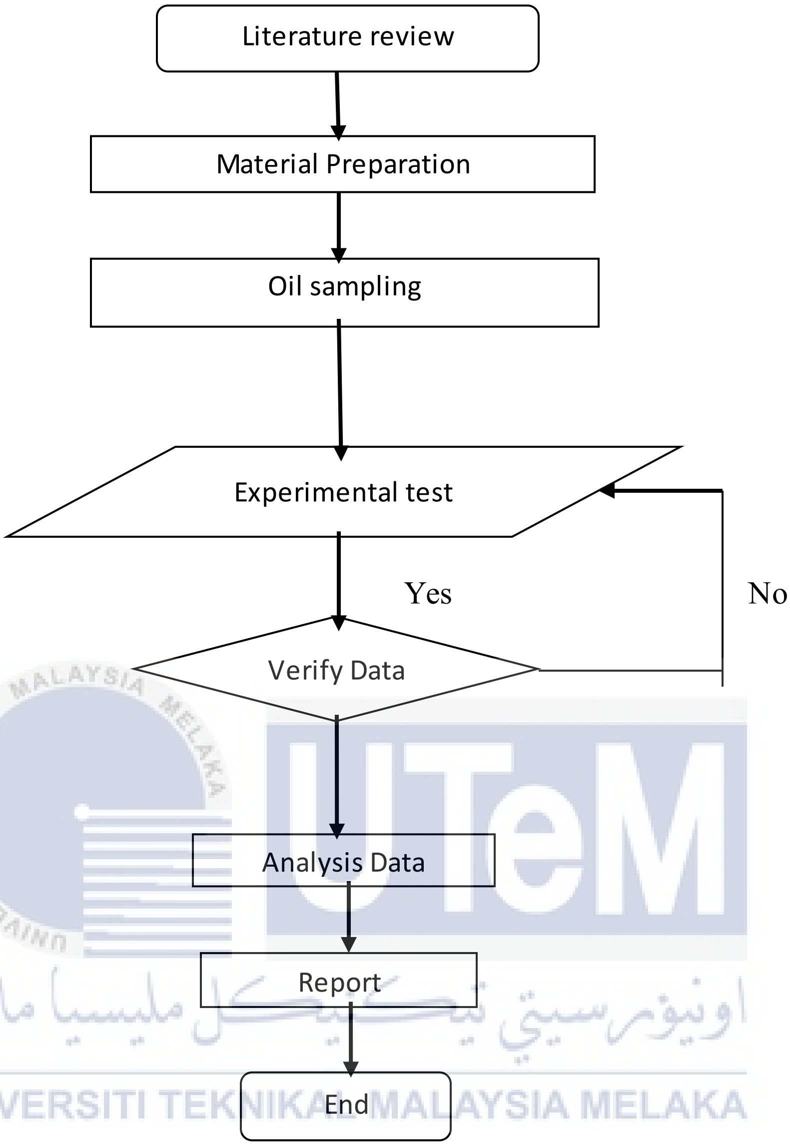


Figure 3.1: Flowchart of methodology

3.2 Experimental specimen

3.2.1 SK11 Ball Bearing

The specimen tested for this project is SK11 steel ball. The detailed mechanical properties of the steel ball are shown in Table 3.1

Table 3.1: Mechanical properties of ball bearing material (Abdullah *et al., 2013*)

[a]Properties	Ball bearing material
Hardness (H), HRC	61
Density (ρ), g/cm^3	7.79
Surface roughness (R_a), µm	0.022

[a]From laboratory measurements

3.2.2 Sample oil

The sample oil used for the whole project is diesel engine oil SAE 15W-40.This type of engine oil meets the requirements needed to carry out the experiment. The properties of diesel engine oil SAE 15W-40 is shown in Table 3.2 below.

