Study of Tribological Performance for Carbon Nanotubes (CNTs) as an Additive in Engine Lubricating Oil

by

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CERTIFICATION OF APPROVAL

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Approved by,

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January2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained

Herein have not been undertaken or done by unspecified sources or persons.

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ABSTRACT

Engine oil is primarily organic compound contains carbon, hydrogen, and oxygen. It is from the wide separation of petroleum which consists a number of complex mixtures of hydrocarbon compounds. Engine oil types, usually are from mineral-based oil which synthesized by petroleum extraction and synthetic-based oil. Basically, the tested engine oil will be chosen from the mineral-based engine oil since it has not been well-modified as the synthetic-based engine oil. The mineral-based engine oil has chemical additives in relation to the tribological performances.

In all these applications, it is necessary to use suitable engine oil for specifications of an engine that has been recommended by the original equipment manufacturer (OEM). Misuses of the different engine oil to the different engine will cause in unexpected maintenance, increasing of operating costs, and decreasing of the engine lifetime. The essential properties of engine oil are the viscosity and the wear of engine oil.

The engine oil has varieties of functions such as reducing friction, as a coolant, cleaning the trapped particles from machinery sheds, and as a sealant that could block the surface from contaminants. Nowadays, the manufacturers are looking for better chemical additive to increase the tribological performances in term of friction, lubrication, & wear.

As the emission regulations demand in high of good quality emission, and increasing demanding in decreasing the engine oil element of phosphorus that can impact the emission system control. Sulfur and metals are also under scrutiny as sulfur is suspected as a poison of DeNOx catalysts, and ash (from metals) may plug after-treatment particulate traps. Modern engine oils rely heavily on ZDDP to provide anti-wear, anti-oxidation, and anticorrosion protection. Since ZDDP is rich in phosphorus, sulfur, and zinc, it becomes an obvious target for emission control [1].

CHAPTER 1:

INTRODUCTION

1.1 Background

Commercial engine oils are formulated from petroleum and/or mineral bases which have been modified by a number of chemical additives to enhance the tribological properties. The term tribology derives from the Greek words '*tribein*' meaning 'to rub', and '*logos*' meaning 'principle or logic'. Tribology is defined as the 'science and technology of interacting surfaces in relative motion and of associated subjects and practices'. The subset of the field includes the research and application of principles of friction, wear and lubrication. In recent times, tribology on the small scale and biological and medical tribology are attracting interest and importance for the development of new products in mechanics, chemistry, electronics, life sciences, and medicine. [3].

The study of nanoparticles has been addressed before as an additive to petroleum-based engine oils to enhance the relativity of tribological performance in term of viscosity and wear. A nanoparticle refers to various tubes and fibers in numbers incorporated built into various sizes and shapes to be called as a structure.

In recent years, *Lee et al.* [4] described emerging nano-sized materials show potential as new alternatives because nanomaterials possess many special properties, such as the quantum-size effect, the small size effect, and surface and interface effects and in the field of tribology, the application of nanoparticles is the subject of significant interest. Many researchers have reported that nano lubricants are effective in reducing wear and friction. Nanoparticles of various materials such as polymer, metal, organic and inorganics were used and applied to the nano lubricant production. However there is no consensus or established theory on exactly why the tribological properties are enhanced but the mending effect, rolling effect, ball bearing effect, colloidal effect, protective film, and third body material transfer have been suggested to be the mechanisms behind friction reduction. *Tao et al.* [17] has proposed that the mechanism of the nanoparticles which acted as a spacing layer between the two friction surfaces gives to the anti-wear and anti-friction effect of the additive.

Engine oils have several numbers of classifications such as for gear, automotive engine, heat dispersion (refrigeration) and other uses. Lubricating oils are from the complex separation of petroleum which contains chains of various hydrocarbons. The main function of engine oils in the lubrication system of an engine is to lessen the friction between contacting surfaces. The recent modification on the engine oil emits unnecessary particles and dangerous to emission control system from Zinc dialkyldithiophosphates (ZDDP) such as phosphorus, sulfur and metals. In this study, Carbon Nanotube (CNT) was selected as an additive because of their excellent lubrication characteristics when used as a solid lubricant.

Samad et al. said [5] has conducted a study where it is stated that the CNT due to their excellent mechanical, electrical and thermal properties (thermal conductivity of 3000 W/mK) have generated interest of researchers in the recent years and is considered as a potential filler material for many polymer matrices.

In general, Lee et al. [6] states the friction loss force is lessened due to the increasing viscosity of the lubricating oil. The friction reduction provides less work required for mechanical travel of the lubricated component. Increasing viscosity of the lubricating oil results in the increase of the loading capacity and decreases the wear force or wear scar diameter (WDSs) which is resulted by Four-Ball Test to the rubbing surfaces in the engine system. The increasing capacity loading brings contaminant particles which have been produced during the rubbing or contact between two surfaces in the system.

There are several numbers of studies previously in adding Carbon Nanoparticle (CNT) as an additive to lubricating oil to enhance the performance of a system. The weight percentage of CNT in lubricating oil is about 0.01% to about 5%.

1.2 Problem Statement

In Automobile area, an engine plays a major role at working the functions of the system. Fuel which enters the system undergoes chemical reaction which then, converted to mechanical reaction and causes the engine moving. Most of the moving parts have many rubbing surfaces which bring to friction phenomena.

When two surfaces are rubbed, the exerted force of the opposite surface must be higher than the other surface's friction loss force. To overcome the friction, lubrication system has been introduced. The function of lubricating oil in the lubrication system is to minimize the force required to rub the surfaces and energy lost in the friction can be saved.

In the lubrication system, nowadays, has diagnosed to have several numbers of problems such as high lubricating oil consumption, low lubricating oil pressure which leads to low gauge-reading and abnormal engine noises, high lubricating pressure which leads to high gauge-reading and oil-filter swelling. Next, the inaccuracy of the gauge-reading will damage the indicator gauge circuit.

To increase the efficiency of the lubricating oil, there are sufficient additive can improvise the efficiency in term of the friction coefficient, viscosity and wear test.

1.3 Objective

The objective of this experimental study is to study the effect of a CNT additive in engine oil in relatively to its tribology properties. With these parameters of sizes and purification of nanoparticle which are from Single-Walled Carbon Nanotubes (SWCNTs) and Multi-walled Carbon Nanotubes (MWCNTs), according to additive percentage in the lubricant, used in the experimental study, we may see the effects of its tribological performance in term of wear test and viscosity can be seen.

1.4 Scope of Study

The experimental study is covered by tribological properties, lubricant, and additive. These are the scope of study:

(a) To mix CNT and lubricant at appropriate proportion based on variables of:

- Single-walled CNT
- Multi-walled CNT

(b) To compare the tribological performances among the mixings based on proportion and variables in term of:

- Viscosity
- Coefficient of friction
- Wear Test

CHAPTER 2:

LITERATURE REVIEW

2.1 The Lubricant:

2.2.1 Type of Lubricant : PETRONAS Mach 5 15W-40

PETRONAS Mach 5 SM 15W-40 is mineral-based or petroleum-based engine oil which provides excellent performance multi-grade engine oil specially designed and formulated to provide extra high level of engine protection and superior performance for engines running under the most severe conditions [7]. Below is the product typical and specifications.

