INVESTIGATION OF THERMAL CONDUCTIVITY AND VISCOSITY OF NANOFLUID

WAN MOHD HANIS BIN WAN HARUN



UNIVERSITI TEKNIKAL MALAYSIA MELEKA

INVESTIGATION OF THERMAL CONDUVTIVITY AND VISCOSITY OF NANOFLUID

WAN MOHD HANIS WAN HARUN

This report is submitted in partial fulfilment of the requirements for the award of the

Degree of Bachelor of Mechanical Engineering (Thermal-Fluids)



Fakulti Kejuruteraan Mekanikal

Universiti Teknikal Malaysia Melaka

JUNE 2013

**SUPERVISOR DECLARATION**



"I hereby declare that I have read this thesis and in my opinion this report is sufficient in terms of scope and quantity for the award of the degree of
Bachelor of Mechanical Engineering (Thermal-Fluids)"

Signature: ………………………………………..

Supervisor: ………………………………………..

Date: ………………………………………...

**DECLARATION**



"I hereby declare that the work in this report is my own except the summaries and quotations which have been duty acknowledge."

Signature: ………………………..………………..

Author: ……………………………..………..

Date: …………………………...…………..

Khas buat

Ayah dan Ibu Tersayang

## ACKNOWLEDGEMENT

All praise to Allah Most Gracious, Most Merciful, Who, Alone, brings forgiveness and light and new life to those who call upon Him.

First of all, I would like to express my deepest appreciation to my family especially my father, Wan Harun Wan Abd Rahman, my mother, Wan Kelthom Wan Ali and all of my siblings. I would also like to acknowledge with much appreciation the crucial role of my supervisor, Mr. Imran Syakir Mohamad, his assistant supervisor, Dr. S. Thiru Chitrambalam and my final year project panel, Mrs. Fadhilah Shikh Anuar.



Special thanks also should be given to all my friends that involve in completing this final year project.

Regards,
Wan Mohd Hanis Wan Harun

## ABSTRACT

Nanofluids are the new technology related to the heat transfer, thermal conductivity and others. Nanofluids can be produce by combination between base fluids and nanoparticles. In this experiment, the type of nanoparticles that used is carbon nanotube. The type of base fluids is water as the water has a good thermal conductivity which is widely used especially in the industry. In nanofluid research, the selection of the carbon nanotube in nanofluid formation is very important. Hence, the Pyrograf HHT 24 has been chosen as the nanoparticles. As the carbon nanotube characteristic is hydrophobic, a dispersing agent was introduced to allow the carbon nanotube dispersed completely in the water. The type of dispersing agent in this research is Sodium Dodecyl Sulphate (SDS). So, the formation of nanofluid will be completed with the combination between carbon nanotube, dispersing agent and water. The stability of nanofluid combination also has been considered in order to continue another test which is thermal conductivity and viscosity. As the nanofluid can enhance the thermal conductivity of the water, the thermal conductivity test has been carried out in order to compare the thermal conductivity of water and nanofluid. Besides that, the viscosity test also being carry out to determine the rate of viscosity of nanofluid. The result shows the thermal conductivity of nanofluid is greater than water as the enhancement is achieved. Besides that, the viscosity of nanofluid increase with the addition of carbon nanotube in the water. The greatest enhancement of thermal conductivity that been achieved is at NF013 which has 47.93 % at temperature 40°C. In conclusion, the enhancement of thermal conductivity and investigation of nanofluid viscosity was achieved.

# ABSTRAK

Bendalir nano adalah teknologi baru yang berkaitan dengan pemindahan haba, kealiran haba dan lain-lain. Bendalir nano dihasilkan oleh dengan cecair asas dan partikel nano. Dalam eksperimen ini, jenis nanopartikel yang digunakan adalah tiub nano karbon. Sepanjang penyelidikan nanofluid, pemilihan bagi karbon nanotiub dalam penghasilan nanofluid adalah sangat penting. Jadi, Pyrograf HHT 24 telah dipilih dalam kajian ini. Ciri-ciri karbon nanotiub adalah hidrofobik, ejen campuran telah diperkenalkan untuk membolehkan karbon nanotiub bercampur dalam air. Jenis ejen campuran dalam kajian ini adalah Sodium Sulfat Dodesil. Jadi, pembentukan bendalir nano telah digabungkan antara tiub nano karbon, ejen campuran dan air. Kestabilan gabungan bendalir nano juga perlu dipertimbangkan untuk menjalankan ujian seterusnya ynag merupakan kealiran haba dan kelikatan. Seperti mana bendalir nano boleh meningkatkan kealiran haba air, ujian kealiran haba akan dijalankan untuk membandingkan keberaliran haba air dan bendalir nano. Selain itu, ujian kelikatan juga telah dijalankan untuk menentukan kelikatan bendalir nano. Jadi, hasil yang dijangkakan yang berkaitan dengan kestabilan, kekonduksian terma dan kelikatan harus dicapai seperti yang dinyatakan dalam objektif kajian. Keputusan eksperimen menunjukkan bahawa kekonduksian terma bendalir nano lebih tinggi daripada air. Selain itu, kelikatan bendalir nano meningkat dengan penambahan karbon nanotiub. Nilai peningkatan kealiran haba tertinggi adalah pada NF013 yang mempunyai peratusan 47.93% pada 40°C. Kesimpulanya, peningkatan kekonduksian bendalir nano dan kajian ke atas kelikatan bendalir nano telah dicapai dengan jayanya.

# TABLE OF CONTENT

# LIST OF TABLES

# LIST OF FIGURE

# LIST OF APPENDIX

# CHAPTER 1

# INTRODUCTION

## 1.1 INTRODUCTION



Nanofluid is a material that contains nanometer-sized allergens dispersed inside base fluids. It is well known around the world that water, oil and also other fluid can be a good heat transfer essential fluids but this kind of previous essential fluids has their particular limitation to be able to transfer and also carry temperature. It can be known in which solid for instance metal thing can exchange more temperature or use a high thermal conductivity test to essential fluids. Even though solid is an excellent thermal conductivity nonetheless it cannot provide as any transfer temperature equipment. It really is known the bigger surface area, the increased of thermal conductivity. According to Xue (2005), the particular thermal conductivity not merely depends on volume fraction of your solid or perhaps liquid, but its depend on the particle dimensions and interfacial attributes.

## 1.2 PROBLEM STATEMENT

In nanofluid, there are several type of fluid used as a base. Water is one of fluid used as a coolant in various types of machine and industries around the world as the water has good thermal conductivity. In this research, CNT is chosen to produce nanofluid. However, CNT properties are hydrophobic and dispersing agent is introduced to make the nanofluid stable. The stable nanofluid will improve and increased the thermal conductivity. In conclusion, this research will focus on investigating of thermal conductivity and viscosity in nanofluid.

## 1.3 OBJECTIVE

The main objective of this project is:



- To analyze and investigate thermal conductivity and viscosity in nanofluid prepare from Pyrograf HHT24 carbon nanotube, Sodium Dodecyl Sulphate (SDS), and water

## 1.4 SCOPE

- To prepare nanofluid with additional CNT to enhance its thermal conductivity higher than normal rate of water
- To investigate thermal conductivity and viscosity for nanofluid prepared

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION



Nanofluid is dilute suspension of nanometer-size particles that dispersed in base fluid. In nanofluid, there are various tests or experiment conducted including heat transfer, stability, thermal conductivity and others. This nanotechnology gives a lot of advantages based on high specific area which gain the heat transfer between particles and fluids and the enhancement of base water. In other words, nanoparticles have a tremendous potential to more effectively improve the thermal transport if compared to the micrometer and milimeter sized particles according to the tininess of nanoparticles. This significant size will increase the specific surface area of nanoparticles. Moreover, the tininess of nanoparticles can gives a great potential to be used in miniaturized electronic cooling and microchannels. In this chapter, the definition of nanofluid, application of nanofluid, synthesis of nanofluid, carbon nanotube, dispersing agent, thermal conductivity and viscosity will be reviewed and discussed.

## 2.2 NANOFLUIDS

### 2.2.1 Definition of Nanofluid

Nanofluids are generally engineered colloids created from a starting fluid along with nanoparticles (1-100 nm), Lixin (2009). According to (Tang et al. 2008), nanofluids are generally suspensions involving nanoparticles throughout conventional fluids including water, ethylene glycol along with engine gas, have captivated great awareness from a lot of researchers this can potential positive aspects and purposes in critical fields including microelectronics, electricity supply, travelling and Heating Ventilation Air Conditioning (HVAC). Singh (2008) has stated that nanofluids are usually suspensions regarding nanoparticles inside base essential fluids, a fresh challenge regarding thermal sciences given by nanotechnology. Nanofluids have got unique features distinctive from conventional solid-liquid mixtures where mm or perhaps μm measured particles regarding metals and also non-metals are usually dispersed. In the investigation of (Peng et al. 2005), nanofluid is a mixture between nanoparticles and fluid which have big potential to improve the efficiency of heat transfer and thermal conductivity.



### 2.2.2 Application of Nanofluid

There is various kind of application in nanofluid which is in industrial, commercial, and residential.

### 2.2.2.1 Chiller

Numerous reported which 40% improve in energy conductivity with regard to 0.4% quantity fraction associated with nanofluids. Thus giving an chance of improving overall performance of chillers in AC systems. Remarkably, the air conditioning capacity from the nanofluids might be increased through 4.2% in the standard score conditions. The 6.7% increase within the capacity had been encountered in a flow price of 60 l/min. The actual unexpected rise within the cooling capacity from the nanofluids had been related towards the dynamic interaction from the flow field and also the nanopowder, (Saidur et al. 2011).