Table 3.2: Properties of diesel engine oil SAE 15W-40 (source: www.shell.com)

Properties			Method	Shell Rimula R2 Extra (CF-4/228.1)
SAE Viscosity Grade				15W-40
Kinematic Viscosity	@40°C	mm²/s	ASTM D 445	104
Kinematic Viscosity	@100°C	mm²/s	ASTM D 445	14.3
Dynamic Viscosity	@-20°C	mPa s	ASTM D 5293	6600
Viscosity Index			ASTM D 2270	141
Density	@15°C	kg/l	ASTM D 4052	0.89
Flash Point (COC)		°C	ASTM D 92	226
Pour Point		°C	ASTM D 97	-33

3.2.3 Nanoparticles

Hexagonal Boron nitride (hBN) is the nanoparticle used in lubricating oil and act as additives in order to study the effect of nanoparticles to the ball bearings. Based on the characteristics of good thermal resistance and good insulator, it is suitable to be used as additives for high temperature lubricating condition (Çelik *et al.*, 2013)

3.3 Oil Sampling

For oil sampling, the engine oil without nanoparticles enhanced of hBN is directly use in 4-Ball Tester to obtain the sample of used oil. In other hand, nanoparticle enhanced engine oil is prepared before use for 4-Ball Tester.

3.3.1 Oil preparation for hBN nanoparticles enhanced

The sample of with nanoparticles enhanced is prepared by dispersing 0.5% volume of 70nm hBN in SAE 15W40 diesel engine oil by sonication technique. This technique is performed by using ultrasonic homogenizer for 20 minutes with 50% amplitude and an active interval of 0.5. Samples were then stabilized by adding surfactant; 0.3% volume oleic acid to prevent sedimentation of nanoparticles. The surfactant had no significant effect on the tribological performance of the lubricants according to previous work by Abdullah *et al.* (2014).

3.3.2 Oil sampling using 4-Ball Tester

The standard test method is ASTM D4172. Before test, the steel balls and oil cup were cleaned with acetone and an ultrasonic cleaner (Kuo *et al.*, 1996). Three 12.7 mm diameter steel balls are clamped together and covered with the engine oil. A fourth 12.7 mm diameter steel ball, referred to as the top ball is pressed into the cavity formed by the three clamped balls for three-point contact with assigned load, speed and temperature. Then, the top ball is set-up to rotate for 60 minutes. The schematic diagram is as shown in Figure 3.2 and the various load, speed and temperature used in each experiment is described in Table 3.3. The variation of load, speed and temperature used are same in both oil sample (with and without nanoparticles enhanced).