Specifications

API SM/CF
ACEA A3/B3
MB 229.1
VW 501/505

Characteristics	15W-40
Density @ 15 °C, kg/l	0.866
Pour Point, °C	-30
Flash Point, °C	227
Kinematic Viscosity, cSt	
@ 40 °C	108.2
@ 100 °C	14.1
Viscosity Index	132
Cold Cranking Visc, cP	
@ - 20 °C	5.500
Sulphated Ash, %wt	0.9
TBN, mg KOH/g	8
ASTM Colour	L2.5

Table 1: Product Typicals and Specification of PETRONAS Mach 5 SM 15W-40 (http://www.mymesra.com.my)

2.2.2 Specifications of Lubricant

- **Viscosity**

Viscosity is the most important in lubricant fluid or oil. Theoretically, viscosity is the ratio of shear stress over shear rate or the resistance to flow. The macro look at viscosity results of thick or thin fluid. To estimate the stirring rate of the viscosity, is to measure it by rotary viscometer by rotating the spindle at different speeds. For each of these speeds, the shear rate can be calculated in which is related to the rotation speed of the spindle and measure the shear stress which is related to the torque needed to rotate the spindle). Then a graph of the shear stress vs. shear rate can be obtained. Viscosity affects heat generation in bearings, cylinders, and gears due to internal fluid friction. It affects the sealing properties of oils and the oil consumption rate. It is, too, determine the ease of an engine to start at various temperature. Lubricant oils have long chain hydrocarbon structures, and viscosity increases with chain length. Viscosity is also a major factor in predicting the performance and fatigue life of rolling elements such as bearings, cylinders and gears. The viscosity of oils is dependent upon temperature and pressure. Viscosity decreases as the temperature increases due to the increasing kinetic energy of molecules and the decreasing collisions among the molecules.

There are two type of measure usually used for viscosity of fluids. The fundamental is centipoise (cP or $mPa\text{-}^{s}$) and centistoke (cSt or mm^2/s). The centipoise is to describe the movement of the different layers of a fluid when subjected to a horizontal force which is commonly known as dynamic viscosity while the another one, centistoke is to describe the ease at which a fluid moves under the force of gravity and is known as kinematic viscosity.

The grades are based on flow rates measured at temperature of 100°C. The initial of specifications such as 10W, 20W, 30W,40W, and 50W are defined as different grades as "W" is weight and numbers of 10,20,30, & 40 is an indication of how much the weight is.

In this case, a multi-grade engine oil is used, which additives enhanced oils which met both warm and cold temperature specifications.

- **Wear Scars**

It determines the wear protection properties of a lubricant. The smaller the average wear scar, the better the wear protection provided by the lubricant oil.

2.2 Carbon Nanotubes (CNTs) As An Additive

2.2.1 Introduction of Carbon Nanotubes (CNTs)

AG Mamalis et al [8] reports that Carbon Nanotubes (CNTs) are increasingly attracting scientific and technological interest by virtue of their unique structures and significant advantages over many existing materials. *S. Prabhu et al.* [9] describes that in term of mechanical properties, CNTs are quite stiff and exceptionally strong. The tensile strength of CNTs are up to a hundred times stronger than steel.

There are two main types of nanotubes: single-walled nanotubes (SWNTs) and multi-walled nanotubes (MWNTs). Generally, synthesizing nanotubes is dependent on applied quantum chemistry and more specifically on orbital hybridization. Nanotubes are composed entirely of sp2 bonds, sharing similarity to graphite. This bonding structure, stronger than the sp3 bonds found in diamond, provides the molecules with their unique strength. Nanotubes usually align themselves together by Van Der Waals forces. Under high pressure, nanotubes can merge together, trading some sp2 bonds for sp3 bonds, giving great possibility for producing strong, unlimited-length wires through high-pressure nanotube linking. [10]

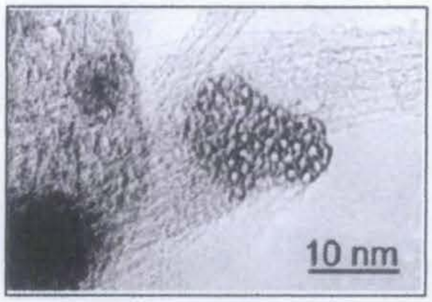


Figure 1 : SWCNTs production by continuous wave laser powder method of a SWCNT-bundle cross-section (M. Daenen, R.D. de Fouw, B. Hawers, P.G.A. Jensen, K. Schouteden, M.A.J. Veld, The Wondrous World of Carbon Nanotubes, 27th February, 2003.)

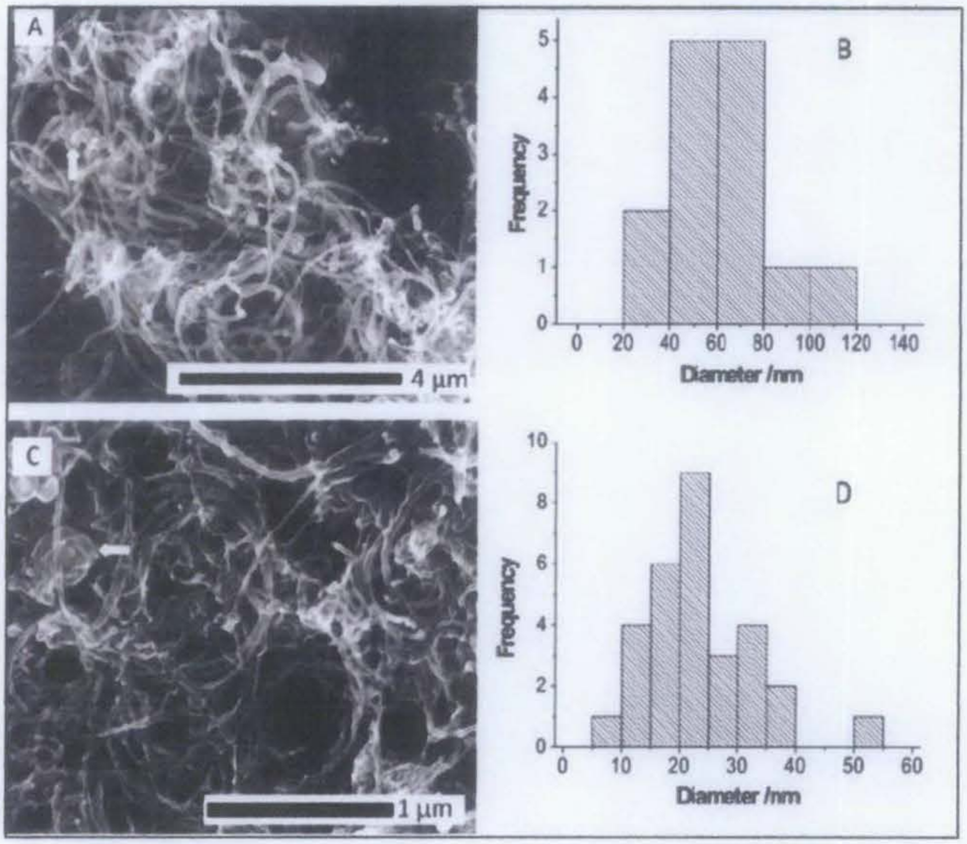


Figure 2: SEM micrographs of MWCNTs synthesized using Fe-Co/ $CaCO_3$ (A,B) and Fe/MCM41(C,D) with the corresponding diameter distribution. (Luis F. Giraldo, Betty L. Lopes, Witold Brostow, Effect of The Type of Carbon Nanotubes on Tribological Properties of Polyamide 6)

A study by *Sinnot et al.* [11] describes current reports about the tribological behaviors of CNTs. The reports however used CNTs as reinforcement for wear parts and are mainly limited in dry and lower load conditions. Few studies have investigated the tribological properties of CNTs as a lubricant and some simulations have investigated the response of CNTs during their friction between two sliding surfaces.

