COMPARATIVE STUDIES ON THERMAL CONDUCTIVITY FOR NANOFLUID-BASED ON CARBON NANOTUBE

AHMAD SAFIUDDIN BIN ZAMANI

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

x

AHMAD SAFIUDDIN SARJANA MUDA KEJ. MEKANIKAL (TERMAL BENDALIR) 2011 UTeM

COMPARATIVE STUDIES ON THERMAL CONDUCTIVITY FOR NANOFLUID-BASED ON CARBON NANOTUBE

AHMAD SAFIUDDIN BIN ZAMANI

This report is submitted in partial fulfillment of the requirements for the award of the degree of Bachelor of Mechanical Engineering (Thermal-Fluids)

Fakulti Kejuruteraan Mekanikal

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

MEI 2011

SUPERVISOR DECLARATION

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

Signature: ……

Author: ……

Date: ……

DECLARATION

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

Signature: ……

Author: ……

Date: ……

Khas untuk keluarga tersayang, khusus untuk ibunda dan ayahanda tercinta

ACKNOWLEDGEMENT

In the name of the Allah, the most compassionate and most merciful. Peace and blessings upon Prophet Muhammad Peace Be upon Him and to his family, companions and those who followed him.

Praise to the Almighty God.

First of all, I would like to show my gratitude to my family; my father, Mr. Zamani Mohd. Sidek, my mother, Mrs. Dyg. Saerah, my brother and my sister. Thank you for all your support. For my supervisor, Mr. Imran Syakir and his research assistant, Mr. Fabrian Idral

Not forgotten to my friends at UTeM, in PERKEPIS and at my hometown. Thank you for all your support and I will not forget your kindness.

Regards,

Ahmad Safiuddin b. Zamani

ABSTRACT

Nanofluids are part of nanotechnology and become a need in industries because nanofluids have a big potential for heat transfer usage such as cooling due to its high thermal conductivity. Nanofluids are suspension of nanoparticles inside base fluid and there are many types of solid particles we used to prepare nanofluid. For our project, we selected carbon nanotube (CNT) rather than other nanoparticles due to its high thermal conductivity differences. Most common heat transfer fluid in industry is water. Hence, we choose water as our based fluid. We choose two different types of CNT that we purchased; Materials and Electrochemical Research Corporation (MER) and Pyrograf Products Incorporated (Pyrograf). The challenge that we faced is to ensure the CNT can disperse inside water is the hydrophobic characteristic of CNT. In this case, we use sodium dedocyl sulphate (SDS) to reduce the surface tension of water to ensure CNT can disperse well inside water. Different weight percentage (wt %) of CNT was used from 0.4-1.0 wt%. We investigate thermal conductivity of the nanofluids that we prepare using KD-2 Pro thermal analyzer apparatus at three different temperatures (6°C, 25°C and 45°C). From our findings, the highest thermal conductivity is from Pyrograf at 1.0 wt% with 0.812 W/mK and it shows great enhancement value more than 30% from the base fluid at 45°C. With high number of surface area (1.718×10^3 m^2/g) and total pore volume (1.078 cc/g), this shows that Pyrograf CNT have a brighter usage to be commercialized and be used as nanoparticles to be suspended inside conventional heat transfer fluids.

ABSTRAK

Teknologi nano bukanlah perkara yang asing di negara kita. Bendalir-nano adalah sebahagian daripada teknologi nano dan menjadi satu keperluan di dalam industri kerana bendalir-nano ini mempunyai potensi yang besar dalam keperluan dalam proses penyejukkan kerana bendalir-nano mempunyai kealiran haba yang tinggi. Bendalir-nano adalah keberadaan partikel nano di dalam bendalir asal dan ada kepelbagaian partikel nano yang digunakan untuk menyediakan bendalir-nano. Untuk projek kami, kami memilih tiub carbon nano (CNT) berbanding dengan partikel nano yang lain kerana CNT mempunyai kealiran haba yang lebih tinggi. Kami memilih air sebagai bendalir asas kerana bendalir yang sering digunakan di dalam proses penyejukan di insdustri adalah air. Kami menggunakan dua CNT yang berbeza iaitu MER dan Pyrograf. Kekangan yang kami hadapi untuk memastikan CNT dapat tersebar dengan baik didalam air kerana sifat CNT yang hidrofobik. Oleh yang demikian, kami menggunapakai sodium dedocyl sulfat untuk mengurangkan ketegangan permukaan air untuk memudahkan CNT dapat tersebar dengan mudah di dalam air. Kami menggunakan nisbah berat CNT yang berbeza dari 0.4-10 wt%. Kemudian kami mengambil kiraan kealiran haba bendalir-nano tersebut menggunakan alat analisis terma KD2-Pro dengan tiga suhu yang berbeza (6°C, 25°C and 45°C). Dari pengamatan kami, Pyrograf mempunyai kealiran haba yang tinggi pada 1.0 wt% dengan nilai 0.812 W/mK dan ia menunjukkan kadar peningkatan yang tinggi iaitu melebihi 30% dari bendalir asas yang digunakan pada suhu 45°C. Dengan luas permukaan (1.718×10^3 m^2/g) dan kadar keliangan yang tinggi (1.078 cc/g),, ini menunjukkan Pyrograf mempunyai peluang untuk dikomersialkan penggunaannya menggantikan bendalir haba yang lain.