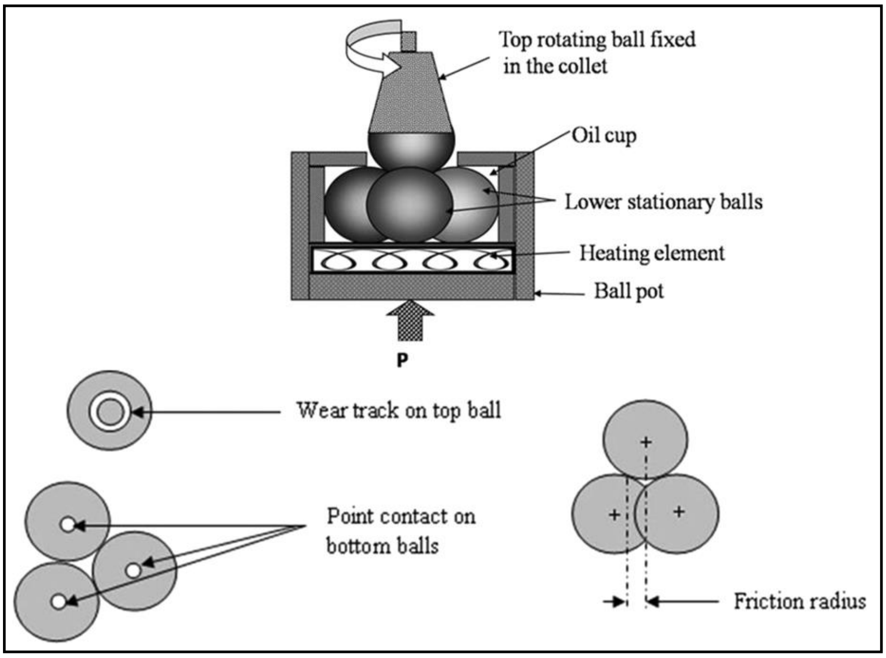


Figure 3.2: Schematic diagram of 4-Ball Tester from source (Gupta *et al.*, 2016)

Table 3.3: variation of load, speed and temperature used

LOAD, N	SPEED, rpm	TEMPERATURE, °C
100	100	Room
		50
		100
	300	Room
		50
		100
	500	Room
		50
		100
300	100	Room
		50
		100
		Room

	300	50
		100
	500	Room
		50
		100
500	100	Room
		50
		100
	300	Room
		50
		100
	500	Room
		50
		100

3.4 Analysis of used oil

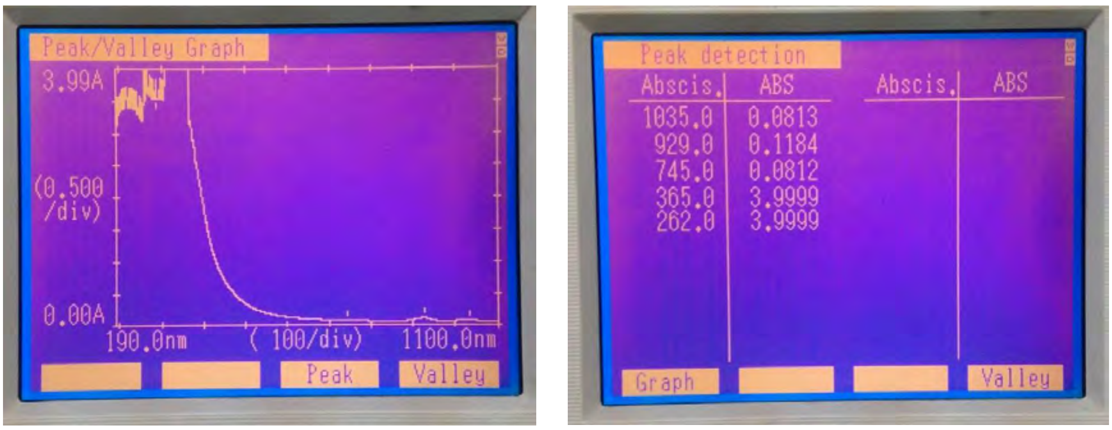
For analysis of used engine oil, the UV spectrophotometer as shown in Figure 3.3 is used. The model of UV spectrophotometer used is Shimadzu UV-mini 1240. The sample of lubricant oil will be put in a glass cuvette of typically 1 cm thickness (Gulzar *et al.*, 2016) and placed at the sample compartment. The spectrum mode is used and the data that will be analyse is wavelength and absorbance from the graph plotted by this instrument. Each sample completed by 4-Ball test with variation of load, speed and temperature will be measured in this UV spectrophotometer.

For the testing purpose, the range limit used for wavelength is 190nm-1100nm while for the absorbance range used is 0-3.99A where the limits for UV spectrophotometer can read to study the behaviour of data input and after the trends of data has been gathered, the range of wavelength has been minimize to 500 nm-1100 nm and 0-1 of absorbance.

Figure 3.3: UV spectrophotometer

3.4.1 Data from UV spectrophotometer

From the experiment, the graph in UV spectrophotometer is plotted as shown in Figure 3.4(a) and the detection of absorbance at certain a wavelength can be obtain as shown in Figure 3.4(b). To be mention that (abscissa) is value for wavelength while (ABS) is value for absorbance. The peak absorbance is selected ignoring value of 3.9999 due to selection of wavelength range is 500 nm – 1100 nm.