### 2.2.2.2 Domestic Refrigerator



Several investigations were performed with nanoparticles inside refrigeration systems to utilize advantageous attributes of nanoparticles to boost the performance and trustworthiness of appliances. For illustration, (Wang et al. 2003) identified that $TiO_2$ nanoparticles may be used since additives to boost the solubility with the mineral acrylic in the particular hydrofluorocarbon (HFC) refrigerant. (Peng et al. 2009) made the research in term impact of nanoparticles about the heat transfer characteristics associated with refrigerant-based nanofluids circulation boiling in the horizontal sleek tube, as well as presented the correlation with regard to predicting warmth transfer overall performance of refrigerant-based nanofluids.

## 2.3 CARBON NANOTUBE (CNT)

Carbon nanotube can be divided into two types which single-walled carbon nanotube (SWNT) and multi-walled carbon nanotube (MWNT). The formation of carbon nanotube is made up from the product of nanoparticles. Based on (Paritosh et al. 2009), nanoparticle can be in form of spherical and cylindrical. Carbon nanoparticle in cylindrical form and tubular structure which in nanometer size of diameter called carbon nanotube. According to Xue (2005), Carbon Nanotubes (CNTs) have the unique structure and remarkable physical properties which attract much attention in past several years. (Patel et al. 2008) state that the stable suspensions connected with nanoparticles (diameter < 100 nm) with liquids usually are called nanofluids, in contrast to suspension connected with carbon nanotube (CNT) from the liquid is referred to as CNT nanofluid. As well as nanotubes (CNTs) are generally relatively brand-new materials that will possess a number of unique components including substantial moduli involving elasticity, substantial aspect rates, and substantial thermal conductivity. (Moisala et al. 2011). In this research, the type of carbon nanotube used is HHT 24 pyrograf which single-walled carbon nanotube.



### 2.3.1 Single-walled Carbon Nanotube (SWNT)

According to (MceEuen et al. 2002), SWNT are the nanoparticles that build up from nanometer-diameter cylinders consisting of single graphene sheet wrapped up to form a tube. Figure 2.1 shows the lattice structure of graphene and the formation of SWNT by rolled up graphene sheet.

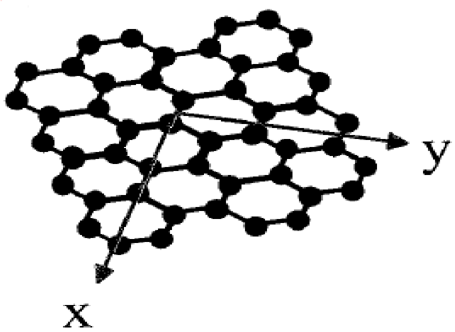


Figure 2.1: Lattice structure of graphene

(Source: MceEuen et al. 2002)

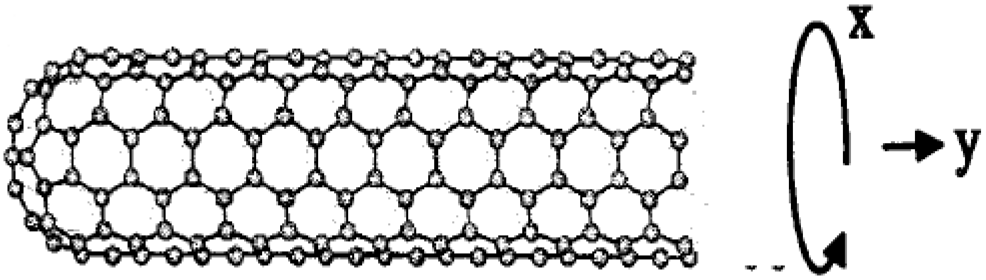


Figure 2.2: Graphene sheet rolled into tubes to form SWNT

(Source: MceEuen et al. 2002)

Based on (Aida et al. 2007), theoretical and experimental work exhibit an uniquely great thermal conductivity in excess of 3000 W/mK to get multi-wall and also carbon nanotubes (MWNT) plus single-wall and also carbon nanotubes (SWNT).

### 2.3.2 Multi-walled Carbon Nanotube (MWNT)

Multi-walled carbon nanotube (MWNT) is another type of carbon nanotube which is involved in formation of nanofluid. This carbon nanotube is called multi-walled because it has double concentric tube in single configuration. MWNT is the first to be discovered which contain the concentric cylinder around common central hollow with a same separation between the layers close to the graphite interlayer spacing, (Tang et al. 2003). Figure 2.3 shows the TEM image of MWNT.



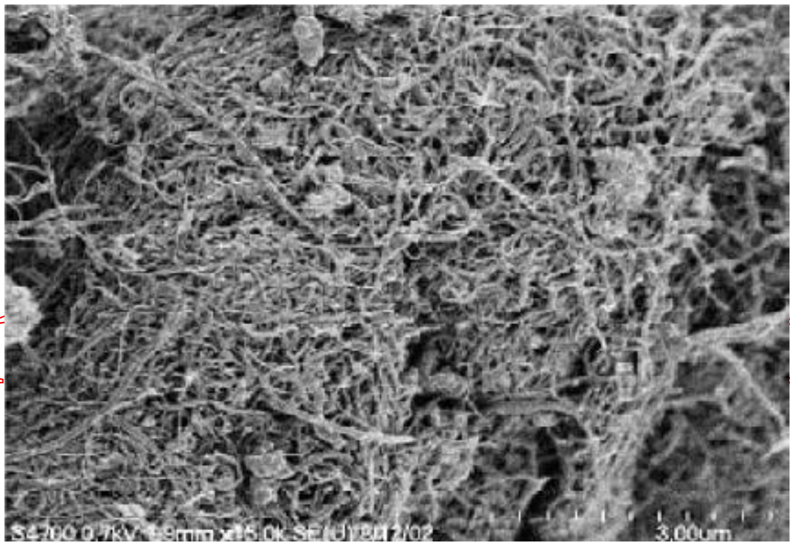


Figure 2.3: TEM image of MWNTs

(Source: Wang et al. 2003)

In the research of Moisala (2006), MWNTs instead of SWNTs happen to be predominantly utilized as conductive fillers because of their lower price, better accessibility and simpler dispersability. Nevertheless, the possibly higher innate electrical as well as thermal conductivity associated with SWNTs should enable an additional reduction within the filler content material required for any given enhancement within the composite qualities.

### 2.3.3 Mechanical Properties of CNT

From the type of carbon nanotube above, both SWNT and MWNT have different mechanical properties. Based on Jonathan (2006), the mechanical properties can follow the analogy of graphite which has stiffness of 1.06 TPa. Besides that, the tensile strength is estimated as high as 130 GPa from properties of C-C bonds. The yield strength also been determined which is 20 GPa, Jonathan (2006). This shows the carbon nanotube is expected to have high strength and stiffness. Figure 2.3 shows the stress and stain curve for MWNT.

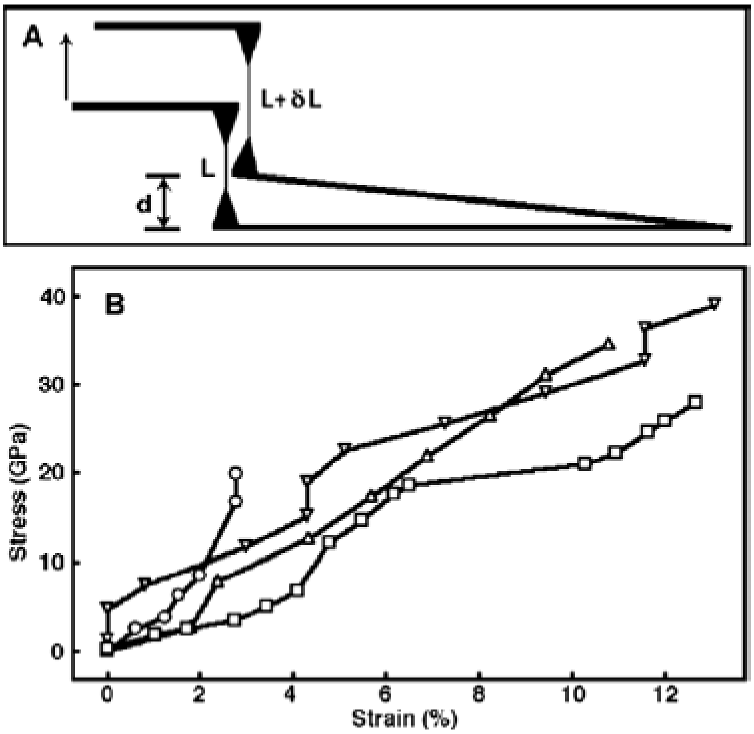




Figure 2.4: Stress strain curve for individual MWNT

(Source: Jonathan, 2006)

## 2.4 DISPERSING AGENT

### 2.4.1 Sodium Dodecyl Sulphate (SDS)

The formation of nanofluid needs the presence of nanoparticles which is carbon nanotube and dispersing agent. As the carbon nanotube immerse in the water, both of carbon nanotube and water will not mix together like the mixing of oil and water. According to Baghalha and Ahmadi (2011), the properties of CNT is does not like the water which is hydrophobic, prone to aggregation and precipitation in water in absence of dispersing agent or surfactant. There is various type of dispersing agent, but in this research Sodium Dodecyl Sulphate (SDS) will be used to enable or modify the hydrophobic surface of CNT and stabilize its suspension in water. Figure 2.5 shows the chemical structure of SDS chemical structure.



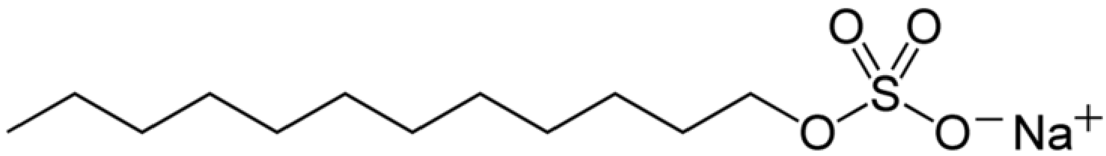


Figure 2.5: Sodium Dodecyl Sulphate (SDS) chemical structure

(Source: Ben, 2013)

In preparation of nanofluid, the presence of dispersing agent was known to be effective to homogeneously disperse carbon nanotube in base fluids. The dispersing agent (SDS) resulted in the electrostatic repulsion between surfactant-coated carbon nanotubes, which will reduces the particle agglomeration due to van der Waals forces of attraction, (Hwang et al. 2008).