A variety of mechanisms behind friction reduction have been proposed to explain the lubrication enhancement of the nanoparticle suspended lubricating oil (i.e., nano-oil). The mechanisms are ball bearing effect, colloidal effect, protective film, mending effect, rolling effect and polishing effect and third body material transfer. These mechanisms can be mainly classified into two groups. The first is the direct effect of the nanoparticles on lubrication enhancement. The other is the secondary effect of the presence of nanoparticles on surface enhancement. [12]

2.3 Tests In Experimental Study

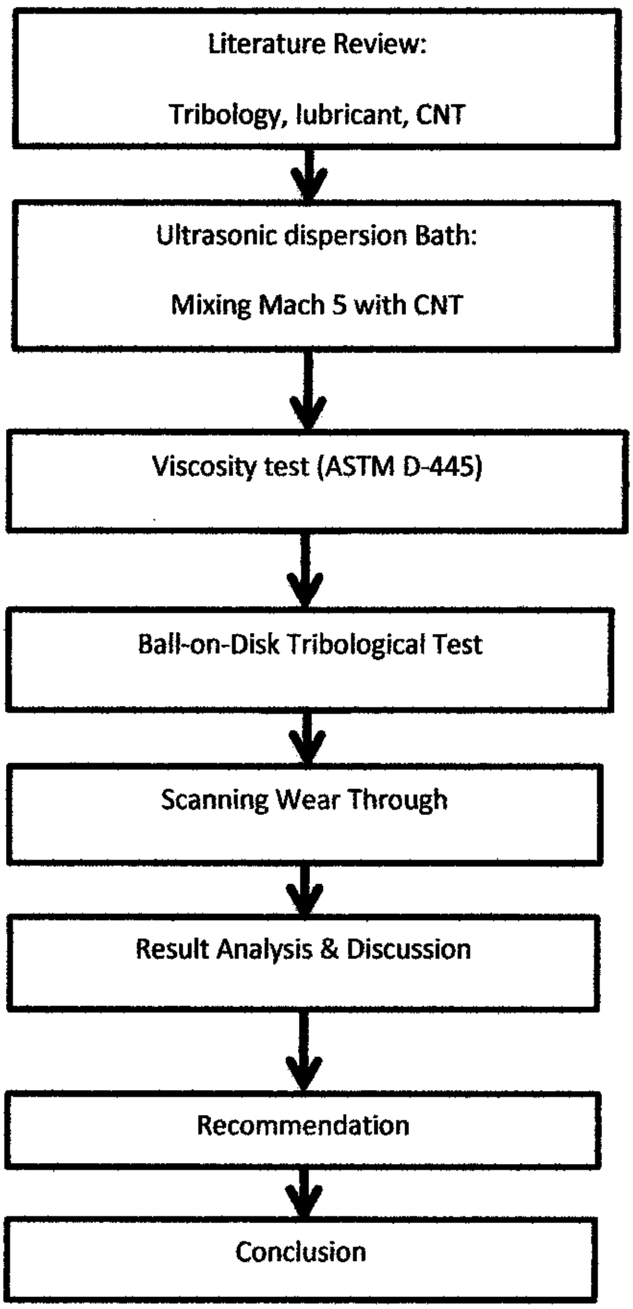
In this study, tribological performances are based on these two (2) tests:

a) Viscosity Test
b) Ball-on-Disc Test

CHAPTER 3:

METHODOLOGY

3.1 Project Flow



3.2 Mixing Engine Lubricating Oil (Mach 5) with CNT Preparation

3.2.1 Concentration of CNTs

Based on the scope of study, three (3) configurations has been identified which are unpurified Single Walled Carbon Nanotubes (SWCNTs), unpurified Multi Walled Carbon Nanotubes (MWCNTs) and purified Multi Walled Carbon Nanotubes (MWCNTs). Based on these, each of the configurations have been set in six (6) samples of concentration of weight which are 0.01 wt %, 0.04 wt %, 0.06 wt %, 0.08 wt %, and 0.10 wt %.

a) SWCNTs concentration

- 0.01 wt % SWCNTs + Mach 5
- 0.02 wt % SWCNTs + Mach 5
- 0.04 wt % SWCNTs + Mach 5
- 0.06 wt % SWCNTs + Mach 5
- 0.08 wt % SWCNTs + Mach 5
- 0.10 wt % SWCNTs + Mach 5

b) MWCNTs concentration

- 0.01 wt % SWCNTs + Mach 5
- 0.02 wt % SWCNTs + Mach 5
- 0.04 wt % SWCNTs + Mach 5
- 0.06 wt % SWCNTs + Mach 5
- 0.08 wt % SWCNTs + Mach 5
- 0.10 wt % SWCNTs + Mach 5

3.2.2 Ultrasonic Dispersion

One major problem in the application of nanodiamonds as an oil additive is the agglomeration of such suspensions. Since Jorge et al. [12] demonstrated ultrasonic treatment as an effective way for the dispersion of ceramic powder in suspension in 1990, many studies [13,14] have been conducted based on this method in ceramic forming and shaping processes. Suzuki et al [15] found that ultrasonic power could reduce the agglomeration of particles in the suspension.

Objective:

To mix the CNTs to the respective lubricant oil (Mach 5)

Apparatus:

-Ultrasonic Bath Device

-Beaker

-Weight electric scales

-Spatula

Procedure:

1. 50 ml of Mach 5 into 200 ml beaker was poured.
2. The lubricant was weighed by using the electric scale. (Average reading taken from three weight readings)
3. 0.01 wt % of CNTs for first test was used.
4. Step 1 to Step 3 were repeated for 0.02 wt%, 0.08 wt%, 0.10 wt %, 0.20 wt%, 0.30 wt%, 0.40 wt%, and 0.50 wt% of CNTs to the respective lubricant oils.
5. The samples were placed in the ultrasonic bath by immersing them partially. (This mixing is about an hour time)

3.3 Viscosity Test (ASTM D-445) using Cannon-Ubbelohde Viscometer

Objective:

To compare the performance of each sample in term of viscosity

Apparatus:

-Viscometer device

-Ubbelohde tube

-Stopwatch

Procedure:

1. The viscometer temperature was set to be at 40°C .
2. The lubricant sample was poured through lube L until the sample arised to the level between line G and H.
3. The ubbelohde tube was placed into the temperature bath and allowed approximately 20 minutes for the sample's temperature to be stable with the temperature bath.
4. Suction by using vacuum was applied by using the vacuum pressure to tube N while applying finger over the tube M, until the liquid reached the center of bulb D.
5. Suction from tube N was removed as well as finger from tube M.
6. Efflux time was measured starting the liquid reached line E until line F.
7. Step 2 to step 6 were repeated for other samples.