(a) (b)

Figure 3.4: (a) Graph plotted by UV spectrophotometer (b) Values detected by UV spectrophotometer

CHAPTER 4

RESULTS AND ANALYSIS

4.1 Result

This chapter describes the result obtained from behaviour of diesel engine oil without nanoparticle enhanced and with nanoparticle enhanced of hBN under different parameters of load, temperature and speed applied on ball bearing that has been set up during the experimental session by using 4-Ball Tester. The speed and load were set to 100, 300, 500 rpm and 100, 300, 500 N respectively. The temperatures were 27, 50 and 100˚C. The standard wavelength of metal dispersed is obtained from the UV spectrometry method. This work also will compare the stability of lubricating oil with and without hBN.

4.1.1 Experimental Data of Diesel Engine Oil (Without hBN)

By referring Table 4.1, the value for wavelength for the highest value of absorbance is taken as indicator to select the further reading in Table 4.2.

Table 4.1: Reading of UV spectrometer for unused diesel engine oil (without hBN)

wavelength (nm)	absorbance
745	0.0872
928	0.123
1034	0.0869

In Table 4.2, reading of UV spectrometer for diesel engine oil (without hBN) used in variable parameters is obtained. The standard wavelength for metal dispersed in diesel engine oil without hBN is determined between 927-929 nm.

Table 4.2: Reading of UV spectrometer for diesel engine oil (with hBN) used in variable parameters.

LOAD, N	SPEED, rpm	Temperature, °C	wavelength, nm	absorbance
100	100	27	927	0.1591
		50	928	0.1461
		100	928	0.4258
	300	27	929	0.1709
		50	928	0.1817
		100	928	0.4223
	500	27	928	0.1329
		50	926	0.1422
		100	927	0.5046
		27	929	0.1492

300	100	50	928	0.2883
		100	924	0.6542
	300	27	928	0.1956
		50	928	0.1879
		100	927	0.2854
	500	27	928	0.1284
		50	927	0.152
		100	928	0.2944
500	100	27	927	0.1877
		50	928	0.1416
		100	927	0.1449
	300	27	928	0.2565
		50	929	0.1664
		100	928	0.2083
	500	27	929	0.1279
		50	929	0.1477
		100	927	0.4821

4.1.2 Experimental Data of Diesel Engine Oil (With hBN)

By referring Table 4.3, the value for wavelength for the highest value of absorbance is taken as indicator to select the further reading in Table 4.4.

Table 4.3: Reading of UV spectrometer for unused diesel engine oil (with hBN)

wavelength (nm)	absorbance
668	3.5063
767	3.4945
870	3.3925

In Table 4.4, reading of UV spectrometer for diesel engine oil (with hBN) used in variable parameters is obtained. The standard wavelength for metal dispersed in diesel engine oil with hBN is determined between 627-722 nm.

Table 4.4: Reading of UV spectrometer for diesel engine oil (with hBN) used in variable parameters.

LOAD, N	SPEED, rpm	Temperature, °C	wavelength, nm	Absorbance
100	100	27	686	3.6876
		50	627	3.5894
		100	660	3.6813
	300	27	671	3.6862
		50	691	3.6997
		100	715	3.41
	500	27	717	3.7052
		50	657	3.673
		100	681	3.6846
300	100	27	699	3.5265
		50	716	3.67
		100	654	3.5851

	300	27	664	3.6511
		50	636	3.4167
		100	686	3.6914
	500	27	658	3.6803
		50	648	3.6776
		100	713	3.9607
500	100	27	662	3.6641
		50	722	3.49
		100	657	3.6722
	300	27	719	3.6812
		50	656	3.6818
		100	672	3.6792
	500	27	659	3.6732
		50	692	3.6715
		100	658	3.6871

4.2 Analysis

4.2.1 Analysis Of Diesel Engine Oil (Without hBN)

Figure 4.1 below show that at load 100 N, the stability of diesel engine oil is better at temperature 100°C as the speed is increased from 100 rpm until 500rpm.