## 2.5 SYNTHESIS OF NANOFLUID

The preparation of nanofluid was first prepared by mixing the nanoparticles with water. As the huge demand of nanofluid and rapid development of nanofluid, there is different type study of nanofluid preparation using different approach. The method is two-step process, chemical approach and laser ablation

### 2.5.1 Two-Step Method

This method will prepare nanoparticles in form of powder, typically by an inert gas. As a result, the nanoparticles will disperse in into a base fluid. This method also will give the impact for agglomeration, (Nasri et al. 2003).



### 2.5.2 Chemical Approach Method

According to Xue (2007), chemical approach using wet technology, single step approach which is the powerful method for growing nanostructures of different metals, semiconductor, and non metals. The advantages of nanochemistry is the surface functionized and nanorods of metals or inorganic semiconductors, disperse in water can be prepared with accurate produce nanodispersed nanostructure, (Lo and Tsung 2006).

### 2.5.3 Laser Ablation Method

Laser ablation is the technique that simultaneously makes and disperses nanoparticles directly in water. There are various nanofluids that has been prepared by laser ablation method by ablating solid metals, semiconductor and others. This method is very useful for further splitting of nanoparticles present in nanofluids to study effect of nanoparticles present in nanofluid, (Phuoc et al. 2007).

## 2.6 STABILITY OF NANOFLUID

Nanofluids are not a simple combination of liquid as well as solid particles. Nanoparticles often aggregate using the time elapsed because of its high surface-activity. The agglomeration associated with nanoparticles results not just the negotiation and clogging associated with microchannels but additionally the lowering of energy conductivity associated with nanofluids. Therefore the investigation upon stability can also be a crucial issue which influenced the thermal conductivities associated with nanofluids with regard to application.



## 2.7 THERMAL CONDUCTIVITY OF NANOFLUID

Thermal conductivity is an important parameter for enhancing heat transfer performance of a heat transfer fluid. There are several methods which is transient hot wire, temperature oscillation and steady-state parallel. Usually the method to measure the thermal conductivity of nanofluid is by using transient hot wire (THW) which is widely used among researcher, Lixin (2009). Since thermal conductivity of solid nanoparticles is much higher than that of fluids, the suspended particles are expected to be able to increase thermal conductivity and heat transfer performance. There are many factor that influence the thermal conductivity of nanofluid which is thermal conductivity of nanoparticle, viscosity, temperature and thermal conductivity of the water, Li (2009).

### 2.7.1 Influence of Nanoparticles

Based on the investigation, it has been exposed that the thermal conductivity of nanofluid will increase if the volume fraction of nanoparticle increases, (Hong et al. 2005). Basically, if the thermal conductivity of nanoparticles is high, so the nanofluid will have the high enhancement of the thermal conductivity.



### 2.7.2 Influence of Base Fluids

Besides the effect or influence of nanoparticles, the other factor like thermal conductivity, temperature and viscosity of base fluid also affect the enhancement of thermal conductivity in nanofluid. According to Xie (2002), if the suspension using the same nanoparticles, the enhance ratio of thermal conductivity is decrease with the increasing of thermal conductivity of base water.

### 2.7.3 Influence of the Liquid-Solid Interface

There is another vital that may give some influence towards the thermal conductivity which is the liquid-solid interface. There are several studies that suggested that nano-layer acts as a thermal bridge between a solid nanoparticle and a bulk fluid and play the vital role in order to enhance the thermal conductivity of nanofluid which is stated by and Choi (2004).

## 2.8 VISCOSITY OF NANOFLUID

Viscosity is one of the important factors related to the properties of nanofluid. Li (2009) stated that the viscosity is the critical point as the important of thermal conductivity in engineering system because the properties of nanofluid itself was expected to present an addition or increase in thermal conductivity without increasing in the pressure drop, which is related to the fluid viscosity. It also stated that the main issue encounter the investigator is factor influencing the viscosity of nanofluids. This factor can include the factor related to the significant in concentration and size of nanoparticles, temperature of nanofluids and shear rate. According to (Chen et al. 2007), for all nanofluid tested, the viscosity has been found that the properties of viscosities to be strongly dependent on both temperature and particle volume fraction. Generally, the dynamic viscosity of nanofluids will increase with an augmentation of particle volume fraction for given temperature. There are a few studies regarding to the effects of shape and size on rheological behaviour of nanofluid. According to (Hwang et al. 2007), the increasing in nanoparticles will affect the shear viscosity while (Chen et al 2008) showed that the shape which is rod-like particles has much stronger shear thinning compare with spherical nanoparticles.

# CHAPTER 3

# METHODOLOGY



## 3.1 INTRODUCTION

In the preparation of nanofluid, the experiment should be carry out by following the correct process which is start with the selection of parameter of carbon nanotube, dispersing agent and water. The figure 3.1 shows the flow chart the process of formation of nanofluid including the stability, thermal conductivity, and viscosity test.

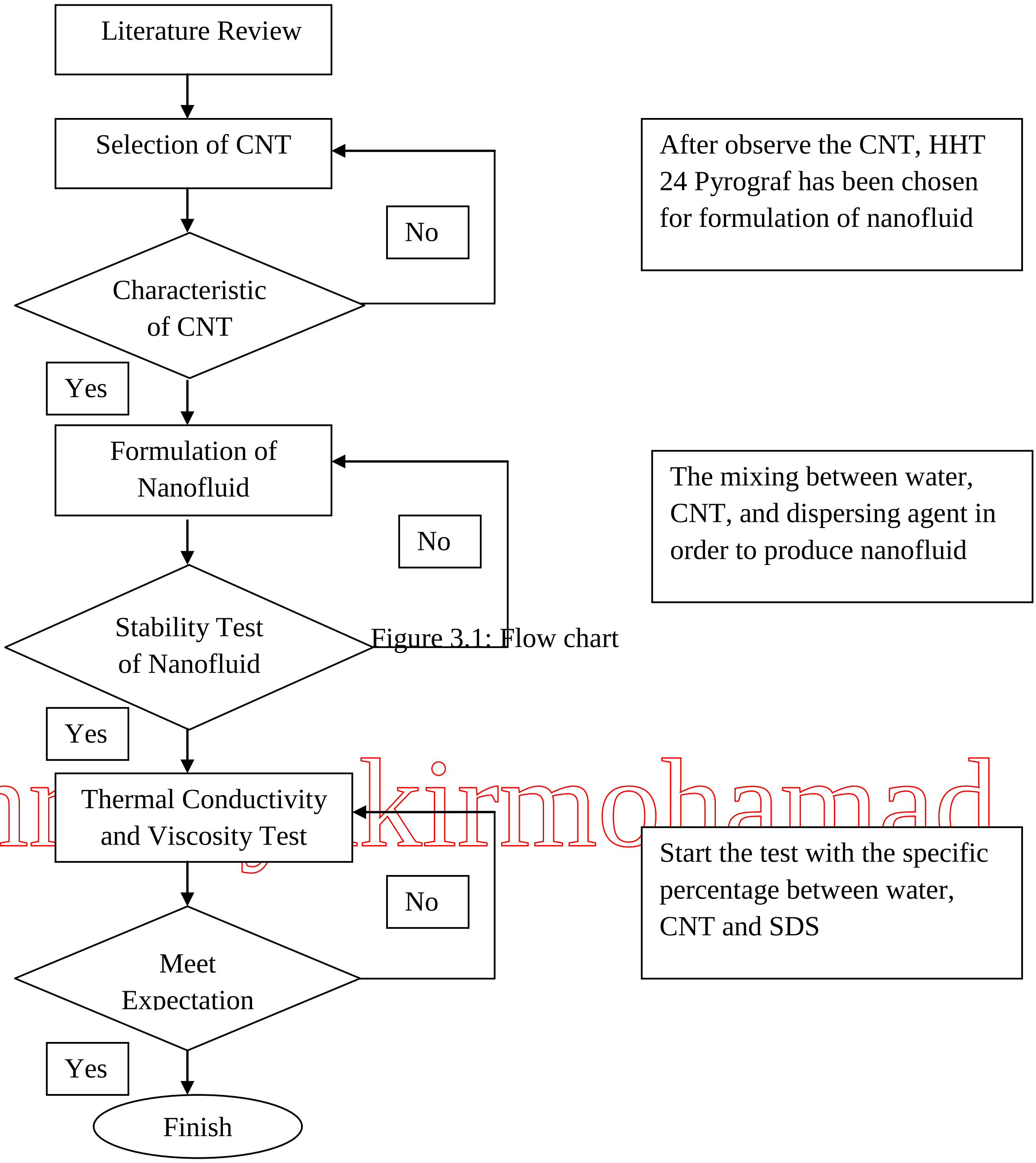


Figure 3.1: Flow chart

## 3.2 PARAMETER

There are four different types of parameter used for the thermal conductivity and viscosity test which are:

i) Base Fluids- Water
ii) Types of CNT- Pyrograf HHT 24
iii) Dispersing Agent- Sodium Dodecyl Sulphate (SDS)
iv) Weight Percentage of CNT, SDS, and Water

### 3.2.1 Properties of Based Fluids

The type based fluid that are using in this experiment is deionized (DI) water. In order to produce deionized water, it may take some process to ensure it completely purify. Besides that, this type of fluids is widely used in industry because it has good thermal conductivity compared to other base fluids. The table 3.1 shows the several properties of deionized water



Table 3.1: Properties of deionized (DI) water

| Parameter | Value |
|---|---|
| Density | Liquid |
| Melting Point | 0 °C |
| Boiling Point | 100 °C |
| Specific Heat | 4180 J/kg °C |
| Latent Heat | 333.35 kj/kg |
| Viscosity | $893x10^{-6}$ kgs/m |
| pH | Approximately 7.0 |

### 3.2.2 Carbon Nanotubes (CNT)

In this experiment, the type of CNT that has been chosen is Pyrograf HHT24 which is single-walled carbon nanotube. The density of this CNT is 2 g/cm$^3$, Applied Science Incorporation (2012). The type of CNT is carbon nanofibre which different with SWNT and MWNT.