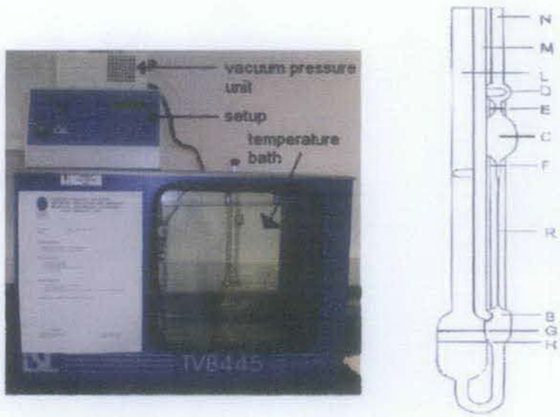


Figure 3:ASTM D-445 : Ubbelohde Viscometer

3.4 Ball-on-Disk Tribological Test

Figure 4 : A Pin-On-Disk Tribological Test Tribometer

<u>Apparatus:</u>

-Tribometer

-Discs (Aluminium Alloy)

-Ball (Stainless Steel)

Procedure:

1. The whole assembly was immersed in an oil bath with 20 ml lubricant for each run.
2. Applied load was set to be 20 N and the sliding speed was set to be 120 rpm.
3. The wear test was run for 0.01 Hour.
4. Friction force reading was taken during the wear test.
5. Specimens were ultrasonically cleaned with acetone for 5 minutes before and after wear test.

3.5 Result Analysis & Discussion

3.6.1 Results

Viscosity Test using Cannon-Ubbelohde Viscometer

Basically, SWCNTs and MWCNTs additives tested at temperature of 40°C and 100°C which are the range of engine operated under ambient pressure. Based on the results obtained in the viscosity test, there are graphs were plotted to ease the observation as below with further discussions.

a) Single-Walled Carbon Nanotubes (SWCNTs)

	at 40 deg C			at 100deg c		
Percentage of SWCNTs (%)	t1 in min	t1 in sec	Viscosity, cSt	t2 in min	t2 in sec	Viscosity, cSt
0	16.5	965	96.5	2	120	12
0.01	16.56	1016	101.6	2.06	126	12.6
0.02	17.03	1030	103	2.1	130	13
0.04	17.1	1050	105	1.58	136	13.6
0.06	19.5	1190	119	2.3	150	15
0.08	19.4	1180	118	2.4	160	16
0.1	18.2	1100	110	2.28	148	14.8

Table 2 : Viscosity data due to percentage of additive according to their respective temperature

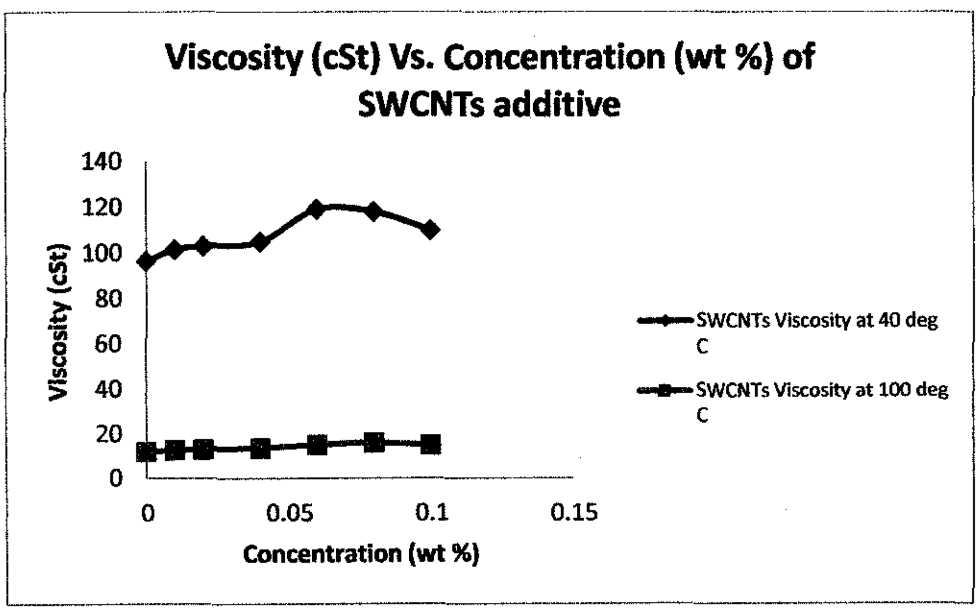


Figure 4: SWCNTs Viscosity (cP) Versus Percentage of Additive according to respective temperatures

b) Multi-Walled Carbon Nanotubes (MWCNTs)

	at 40 deg C			at 100deg c		
Percentage of MWCNTs (%)	t1 in min	t1 in sec	Viscosity, cSt	t2 in min	t2 in sec	Viscosity, cSt
0	16.5	965	96.5	2	120	12
0.01	17.32	1052	105.2	2.1	130	13
0.02	17.5	1070	107	2.49	169	16.9
0.04	19.25	1165	116.5	3.01	190	19
0.06	19.5	1190	119	2.57	177	17.7
0.08	19.4	1180	118	2.55	175	17.5
0.1	19.2	1160	116	2.55	175	17.5

Table 3: Viscosity data due to percentage of additive according to their respective temperature

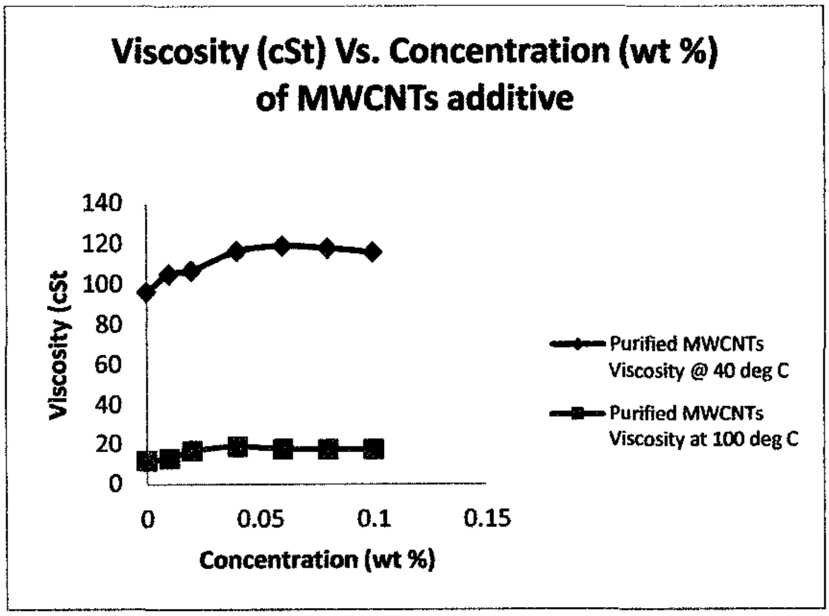


Figure 5: Graph of MWCNTs Viscosity (cP) Versus Percentage of Additive according to respective temperatures