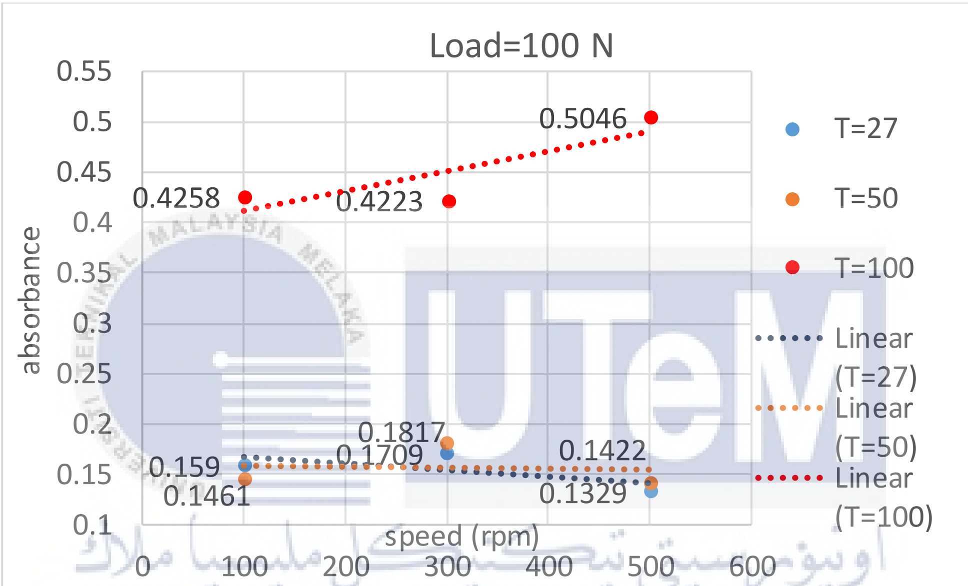


Figure 4.1: Graph at load 100 N (without hBN)

Figure 4.2 below show that at load 300 N, the stability of oil is better at temperature 100°C as the speed is increased from 100 rpm to 500rpm.