### 3.2.3 Dispersing Agent

The type of dispersing agent for this experiment is Sodium Dodecyl Sulphate (SDS) which is the compound that help to lower the surface tension of water and enable the CNT to dispersed in water. Without dispersing agent or surfactant, the CNT cannot disperse completely in water because its characteristic is hydrophobic. The density of SDS is 1.01 g/cm$^3$, VWR Corporation (2007).



### 3.2.4 Weight Percentage of CNT, SDS and Water

In the calculation, the total between CNT, SDS, and water must be equal to 40 ml. Volume of CNT and SDS is determined from its density and weight percentage. Table 3.2 shows the example of weight percentage and volume CNT, SDS, water.

Table 3.2: Example of weight percentage and volume of CNT, SDS, and water

| CNT( %) | Volume CNT Pyrograf HHT 24 | SDS (%) | Volume SDS | water (ml) |
|---|---|---|---|---|
| 0.04 | 0.0200 | 0.0080 | 0.00792 | 39.97208 |

## 3.3 EQUIPMENT

In this experiment, there are several equipment used to run the required test which is:

i) Mechanical Homogenizer
ii) Ultrasonicator
iii) pH meter
iv) Stability Test Rig
v) KD2-Pro
vi) Viscometer

### 3.3.1 Mechanical Homogenizer



From the specification of the homogenizer, it was manufactured by LabGenius. This homogenizer can be use for homogenize between CNT, dispersing agent, and water. It also can speed up to 27000 rpm. Figure 3.2 shows the mechanical homogenizer operates with the nanofluid.

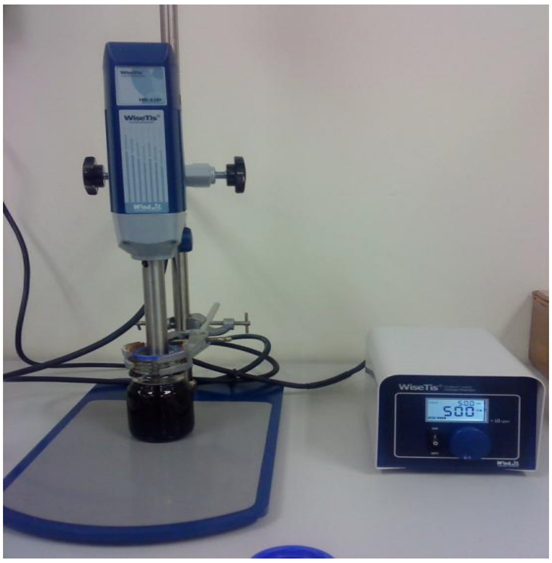


Figure 3.2: Mechanical Homogenizer

### 3.3.2 Ultrasonic Cleaner

This ultrasonic cleaner was manufactured by Elma Hans Schmidbauer GmbH & Co. KG, a German company. Ultrasonic cleaner will disperse completely the mixture of CNT, dispersing agent and water in 60 minutes. Figure 3.3 shows the sample of nanofluid disperse in ultrasonic cleaner.




Figure 3.3: Ultrasonic Cleaner

### 3.3.3 pH Meter

pH meter is used to identify the required pH in order to improve the stability of nanofluid after disperse in ultrasonic cleaner. Figure 3.4 shows the pH meter.

Figure 3.4: pH meter

### 3.3.4 Stability Test Rig

Stability test rig function is to measure or identify the stability of nanofluid by penetrate the light through the test rig. It was measure after pH checking. The process of checking started with the placement of nanofluid sample into the hole and the light will penetrate through the sample. As a result, the stability of nanofluid can be determined. Figure 3.5 shows the sample of nanofluid being tested in stability test rig.



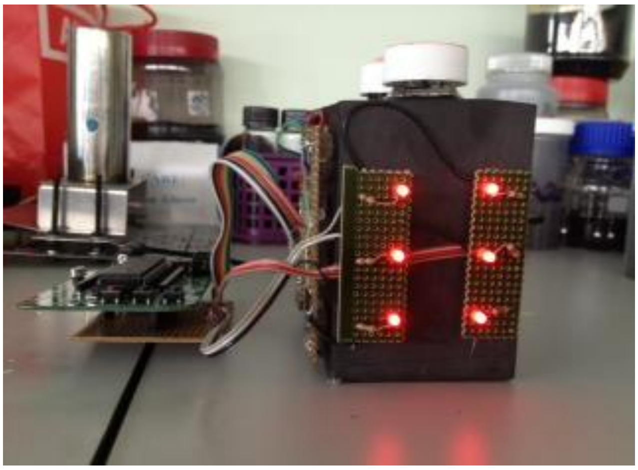

Figure 3.5: Stability Test Rig

### 3.3.5 KD2-Pro

KD2-Pro is the portable device that measures the thermal conductivity by using the transient line heat source. This device also can measure the resistivity, diffusivity and the specific heat. After checking the stability of the nanofluid, the thermal conductivity is measure. The sensor that been used in thermal conductivity test of nanofluid is KS-1 which is work on normal fluid medium. Figure 3.6 shows the KD2-Pro equipment and sensor.



Figure 3.6: KD2-Pro

### 3.3.6 Viscometer

Viscometer is a device that measures the viscosity of fluid. This are require to check the rate of viscosity by following the required temperature and ratio. The type of viscometer that been used in this experiment is Brookfield. Around 6.7 ml has been taken out from the bottle to test in viscometer. The full speed of spindle has been set to check the viscosity of nanofluid. Figure 3.7 shows the viscometer that has been set up.

Figure 3.7: Viscometer

## 3.4 PROCEDURE



The following procedure will discuss about the preparation of nanofluid including the thermal conductivity and viscosity:

a) All the parameter for nanofluid preparation was weighed up which is CNT, SDS, and water

b) Then, the CNT, SDS is mixed together in the deionized water by following the correct ratio in the glass beaker. The bottle was shook in order to make the solution well-mixed

c) The homogenizer was setup with the mixture of nanofluid. The propeller of the homogenizer is placed a few centimetres from the bottom of glass beaker. The speed of the homogenizer is set to 10000 rpm and this process took 60 second to complete.

d) After the mixture of nanofluid is well homogenized, the ultrasonic cleaner was set up. The mixture of nanofluid is placed inside the ultrasonic cleaner. The temperature was set to 25°C at the highest frequency in order ensure the

CNT and dispersing agent disperse evenly and completely inside the deionized water. This process took 60 minutes to complete

e) The pH of the nanofluid was measured by using the pH metre before carry out the stability test.

f) The mixture of nanofluid once again being homogenized by mechanical homogenizer by set the 1000 rpm of propeller speed in a few minutes like stated in procedure number 3.

g) For the stability test to determine whether the actual CNT had been totally dispersed within the deionized water, it will begin right following the mixture had been produce and it might take a week to check on if any kind of agglomerate occurs in the beaker. These types of stability assessments were examined periodically inside 1 in order to 100 several hours.

h) After the nanofluid passes the stability test, the mixture of nanofluid can be tested with thermal conductivity test and viscosity test by using the KD2-Pro and viscometer respectively.



## 3.5 Safety Precaution

Each Sodium Dodecyl Sulphate as well as CNT have been in powder type. For CNT, skin as well as eye contact could cause irritation. Inhalation associated with CNT could cause lung harm or illness. Hence, using dust respirator is of the face mask is really a must and just in case the CNT natural powder is leaking, remove it by utilizing sweeper or vacuum or squirt with drinking water.

# CHAPTER 4

# RESULT AND DISCUSSION

## 4.1 RESULT



As an experiment has been carried out, so the desire and required result has been obtain by following the correct method and procedure of experiment. The tabulation of data will be performed in form of table and graphical format in order to make an effective analysis and comparison.

### 4.1.1 Stability Test

The result of stability has been obtained after 100 hours by following the procedure and method. The CNT that been used is Pyrograf HHT 24 while dispersing agent is Sodium Dodecyl Sulphate (SDS). The sample of nanofluid has been tested in stability test rig. The sample has been tested in stability test rig in specific ratio between CNT and dispersing agent. From the stability test rig, the sample of nanofluid is stable when all the led light is light up, see Appendix B. From Table 4.1, the first third samples of nanofluid are not stable and the other samples are stable. After stability test, the stable sample will be tested on thermal conductivity and viscosity test

Table 4.1: Sample of nanofluid

| CODE | CNT( %) | Volume (V) CNT | SDS (%) | Volume (V) SDS | water (ml) | Stability |
|---|---|---|---|---|---|---|
| **NF001** | 0.04 | 0.0200 | 0.0000 | 0.00000 | 39.98000 | unstable |
| **NF002** | 0.04 | 0.0200 | 0.0080 | 0.00792 | 39.97208 | unstable |
| **NF003** | 0.04 | 0.0200 | 0.0160 | 0.01584 | 39.96416 | unstable |
| **NF004** | 0.04 | 0.0200 | 0.0240 | 0.02376 | 39.95624 | stable |
| **NF005** | 0.04 | 0.0200 | 0.0320 | 0.03168 | 39.94832 | stable |
| **NF006** | 0.04 | 0.0200 | 0.0400 | 0.03960 | 39.94040 | stable |
| **NF007** | 0.08 | 0.0400 | 0.0320 | 0.03168 | 39.92832 | stable |
| **NF008** | 0.16 | 0.0800 | 0.0640 | 0.06337 | 39.85663 | stable |
| **NF009** | 0.20 | 0.1000 | 0.0800 | 0.07921 | 39.82079 | stable |
| **NF010** | 0.24 | 0.1200 | 0.0960 | 0.09505 | 39.78495 | stable |
| **NF011** | 0.32 | 0.1600 | 0.1280 | 0.12673 | 39.71327 | stable |
| **NF012** | 0.40 | 0.2000 | 0.1600 | 0.15842 | 39.64158 | stable |
| **NF013** | 0.48 | 0.2400 | 0.1920 | 0.19010 | 39.56990 | stable |
| **NF014** | 0.56 | 0.2800 | 0.2240 | 0.22178 | 39.49822 | stable |
| **NF015** | 0.60 | 0.3000 | 0.2400 | 0.23762 | 39.46238 | stable |
| **NF016** | 0.64 | 0.3200 | 0.2560 | 0.25347 | 39.42653 | stable |
| **NF017** | 0.72 | 0.3600 | 0.2880 | 0.28515 | 39.35485 | stable |
| **NF018** | 0.80 | 0.4000 | 0.3200 | 0.31683 | 39.28317 | stable |

### 4.1.2 Thermal Conductivity Test

The stable nanofluid will be tested using KD2-Pro device after make observation and validation on stability of nanofluid in order to obtain thermal conductivity of nanofluid. Thermal conductivity test being carried out on three different temperatures which is 6°C, 25°C, and 40°C. As the objectives need an enhancement of thermal conductivity, so the addition of nanoparticles which is Pyrograf HHT 24 carbon nanotube. Table 4.2 shows the thermal conductivity reading for Pyrograf HHT 24 at different weight percentage and temperature.