c) Comparison between SWCNTs additive versus MWCNTs additive at 40 °C

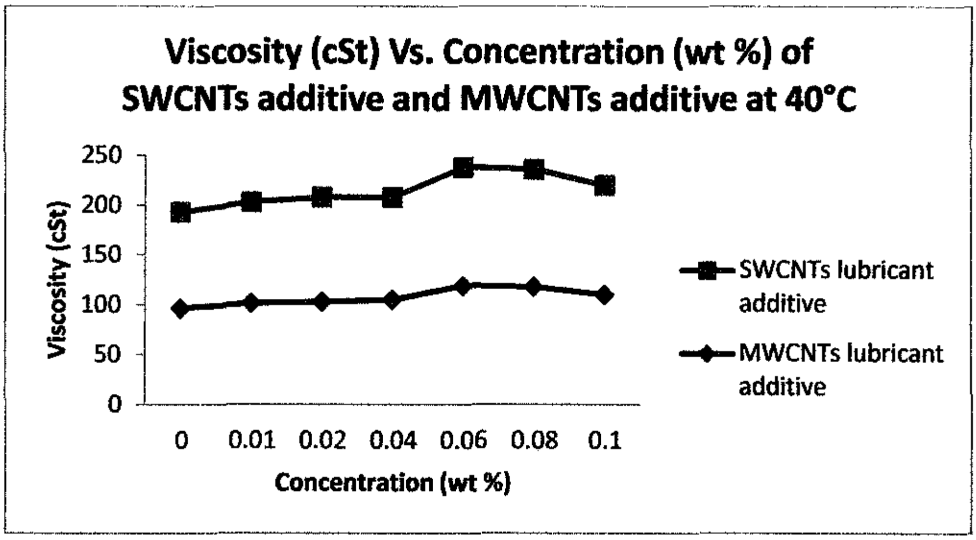


Figure 6: Graph of MWCNTs and SWCNTs Viscosity (cP) Versus Percentage of Additive according to respective temperatures

d) Comparison between SWCNTs additive versus MWCNTs additive at 100°C

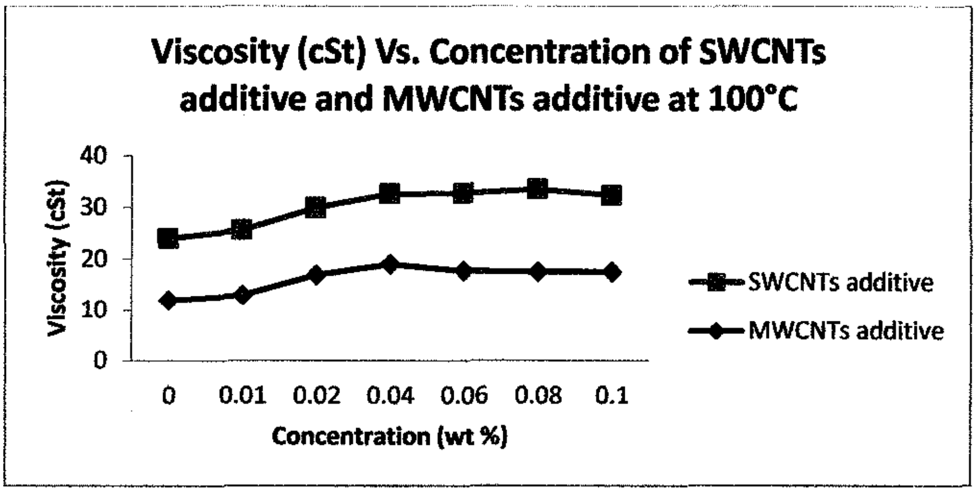


Figure 7: Graph of MWCNTs and SWCNTs Viscosity (cP) Versus Percentage of Additive according to respective temperatures

Coefficient of Friction (COF) Test Results

- MWCNTs additive

	Concentration	0 wt %	0.01 wt %	0.04 wt%	0.08 wt %
	Time (Hrs)	COF	COF	COF	COF
	0.010	0.000	0.010	0.020	0.070
	0.020	0.170	0.030	0.038	0.070
	0.030	0.158	0.100	0.028	0.080
	0.040	0.110	0.025	0.042	0.070
	0.050	0.050	0.010	0.062	0.080
	0.060	0.145	0.018	0.022	0.090
	0.070	0.110	0.010	0.050	0.080
	0.080	0.070	0.038	0.028	0.068
	0.090	0.070	0.015	0.038	0.090
	0.100	0.100	0.020	0.100	0.080
Average		0.098	0.028	0.043	0.078

Table 4: Coefficient of Friction of each concentration of MWCNTs additive (wt %) in lubricant according to time (Hrs)