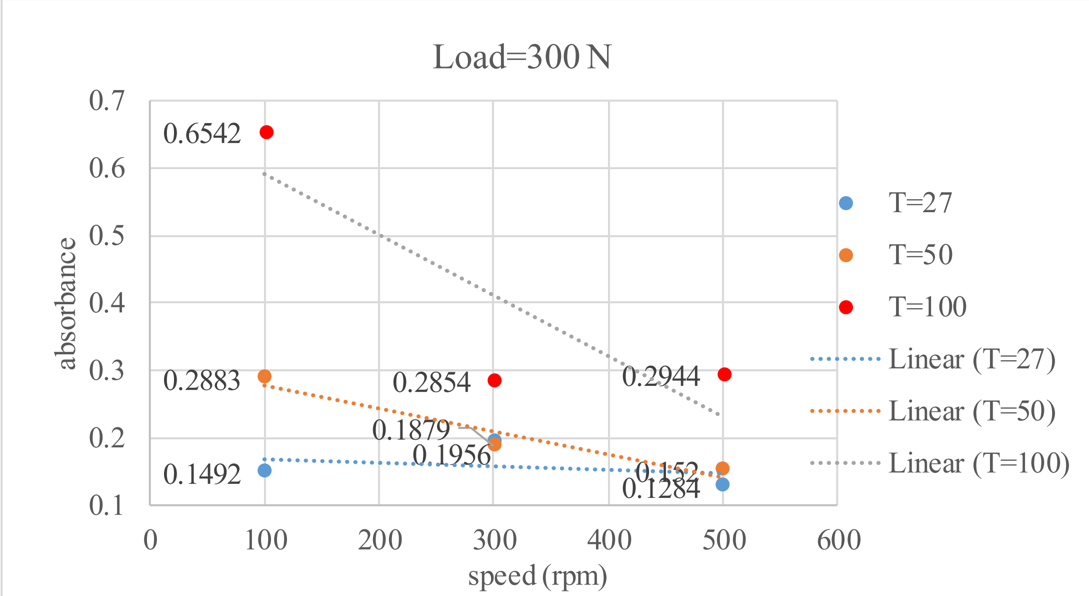


Figure 4.2: Graph at load 300 N (without hBN)

Figure 4.3 below show that at load 500 N, the stability of oil is better at temperature 100°C as the speed is increased from 100 rpm until 500rpm.

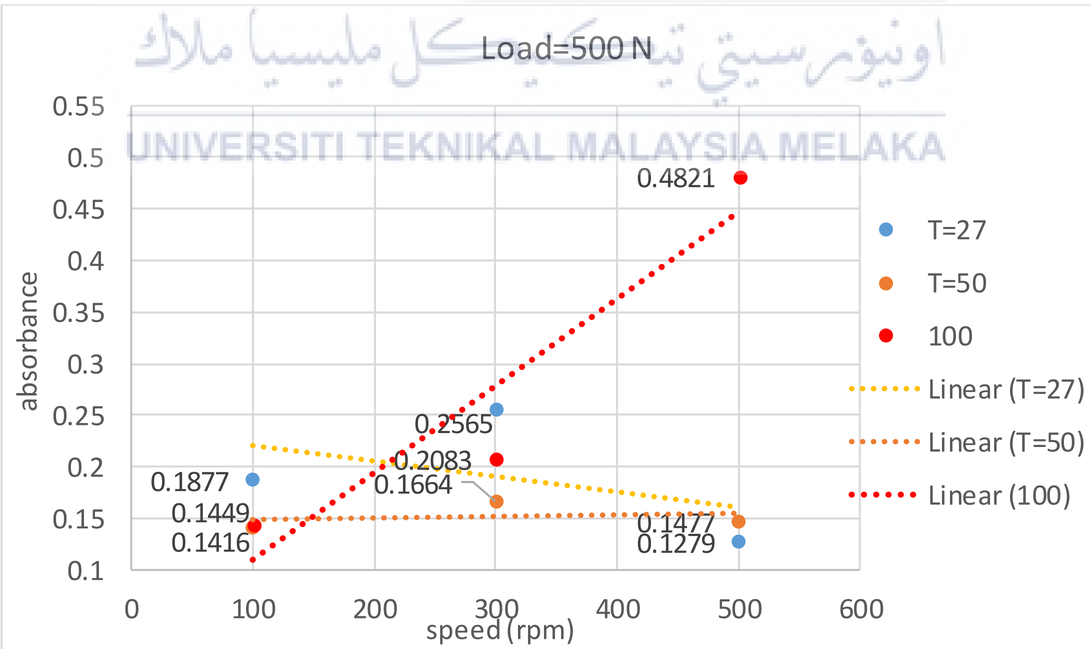


Figure 4.3: Graph at load 500 N (without hBN)

From the graphs, overall the stability of diesel engine oil without hBN is better at high temperature (100°C) as the speed increase which means that the capability of diesel engine oil as lubricant operating better at high temperature and not performing well at low temperature.

4.2.2 Analysis Of Diesel Engine Oil (With hBN)

Figure 4.4 below show that at load 100 N, the stability of oil is better at temperature 27°C as the speed is increased from 100 rpm until 500rpm.