Table 4.2: Thermal Conductivity of Pyrograf HHT 24 CNT

| Code | CNT % | Thermal conductivity (W/m.K) at temperature (°c) | | |
|---|---|---|---|---|
| | | 6°C | 25°C | 40°C |
| **NF004** | 0.040 | 0.554 | 0.572 | 0.598 |
| **NF005** | 0.040 | 0.602 | 0.613 | 0.624 |
| **NF006** | 0.040 | 0.501 | 0.537 | 0.684 |
| **NF007** | 0.080 | 0.506 | 0.655 | 0.639 |
| **NF008** | 0.160 | 0.583 | 0.670 | 0.676 |
| **NF009** | 0.200 | 0.534 | 0.671 | 0.69 |
| **NF010** | 0.240 | 0.583 | 0.673 | 0.697 |
| **NF011** | 0.320 | 0.506 | 0.582 | 0.631 |
| **NF012** | 0.400 | 0.562 | 0.570 | 0.582 |
| **NF013** | 0.480 | 0.525 | 0.563 | 0.858 |
| **NF014** | 0.560 | 0.569 | 0.583 | 0.759 |
| **NF015** | 0.600 | 0.495 | 0.600 | 0.732 |
| **NF016** | 0.640 | 0.504 | 0.534 | 0.701 |
| **NF017** | 0.720 | 0.582 | 0.655 | 0.681 |
| **NF018** | 0.800 | 0.673 | 0.675 | 0.694 |

The Table 4.2 will be perform in graphical format as shows in Figure 4.1 below in order to compute effective and reasonable analysis.

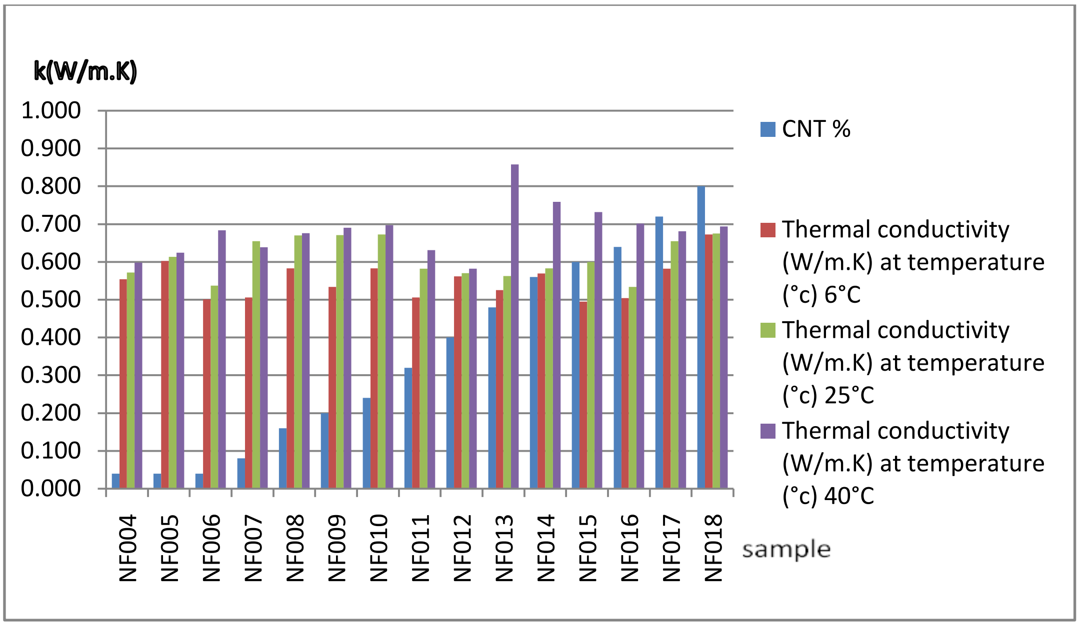


Figure 4.1: Graph of thermal conductivity of Pyrograf HHT 24 CNT



Based on Figure 4.1 and Table 4.1, the highest thermal conductivity at 6°C is at 0.8% with the thermal conductivity of 0.673 W/m.K followed by 0.16%, 0.72% and the lowest thermal conductivity is at 0.60% with 0.495 W/m.K. At 25°C, the highest thermal conductivity is 0.8% with 0.675W/m.K followed with 0.24%, 0.20%, and the lowest thermal conductivity is at 0.64% with 0.534W/m.K. At the highest temperature which is 40°C, the highest thermal conductivity is 0.48% with 0.858W/m.K followed by 0.56%, 0.60% and the lowest thermal conductivity at this temperature is 0.40% with 0.582 W/m.K.

4.1.2.1 Percentage of Enhancement of Thermal Conductivity

In the experiment, the rate of thermal conductivity of deionized water being obtained by using the same device which is KD2Pro. Table 4.3 shows the reading of thermal conductivity for three different temperatures.

Table 4.3: Thermal Conductivity of deionized water

| **Temperature (°C)** | **Thermal Conductivity (W/m.K)** |
|---|---|
| 6°C | 0.540 |
| 25°C | 0.560 |
| 40°C | 0.580 |

The thermal conductivity obtain from the addition of CNT has been compared with the normal rate of water by calculating the percentage of enhancement between both result. Table 4.3 shows the percentage of enhancement of thermal conductivity. The sample calculation of percentage has been shown in Appendix A.

Table 4.4: Percentage enhancement of thermal conductivity

| Code | CNT % | Percentage of Enhancement (%) at temperature (°c) | | |
|---|---|---|---|---|
| | | 6°C | 25°C | 40°C |
| NF004 | 0.04 | 2.59% | 2.14% | 3.10% |
| NF005 | 0.04 | 11.48% | 9.46% | 7.50% |
| NF006 | 0.04 | -7.22% | -4.11% | 8.06% |
| NF007 | 0.08 | -6.29% | 16.96% | 10.17% |
| NF008 | 0.16 | 7.96% | 19.64% | 16.55% |
| NF009 | 0.20 | -1.11% | 19.82% | 18.96% |
| NF010 | 0.24 | 7.96% | 20.17% | 20.17% |
| NF011 | 0.32 | -6.29% | 3.90% | 8.79% |
| NF012 | 0.40 | 4.07% | 1.78% | 0.34% |
| NF013 | 0.48 | 7.22% | 0.53% | 47.93% |
| NF014 | 0.56 | 5.37% | 7.96% | 30.86% |
| NF015 | 0.60 | -8.33% | 7.10% | 26.20% |
| NF016 | 0.64 | -6.66% | 4.64% | 20.86% |
| NF017 | 0.72 | 7.77% | 16.96% | 17.41% |
| NF018 | 0.80 | 24.63% | 20.53% | 19.60% |



From Table 4.4, the greatest enhancement is 0.48% of CNT at 40°C with the enhancement of 47.93% followed by 30.86%, 24.63 at 6°C and the lowest percentage of enhancement is -8.33% at 6°C. The red marked on the Table 4.4 shows the three highest percentage of enhance for each temperature. In conclusion, the percentage of enhancement increases with the addition of nanoparticles or CNT. The sample calculation can be seen in Appendix A. The nanofluid of NF013 has the highest thermal conductivity at 40°C because of temperature and the ratio of nanoparticles factor which will be discuss more on discussion part. The graphical view for the highest percentage enhancement has been shown in Figure 4.2, 4.3, and 4.4 for each temperature.