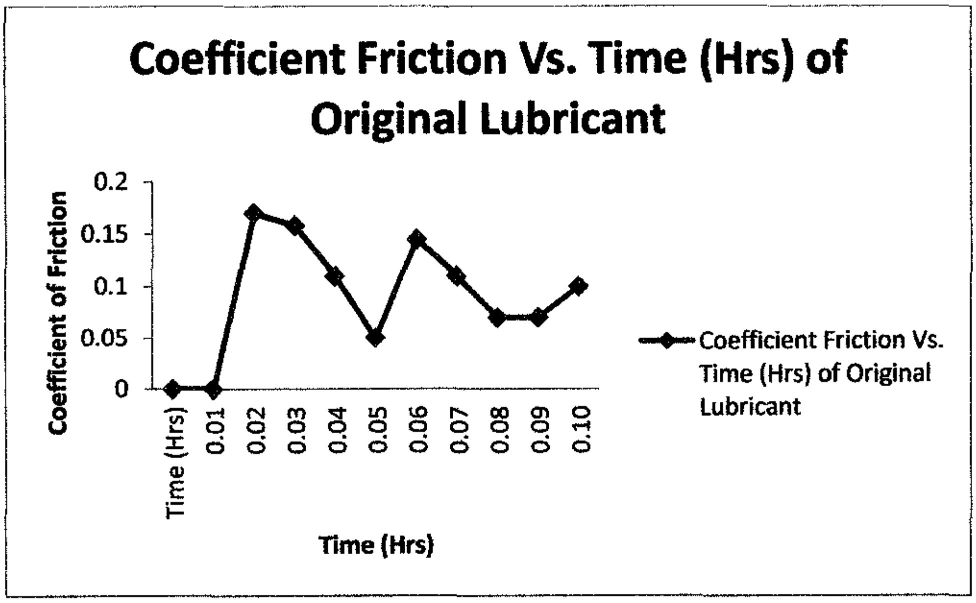


Figure 8: Coefficient Friction Vs. Time (Hrs) of Original Lubricant

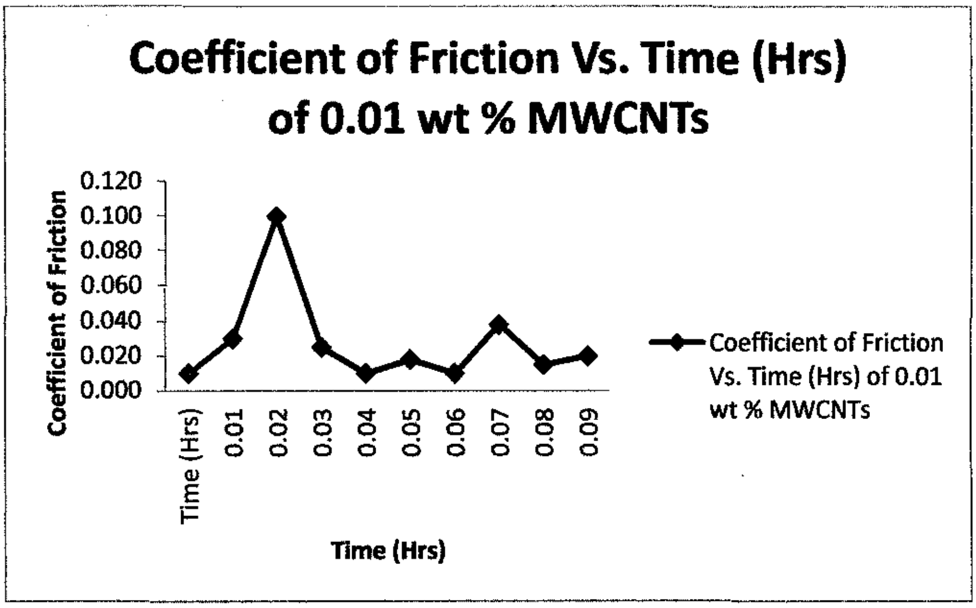


Figure 9: Coefficient of Friction Vs time (Hrs) of 0.01 wt % MWCNTs

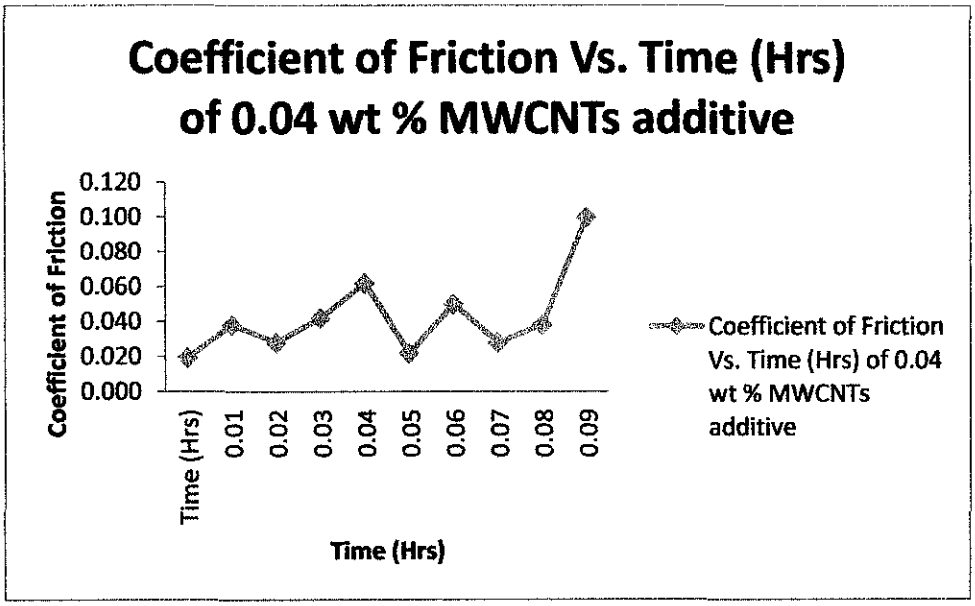


Figure 10: Coefficient of Friction vs. Time (Hrs) of 0.04 wt % MWCNTs additive

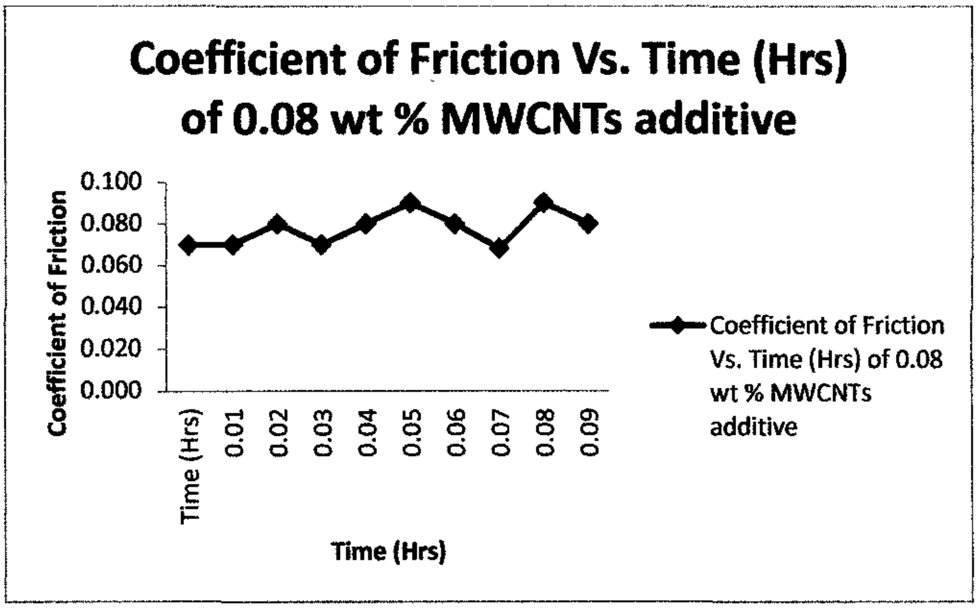


Figure 11: Coefficient of Friction Vs. Time (Hrs) of 0.08 wt % MWCNTs additive

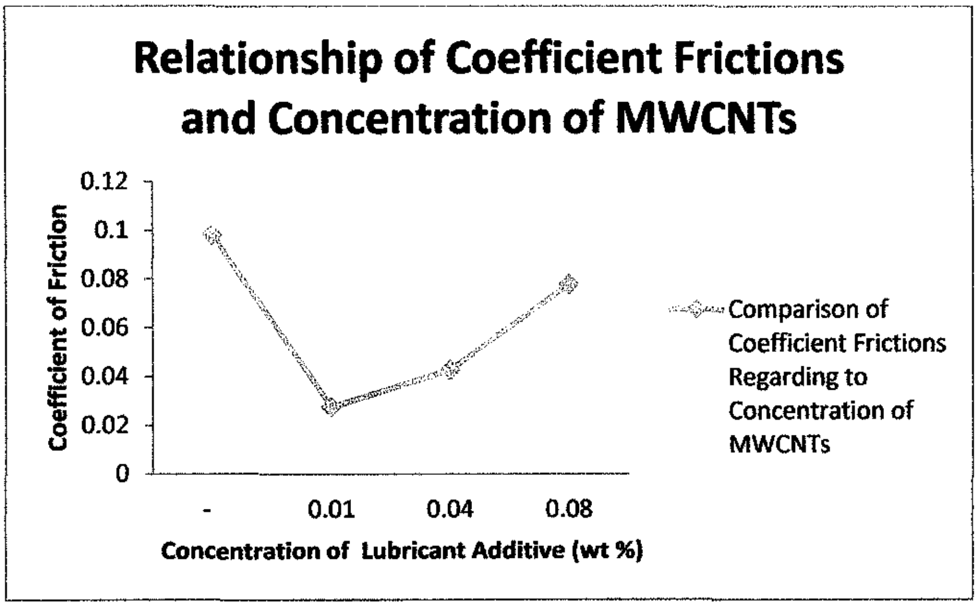


Figure 12: Comparison of Coefficient Friction Regarding to Concentration of MWCNTs additive

Wear Diameter Scars (WDSs) Test Result

Concentration of MWCNTs additive (wt %)	0 WDSs (micrometers)	0.01 WDSs (micrometers)	0.04 WDSs (micrometers)	0.08 WDSs (micrometers)
time (Hrs)				
0	0	0	0	0
0.01	30	70	75	80
0.02	30	60	52	100
0.03	30	80	123	150
0.04	30	75	105	120
0.05	30	55	100	95
0.06	30	110	20	75
0.07	30	100	95	85
0.08	30	20	23	80
0.09	30	100	52	65
0.1	30	10	100	100
Average WDSs (micrometers)	30	68	74.5	95

Table 6: Table of WDSs according to concentration of MWCNTs additive (wt %) and Time (Hrs)

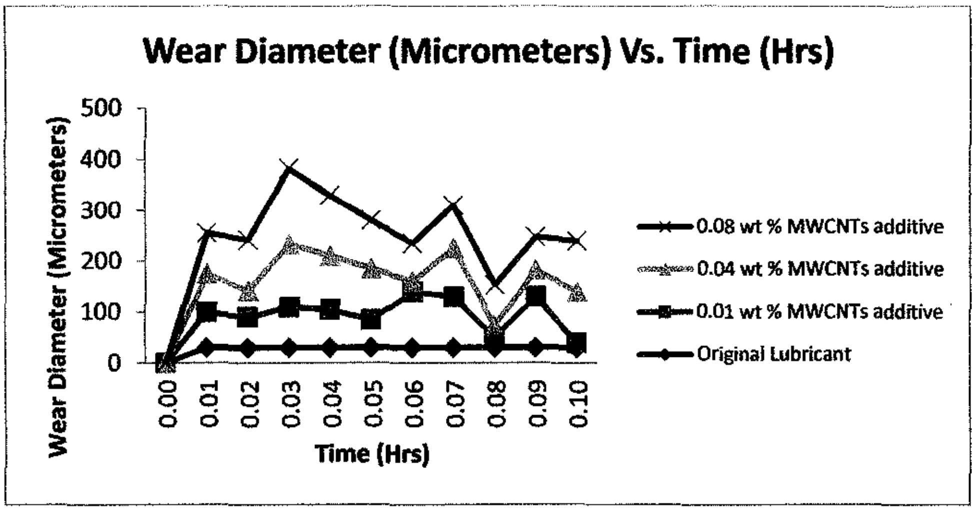


Figure 13: Wear Diameter (Micrometers) Vs. Time (Hrs)

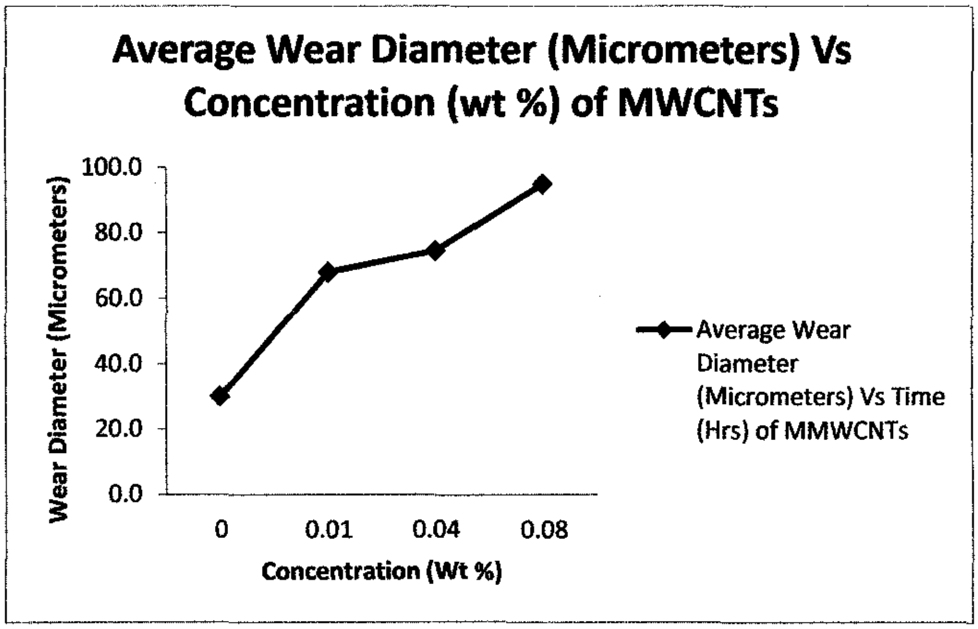


Figure 14: Concentration (wt %) of MWCNTs

3.6.2 Discussion