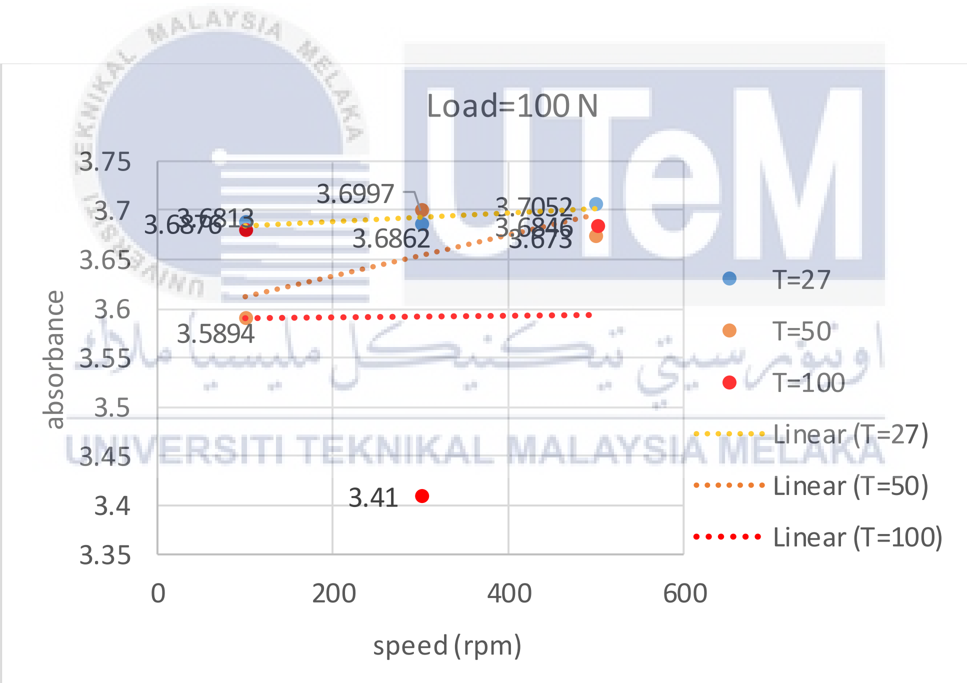


Figure 4.4: Graph at load 100 N (with hBN)

Figure 4.5 below show that at load 300 N, the stability of oil is better at temperature 100°C as the speed is increased from 100 rpm until 500rpm.

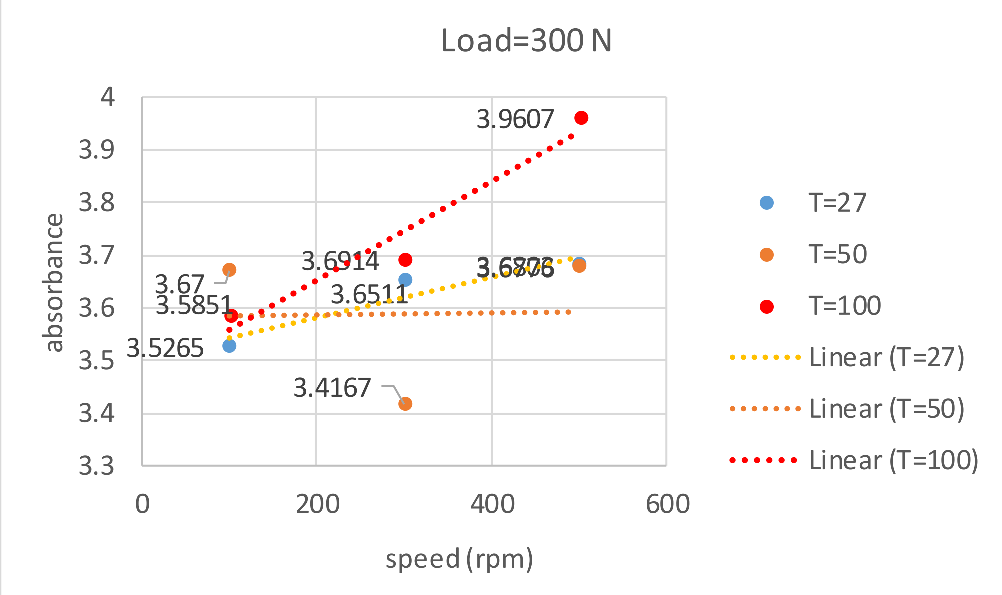


Figure 4.5: Graph at load 300 N (with hBN)

Figure 4.6 below show that at load 500 N, the stability of oil is better at temperature 100°C as the speed is increased from 100 rpm until 500rpm.