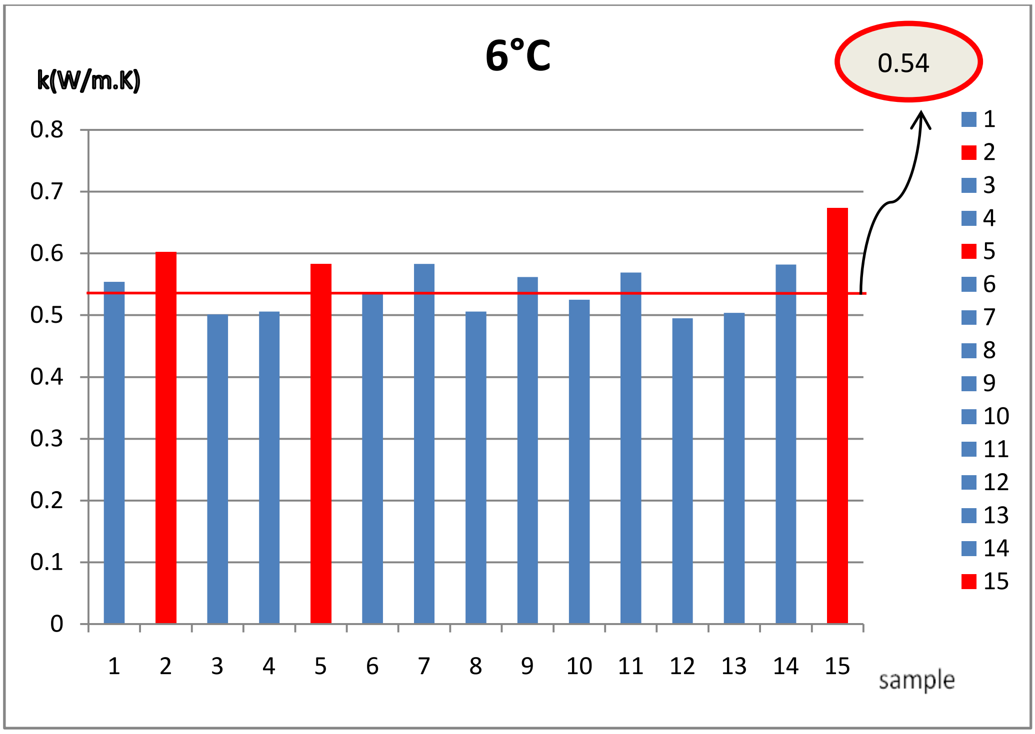


Figure 4.2: Thermal Conductivity at 6°C



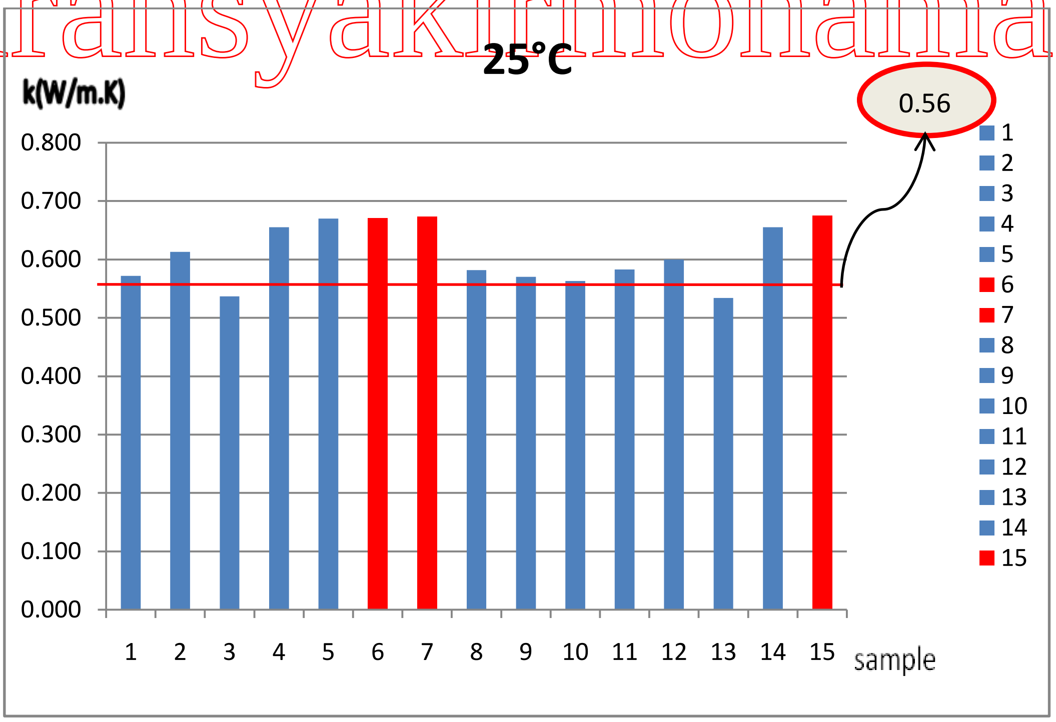


Figure 4.3: Thermal Conductivity at 25°C

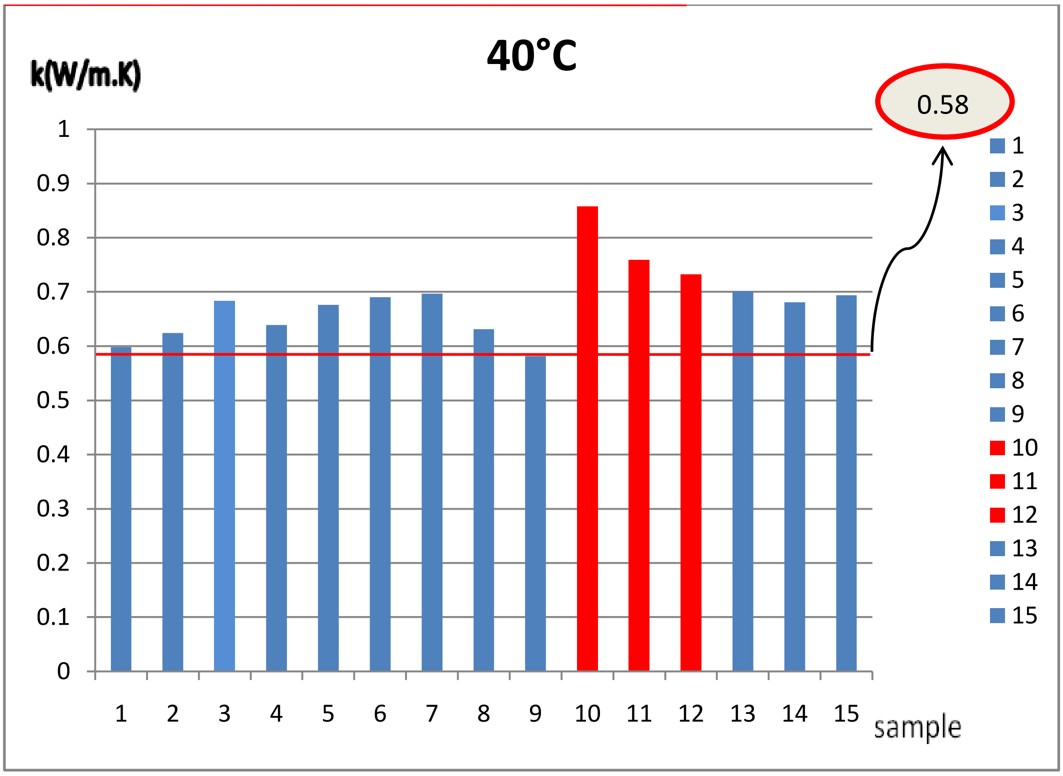


Figure 4.4: Thermal Conductivity at 40°C

### 4.1.3 Viscosity Test

As the nanofluid was stable, the sample will be test on viscometer device in order to obtain the reading of viscosity. All of sample will be tested by take out around 6.7ml of nanofluid from 40ml sample. The result will be obtain around five minutes for each sample by using S-18 spindle which is for fluid with the full speed of rotation. Table 4.5 below shows the reading of viscosity using Pyrograf HHT 24 CNT.

Table 4.5: Viscosity of Pyrograf HHT 24 CNT

| Code | CNT % | Viscosity (Pa.s) at temperature (°c) | | |
|---|---|---|---|---|
| | | **6°C** | **25°C** | **40°C** |
| **NF004** | 0.04 | 1.56 | 1.14 | 0.72 |
| **NF005** | 0.04 | 1.58 | 1.08 | 0.80 |
| **NF006** | 0.04 | 1.74 | 1.09 | 0.87 |
| **NF007** | 0.08 | 1.59 | 1.09 | 0.89 |
| **NF008** | 0.16 | 1.68 | 1.10 | 0.90 |
| **NF009** | 0.20 | 1.62 | 1.11 | 0.90 |
| **NF010** | 0.24 | 1.65 | 1.11 | 0.96 |
| **NF011** | 0.32 | 2.25 | 2.28 | 2.24 |
| **NF012** | 0.40 | 2.43 | 2.64 | 2.59 |
| **NF013** | 0.48 | 2.45 | 2.34 | 2.25 |
| **NF014** | 0.56 | 2.31 | 2.26 | 2.11 |
| **NF015** | 0.60 | 3.81 | 3.42 | 3.21 |
| **NF016** | 0.64 | 4.11 | 4.01 | 4.00 |
| **NF017** | 0.72 | 4.14 | 4.09 | 4.05 |
| **NF018** | 0.80 | 4.23 | 4.12 | 4.10 |



The Table 4.5 will be present in graphical format to distinguish between different temperature and weight of CNT

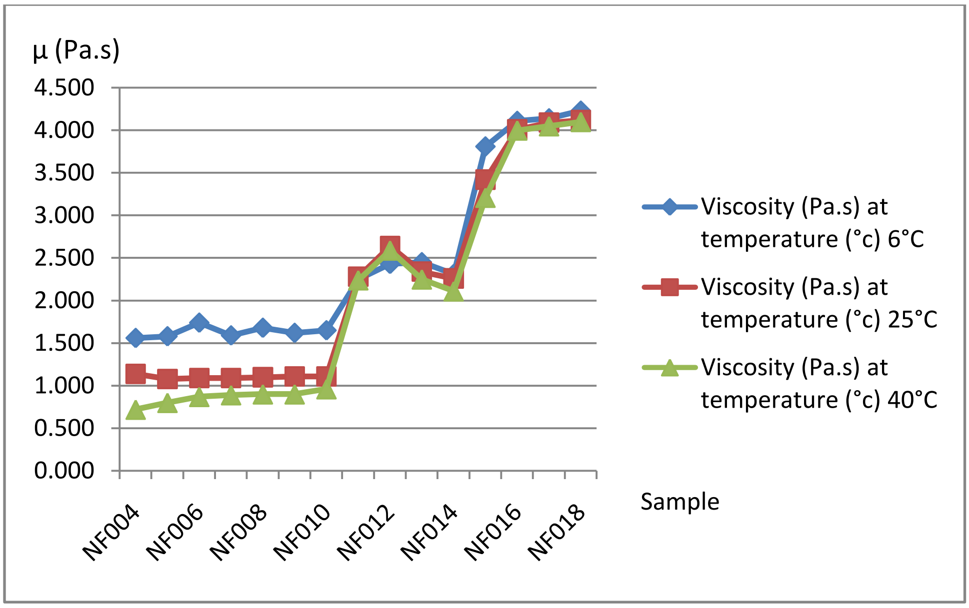


Figure 4.5: Graph of viscosity of Pyrograf HHT 24 CNT

From the graph and table above, the highest viscosity is at 0.8% at 6°C followed by 0.72%, 0.8% at 25°C and 0.8% while the lowest viscosity is 0.04% at 40°C followed by 0.04% at 25°C and 0.04% at 6°C. The reading of viscosity shows an increment as the weight of Pyrograf HHT 24 CNT increase. From the graph, there are obvious changes in two parts which is starting at 0.24% of CNT and 0.56% of CNT. The lowest temperature which is 6°C also shows the highest viscosity compare with 25°C and 40°C.