In term of the temperature condition, shows in **Figure 4** and **Figure 5**, the viscosity of additive lubricant is in higher viscosity at lower temperature. It is discussed at lower temperature; the kinetic energy is at less activity reaction, thus the molecules of intermolecular of CNTs travel at the average velocity, compared to higher temperature, the kinetic energy is higher causes the velocity of intermolecular activity higher. As the higher temperature increases, the viscosity decreases [18].

Based on **Figure 6** and **Figure 7**, roughly shows as the concentration (wt %) of CNTs increases, the viscosity increases at the optimum and indicates constant reading. As the concentration of CNTs increases, the viscosity of CNTs-MACH 5 lubricant mixture increases, as well. That causes the solution becomes thicker. Higher concentration of CNTs additives increases intermolecular force attraction between MACH 5 and CNT molecules which later [19].

In justification of comparison between SWCNTs additive and MWCNTs additive shows that at ambient pressure and ambient temperature of 40°C, the optimum reading are at the same, which indicates the layers of wall is not affected at the temperature to viscosity. At 40°C, the viscosity increases until at 0.06% additive, and it decreases at 0.08% additive and 0.10% additive of MWCNTs. The optimum viscosity at 40°C is at 0.06% additive. At 100°C, the viscosity increases, at 0.00% to 0.04% additive, and decreases slightly when it reaches 0.06% additive, and constant at 0.08% and 0.10%. Overall trend of the graph is similar to the desired result which states theoretically, as the percentage of additive increases, the viscosity increases. This result is reliable to be applied.