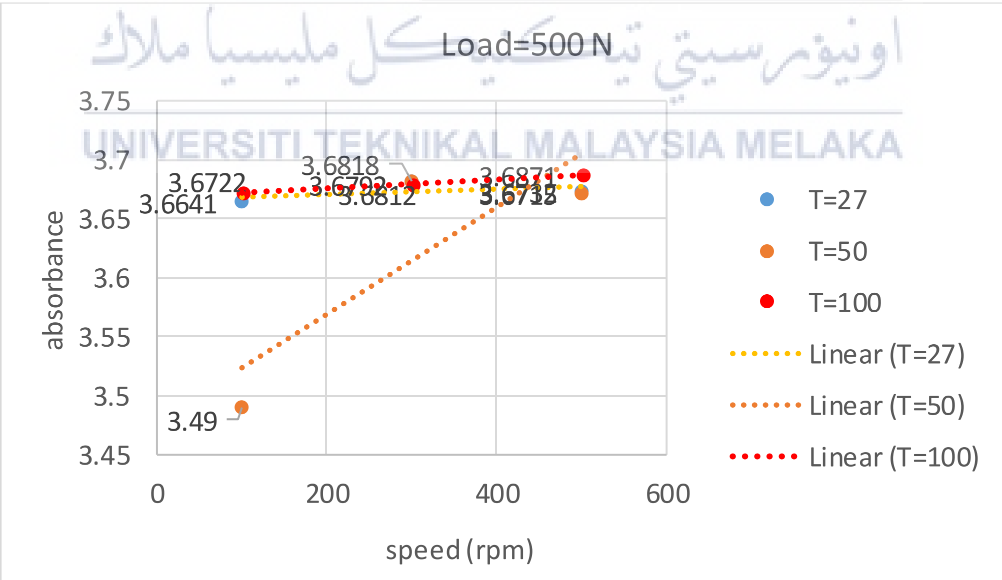


Figure 4.6: Graph at load 500 N (with hBN)

From the graphs, at low load (100N), the stability of diesel engine oil with hBN is better at low temperature (27°C). As the load increase, stability of diesel engine oil is better at high temperature (100°C) which means that diesel engine oil with hBN is functioning well as lubricant even at low temperature when lower load is applied and as load increase, it operating better at high temperature.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

As conclusion, based on result that have been obtained, standard range of wavelength for metals disperse in lubricating oils by using UV spectrometry method is obtained which the standard wavelength for metal dispersed in diesel engine oil without hBN is determined between 927-929 nm and the standard wavelength for metal dispersed in diesel engine oil with additives of hBN is determined between 627-722 nm. Otherwise, the comparison of absorbance between two lubricant conditions; engine oil and nanoparticle-enhanced engine oil was shown in this study which the stability of diesel engine oil is greater when added with hBN. The hBN nanoparticles added into engine oil was said able to improve tribological properties of lubricant and improve the performance of engine oil to reduce wear.

As recommendation, hopefully in future more research and study about investigation of oil by using UV spectrometry method should be done with addition of reagent and solvents to increase the precise of UV spectrometer reading data. Besides that, the other factor could be considered such as different type of lubricant used, different type of ball bearing, and more variable of parameters in order to study its significant effect to wear metals dispersed in lubricating oil. Further study also could be done to know the the mass of a wear metals per unit volume in used engine oil by using UV spectrometry method.

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