## 4.2 DISCUSSION

### 4.2.1 Analysis of Stability

In the stability test of nanofluid, the surfactant or dispersing agent which is Sodium Dodecyl Sulphate was introduced in order to lower the surface tension of nanofluid as the CNT is hydrophobic. According to (Nasiri et al. 2010), the using of dispersing agent or surfactant method changes the wetting adhesion behaviour which helps in reducing their tendency to agglomerate. From Table 4.1, it clearly showed that the addition of dispersing agent will make the nanofluid become more stable as the first three sample are not stable because lack of dispersing agent. The process of ultrasonication also important factor in stability of nanofluid which is the process need to carried out intermittently to avoid overheating that can reduce the quality of nanofluid, (Nasiri et al. 2010). As a conclusion, there are two factors that contribute to stability of nanofluid which is the role of dispersing agent towards nanofluid and the process of ultrasonication.



### 4.2.2 Analysis of Thermal Conductivity

After the result was obtained from the experiment that shown in Table 4.4, the analysis need to be carried out in order to obtain the significant factor or reason of nanofluid enhancement. There are several factor involve in nanofluid enhancement which is temperature, types of CNT, length and surface area.

#### 4.2.2.1 Temperature

From Table 4.1 and Figure 4.2, 4.3 and 4.4, thermal conductivity increase according to the high temperature of the nanofluid. As the temperature increases, the average kinetic energy of the nanoparticles increases, which means the nanoparticles move about more energetically. As a result, the thermal conductivity becomes higher as temperature increase. In the latest research of (Murshed et al 2007), the enhancement of thermal conductivity increase according to increment of temperature that being investigated.

#### 4.2.2.2 Types of CNT



The types of CNT that been used in this experiment is Pyrograf HHT 24 which obtain from manufacturer of Pyrograf Product, Inc. Table 4.6 shows the properties of carbon nanofibre according to the manufacturer of Pyrograf Product, Inc.

Table 4.6: Properties of Pyrograf HHT 24 CNT

| | |
|---|---|
| Fibre diameter, nm (average | 100 |
| CVD carbon overcoat present on fibre | no |
| Surface area, $m^2$/gm | 41 |
| Dispersive surface energy ,mJ/$m^2$ | 135 |
| Moisture, wt% | <5 |
| Iron, ppm | <100 |

(Source: Pyrograf, 2013)

This type of CNT is carbon nanofibre which has the advantage in term of length of CNT. Figure 4.6 shows the Scanning Electron Microscope (SEM) image for carbon nanofibre.

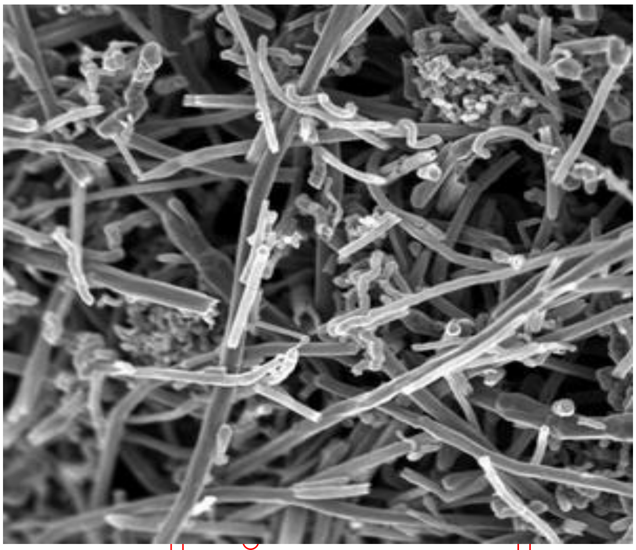



Figure 4.6: SEM image for Pyrograf

(Source: Ahmad, 2011)

Figure 4.6 shows that Pyrograf have an advantage in term of length which have longer tube. So this factor may affect the thermal conductivity of nanofluid as the longer tube has more surface area. As a result, more surface of CNT exposed and gained the thermal conductivity of nanofluid. According to (Murshed et al 2007), the length of CNT play the main role in thermal conductivity enhancement. In conclusion based on the input of journal, research and experiment, the temperature, types of CNT, length and surface area can affect the enhancement of thermal conductivity.

### 4.2.3 Analysis of Viscosity

Viscosity is a measure of resistance in the fluid which involve the shear stress or tensile stress. From the result, viscosity increase with addition of CNT into deionized water. It can be seen from the experiment result which is shown in Figure 4.5. Experimental measurements and theoretical analyses also suggest that nanoparticle structuring is responsible for the viscosity increase due to the addition of nanoparticles, Chen (2009). According to (Phuoc et al. 2009), the size of particles and shape affect the viscosity of nanofluid. (Haggenmueller et al. 2009) showed experimentally that an increase in particles size led to increase in shear viscosity, whereas (Chen et al. 2009) showed that nanofluid that contain rod-like shape has higher viscosity compared to the spherical shape. This is because of the rod-like shape will exert more resistance in the water compare to the spherical which have less resistance. In this experiment, the rod-like shape a nanoparticle has been used which is in form of tube and continuously effect the viscosity of nanofluid. From the experiment of (Chen et al. 2005) also showed that the kinematic viscosity decrease with the increase of temperature. So, the outcome is similar as the result above which the lowest temperature has higher viscosity compare to other temperature.

# CHAPTER 5

# CONCLUSION



## 5.1 CONCLUSION

The preparation of nanofluid, stability test, thermal conductivity test and viscosity test has been investigated by using Pyrograf HHT 24, Sodium Dodecyl Sulphate (SDS). By arrange and form the specific ratio of nanofluid from 0.04% to 0.80%, the best result of stability, thermal conductivity has been obtained. For the stability test, the process involved which is homogenized, pH meter check, and ultrasonicator. After 100 hours, the stability of 18 samples of nanofluid has been checked using stability test rig. The result showed the first three samples are not stable due to low volume of dispersing agent which is Sodium Dodecyl Sulphate (SDS) as shown in Table 4.1. After stability test, the stable nanofluid has been chosen for thermal conductivity test by using KD2Pro device. Hence, there are 15 samples tested for thermal conductivity in three different temperatures which is 6°C, 25°C, and 40°C. The highest thermal conductivity enhancement of Pyrograf HHT 24 is 0.48% (NF013) at temperature of 40°C with 47.93% of enhancement compare with normal rate of water which is 0.58 W/m.k. The second highest of thermal conductivity enhancement is 0.56% (NF014) at 40°C with 30.86% of enhancement. It can be conclude that temperature is the important factor as the all highest enhancement at 40°C. In the same temperature also, there are difference thermal conductivity which has high and low. This is due to the volume fraction or ratio of CNT which the ratio tested is increase. The factor which contributes to highest enhancement is temperature, length of CNT and surface area as it been elaborated in discussion part. In viscosity test using viscometer, the highest viscosity is 0.8% at 6°C followed by 0.72% at 6°C and 0.8% at 25°C. The viscosity results show the addition of CNT in directly proportional with viscosity of nanofluid as shown in Figure 4.5 which the percentage ratio of CNT keep increases. Besides that, the size and shape of nanoparticles also influence the viscosity of nanofluid. The small size of CNT and rod-like shape will increase the viscosity of nanofluid as been discussed in discussion part.

# REFERENCE

Aida, N., Mojtaba, S.N., Alimorad, R., Azadeh, A. and Ramin, K. (2011). "Effect of Dispersion Method on Thermal Conductivity and Stability of Nanofluid". *Experimental Thermal and Fluid Science* 35. pp 717-723

Applied Science Inc. (2012) "Pyrograf III" Cedarville (Ohio): Pyrograf Carbon Fibre Catalog



Baghalha, M. and Ahmadi, M. K. (2011). "The Effect of SDS and CNT Concentrations on the Rate of Copper Corrosion". *The Electrochemical Society* vol.20.

Ben Mill (2011). Two Dimensional Chemical Structure of Sodium Dodecyl Sulphate. Retrieve September, 2011 from the World Wide Web: http://chemistry.about.com/od/factsstructures/ig/Chemical-Structures.html

Chen, L. , Xie,H. , Li,Y. , Yu,W. (2008). "Nanofluid Containing Carbon Nanotube Treated by Mechanochemical Reaction". *Journal Thermochimica Acta* .477. pp. 21-24.

Haggenmueller, R., Guthy, C., Lukes, J. R., Fischer, J. E. And Winey, K. I. (2007). “Single Wall Carbon Nanotube/ Polyethylene *Nanocomposites Thermal and Electrical Conductivity*”. Macromolecules. 40. pp 2417-2421

Hong, T. K. and Yang, H. S. (2005). “Study of the Enhanced Thermal Conductivity of Fe Nanofluids”. *Journal of Applied Physics*. 97.