A minor problem faced is at 0.06%, 0.08%, and 0.10% additive which the viscosities decrease slightly as the percentage of additive increases. This problem may be caused by the inappropriate dispersion during ultra-dispersion, and inaccuracy during estimating the value of viscosity in laboratory.

It is suggested that during the viscosity test, a sample must be handled in a day due to segregation of the carbon nanotubes and lubricant. As in the viscosity test, a Cannon-Ubbelohde Viscometer is used as the equipment in estimating the viscosity. These are several problems faced during the test conducted:

1) The heater of the viscometer is sensitive
2) The ubbelohde tube has the level of initiation. One must be aware and standardized of the level of each sample to get precise readings.
3) The ubbelohde tube must be cleaned up thoroughly to make sure the next solution is not affected by its reading.

Before conducting viscosity test, one should make sure the dispersion made is thoroughly dispersed and ready to be run. The reason of thorough dispersion is to make sure the standardization of viscosity readings and to obtain accuracy and precision in results.

3.6 Conclusion

The application of engine lubricating oil is to enhance the life time of lubricant and to decrease the friction on the rubbing surface of the engine. CNTs is one of potential additive in lubricant to decrease the friction and need some modification and treatments beside synthesizing single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs) since the properties of these two CNTs give slightly different result readings.

To verify the problem statement, using CNTs increases the tribology properties in term of viscosity, coefficient of friction, and wear diameter scars, experiments conducted as the respective tests using ASTM D-445 for viscosity test and ball-on-disc tribometer.

Based on the trend of the viscosity MWCNTs and SWCNTs, overall, viscosity of additive lubricant increases as percentage of CNTs additive increases until its optimum reading, then viscosity decreases. The optimum result for SWCNTs is at 0.06 wt %, giving 119 Cst reading, as well as MWCNTs is at 0.06 wt %, 119 Cst at 40°C .At the temperature of 100°C The optimum result for SWCNTs is at 0.10 wt %, giving 14.8 Cst reading, while MWCNTs is at 0.06 wt %, giving 17.7 Cst reading.

Based on Coefficient Friction graph result, the best result for coefficient friction is at 0.01 wt % MWCNTs, followed by 0.04 wt % MWCNTs, and 0.08 wt % MWCNTs. Overall, all CNT additives give better results compared to original lubricant.

Based on WDSs result, none of CNTs additive s gives better result compared to original lubricant. CNTs additive is not good in term of wear rate.

Based on the results in the experiments it can be concluded that by adding CNTs additive in lubricant increases the viscosity. This case goes to MWCNTs, as well. In term of coefficient of friction, the CNTs is good in reducing the friction since as CNTs added in the lubricant, the coefficient of friction decreases in a large number, comparing to

MACH 5 viscosity reading. At 0.01 wt % MWCNTs give the optimum result of the lowest coefficient of friction reading. In term of wear diameter scars (WDSs), the results indicate that CNTs need more modification in term of the material coating around the CNTs particles which result a good performance in term of tribology. The CNTs is too abrasive and it causes the high WDSs result.

3.7 Recommendation

There are some recommendations to be proposed for the next experiment:

In term of improving the CNTs properties, some investigations should be conducted to have excellent mechanical properties in suiting with lubricant.

To stabilize the dispersion of CNTs in lubricant, it needs stabilizer to ensure that the distribution of CNTs in the lubricant in well-dispersion. A study by *Lee et al.* [21] said that to prevent agglomeration of CNTs dispersion in lubricant, a stabilizer or a dispersant should be used which in his case is Alkyl aryl sulfonate.

The possible tests that should be continuing in this study are:

a) Oxidation Stability Test or The thin-Film Oxygen Uptake Test (TFOUT) -to measure the oxidation stability of the engine lubricating oil.
b) The Viscosity Test or The High Temperature High Shear (HTHS) -to measure the viscosity of engine lubricating oil under critical operating condition.
c) Alkalinity Test or Total Base Number (TBN)- to measure lubricant's alkalinity
d) Cold Cranking Viscosity Test or The Cold Cranking Simulator Test (CCS)
e) Pour Point Test

Thus, the results will be more accurate and comparable. It eases the analysis task to decide the performance of the additive lubricant t

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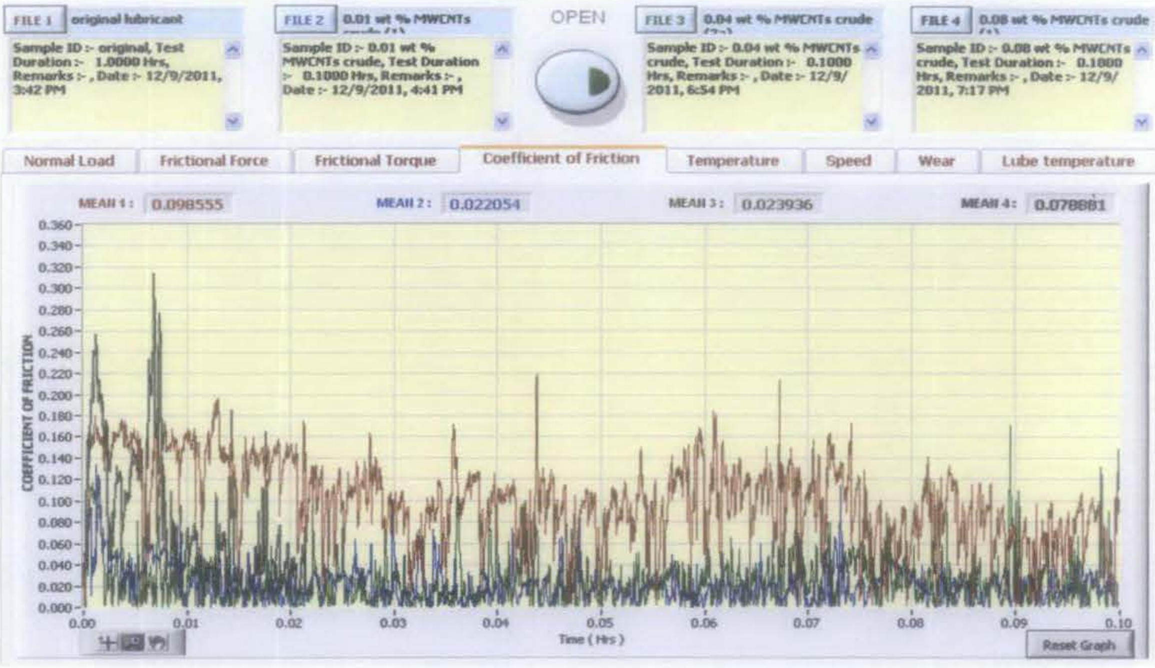
APPENDICES

Tribomachine Software : Winducom

APPENDIX A: Coefficient of Friction Comparison



APPENDIX B: Vertical Wear Comparison