Hwang, Y., Lee, J.K., Lee, C.H., Jung, Y.M., Cheong, S.I., Lee, C.G., Ku, B.C. and Jang, S.P. (2007). “Stability and Thermal Conductivity of Nanofluid”. *Thermochimica Acta*. 455. pp 70-74

Hwang, Y., Lee, J. K., Lee, J. K., Jeong, Y. M., Cheong, S., Ahn, Y. C. And Kim, S. H. (2008). “Production and Dispersion Stability of Nanoparticles in Nanofluids”. *Powder Technology*. 186. pp 145-153

Jonathan, N. C., Khan, U., Blau, W. J., Yuri, K. and Ko, G. (2006). “A Review of the Mechanical Properties of Carbon Nanotube Polymer Properties”. *Carbon*. 44. pp1624-1652

Kanagraj, S., Varanda, F. R., Zhil’tsova, T. V., Oliveira, M. S. A. and Simoes, J. A. O. (2007). “Mechanical Properties of High Density Polyethylene/ Carbon Nanotube Composites”. *Composites Science and Technology*. 67. pp 3071-3077

Li, Y., Zhou, J., Tung, S., Schneider, E. and Xi, S. (2009). “A Review on Development of Nanofluid Preparation and Characterization”. *Powder Technology*. 196. pp 89-101

Lixin, C. (2009). “Nanofluid Heat Transfer Technologies”. *Recent Patents on Engineering*. 3. pp 1-7

Lo, C. and Tsung, T. (2006). "High Thermal Conductivity Nanofluid Fabrication". *IEEE Transactions on Nanotechnology*. pp 686-689

McEuen, P. L., Fuhrer, M. S. And Park, H. (2008). "Single-Walled Carbon Nanotube Electronic". *IEEE Transactions on Nanotechnology*. vol.1, 1.

Moisala, A., Li, Q., Kinloch, I. A., Windle, A.H. (2006). "Thermal and Electrical Conductivity of Single and Multi-Walled Carbon Nanotube Epoxy Composites". *Composites Science Technology*. 66. pp 1285-1288

Murshed, S. M. S., Leong, K. C. & Yang, C. (2008). "Investigation of Thermal Conductivity and Viscosity of Nanofluid". *International Journal of Thermal Science*. 47. pp 560-568



Naisri, A., Shariaty, M.N., Rashidi, A.M. and Khodafarin, R. (2012). "Effect of CNT Structures on Thermal Conductivity and Stability of Nanofluid". *International Journal of Heat and Mass Transfer*. 55. pp 1529-1535

Paritosh, G., Alvarado, J. L., Marsh, C., Carlson, T. A., Kessler, D. A. & Annamalai, K. (2009). "An Experimental Study on the Effect of Ultrasonication on Viscosity and Heat Transfer performance of multi-wall carbon nanotube-based aqueous nanofluids". *International Journal of Heat and Mass Transfer*. 52. pp 5090-5101

Patel, H. E., Anoop, K. B. and Sundarajan, T. (2008). "Model for Thermal *Conductivity of CNT-Nanofluids*". Bull. Material Science. vol. 31, 3, pp 387-390

Peng, H., Ding, G., Jiang, W., Hu, H. and Gao, Y. (2009). “Heat transfer Characteristics of Refrigerant-Based Nanofluid Flow Boiling inside a Horizontal Smooth Tube”. *International Journal Refrigerant.* 32. pp 1259–1270

Phuoc, T. X., Massoudi, M. and Chen, R. H. (2011). “Viscosity and Thermal conductivity of Nanofluids Containing Multi-walled Carbon Nanotubes Stabilized”. *International Journal of Thermal Sciences*. 50. pp 12-18

Pyrograf Product Inc. Pyrograf III Carbon Nanofibre. Retrieve January, 2013 from the World Wide Web: http://pyrografproducts.com/nanofiber.html

Saidur, R., Leong, K. Y. and Mohammad, H. A. (2011). “A Review on Applications and Challenges of Nanofluids”. Renewable *and Sustainable Energy Reviews*. 15. pp 1646-1668



Singh, A. K. (2008). “Thermal Conductivity of Nanofluids”. *Defence Science Journal*, 58. pp 600-607

Tang, W., Santare, M. H., and Advani, S. G. (2003). “Melt Processing and Mechanical Property Characterization Multi-Walled Carbon Nanotube/ High Density Polyethylene Composite Films”. *Carbon*. 41. pp 2779-2785

VWR Corp. (2007) “Critical Product: chemicals, furniture, equipment, instruments, apparel and consumables” United States: VWR Catalog

Wang, R. X., Xie H. B. (2003). “A refrigerating system using HFC134a and Mineral Lubricant Appended with $TiO_2$(R) as working fluids”. *In Proceedings of the 4$^{th}$ International Symposium*. pp. 888–920

Xie, H., Wang, J., Xi, T., Liu, Y. and Ai. F. (2002). “Thermal Conductivity Enhancement of Suspensions Containing Nanosized Alumina Particle”. *Journal Applied Physics*. 92. pp 4568–4572

Xue, Q. Z. (2005). “Model for Thermal Conductivity of Carbon Nanotube-Based *Composites*”. Physic B. 368. pp 302-307

**BIBLIOGRAPHY**

Cheng L. (2009) “Nanofluid Heat Transfer Technologies”. *Recent Patents on Engineering*. 3. pp. 1-7.

Ho, C.J. , Chen, M.W. , Li, Z.W. (2008). “Numerical simulation of natural convection of nanofluid in a square enclosure”. *Effects due to uncertainties of viscosity and thermal conductivity*. 52. pp. 4506- 4516.

Linda Vaisman, H. Daniel Wagner, Gad Marom (2006). “The role of surfactants in dispersion of carbon nanotubes”. *Journal of Nanomaterials*. 83. pp. 128-135.

# APPENDIX A

## Sample Calculation

1. Sample Calculation for Percentage Enhancement of Thermal Conductivity

   Thermal conductivity of water at 6°C = 0.54W/m.K

   Thermal Conductivity of nanofluid at 6°C = 0.554W/m.K

$$\frac{0.554}{0.54} X100\% = 102.59\%$$

$$102.59\% - 100\% = 2.59\%$$

# APPENDIX B

## Experiment

1. Stability Test



Figure 5.1: Stable nanofluid

Figure 5.2: Unstable nanofluid

2. Thermal Conductivity Test

Figure 5.3: Thermal conductivity test using KD2Pro

3. Viscosity Test

Figure 5.4: Viscosity test using viscometer

# APPENDIX C

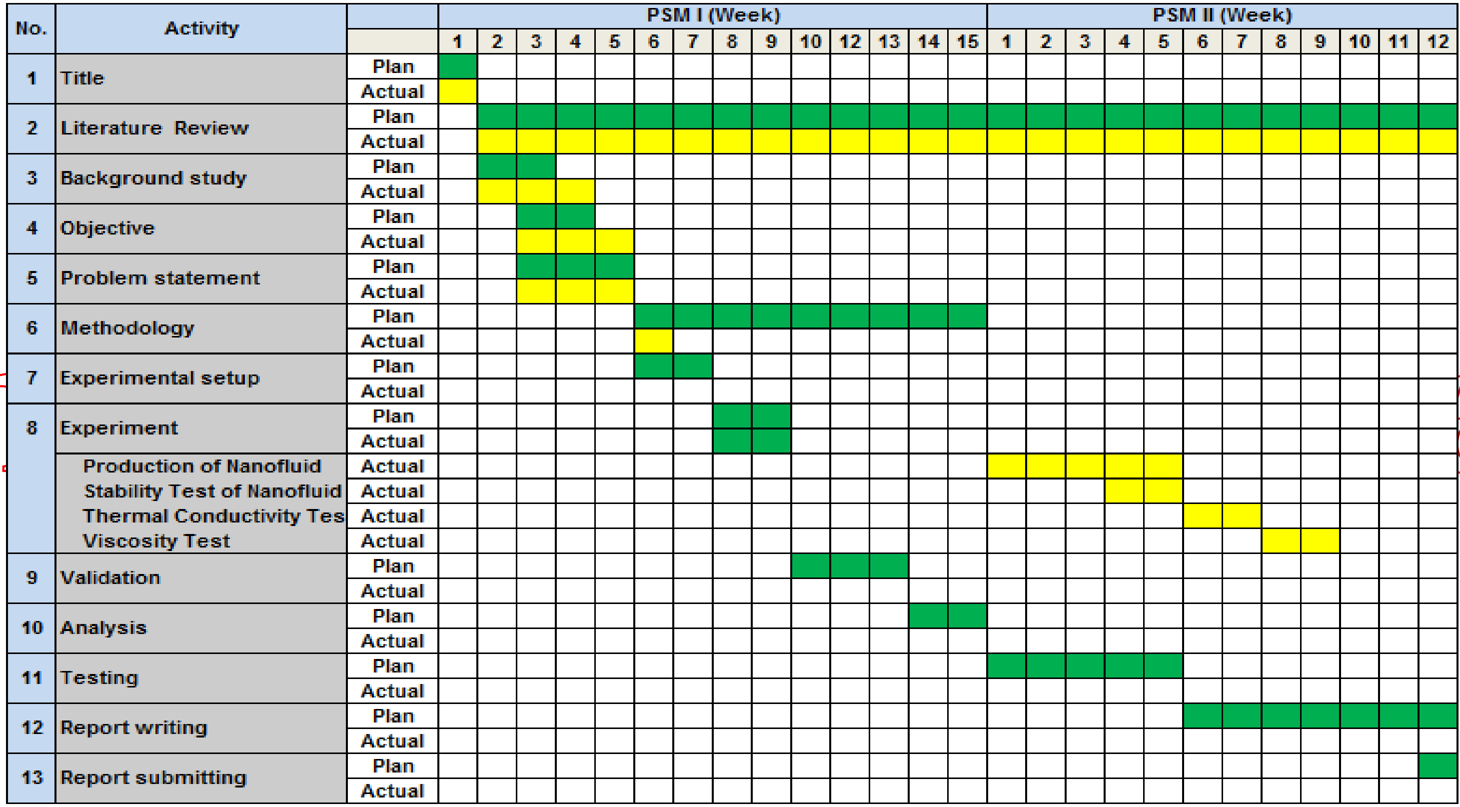


Figure5.5: Gantt chart