TABLE OF CONTENT

CHAPTER	CONTENT	PAGE

CHAPTER	CONTENT	PAGE

LIST OF TABLES

LIST OF FIGURES

NO.	CONTENT	PAGE

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Nanofluid is a material that consists of nanometer-sized particles dispersed in base fluids. It is well known around the globe that water, oil and etc. is a traditional heat transfer fluids but this traditional fluids has their limitation to transfer and carry heat. It is also known that solid such as metal object can transfer more heat or have a high thermal conductivity compare to fluids. Even though solid is a good thermal conductivity but it cannot be used as a transfer heat equipment. It is known that the bigger surface area, the higher thermal conductivity. Moreover, based on Q. Xue (2004) the thermal conductivity not only depends on volume fraction of a solid or liquid, but also depended on the particle size and interfacial properties.

1.2 PROBLEM STATEMENT

Water was normally used as coolant in industries around the world. Based on Y.A. Cengel (2007), the value of thermal conductivity of water is 0.613 W/mK. It is believed that to enhance and improve the usage of water as a heat transfer fluids we used to merge and dispersed it with nano-particles to increase the surface area of the particle size. This is due to low thermal conductivity of conventional heat transfer fluid and this nano-fluid was believed to can enhance the thermal conductivity of conventional heat transfer fluid. Hence, this research will focus on merge and dispersion of carbon nano-tube with water to investigate the thermal conductivity whether it can be applied for industrial activities in Malaysia.

1.3 OBJECTIVE

This project has two main objectives which are to:

1.2.1 Prepare nanofluid-based carbon nanotube using variety of CNT types.

1.2.2 Analyze and investigate the thermal conductivity performance of the nanofluid prepared from the experiment.

1.4 SCOPE

This project will mainly focus on analyzing and investigating the thermal conductivity of nanofluid-based carbon nanotube. The project will focus on several aspects and will be elaborate below:

a. The base fluid used is water because we need to increase the thermal conductivity of water that has been used for decades.

b. The amount of carbon nanotube used will be around 0.1-1.0% weight

c. The thermal conductivity of our solution will be investigated using KD2-Pro thermal analyzer equipment.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Nanotechnology keeps gaining attention of the scientist around the world. It has a lot of potential that can be explored and the application of the nanotechnology can be widen even though the current research on nanotechnology is focused more on micro electric application and microprocessor. Conventional fluids' ability to conduct heat is significantly inferior to solids. Initial experiments involved adding solid particles with more desirable properties to the base fluid under the hypothesis that the overall mixture's thermal behavior would be more favorable. Although in some cases enhancement was observed, for reasons discussed in detail later this did not prove to be of any practical use. Not until technology's recent ability to manufacture nanoparticles did additive experimentation and thus nanofluids become more promising.

2.2 NANOTECHNOLOGY AND MINIATURE

According to J. Clarence Davies (2004), nanotechnology is the production and use of materials with purposely engineered features close to the atomic or molecular scale. Nanotechnology deals with putting things together tomby-atom and with structures so small they are invisible to the naked eye. It provides the ability to create materials, devices and systems with fundamentally new functions and properties. It is the use and manipulation of matter at a tiny scale. At this size, atoms and molecules work differently, and provide a variety of surprising and interesting uses.

The prefix of nanotechnology derives from ‘nanos’ – the Greek word for dwarf. A nanometer is a billionth of a meter, or to put it comparatively, about 1/80,000 of the diameter of a human hair. Although often referred to as the 'tiny science', nanotechnology does not simply mean very small structures and products. Nanoscale features are often incorporated into bulk materials and large surface area. When we talk about nanotechnology, there is possibility that we might minimize the size of current heat exchanger into a smaller size.

Researchers tried to increase the thermal conductivity of base fluids by suspending micro- or larger-sized solid particles in fluids since the thermal conductivity of solid is typically higher than liquids (X.Q. Wang, et al, 2006). Nanofluids are part of nanotechnology. This technology is still fresh and new in our country but still got a lot of potential to be explored and our research still progressing towards that goal. In order to develop a new heat transfer fluid, researchers keep on developing new method to increase conventional heat transfer fluids.

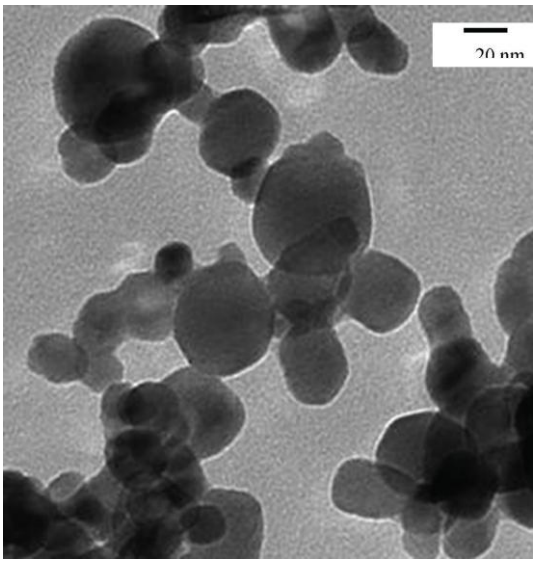

Figure 2.1: Transmission electron microscopy (TEM) images of nanoparticles

(Source: S. Choi, 2006)

Due to increasing global competition, industries have a strong need to develop a new heat transfer fluids with significantly high thermal conductivity. From Table 2.1, conventional heat transfer fluids; water, ethylene glycol, air, and oil that has been widely used as coolant all around the world which has low thermal conductivity compared to solid. The answer is nanofluids. Nanofluids have a very high potential as a new heat transfer fluid due to its potential to enhanced the thermal conductivity of conventional heat transfer fluids.

Table 2.1 List of thermal conductivity

Material	**Form**	**Thermal Conductivity (W/mK)**
Carbon	Nanotubes Diamond Graphite Fullerenes film	1800-6600 2300 110-190 0.4
Metallic solids (pure)	Silver Copper Nickel	429 401 237
Non-metallic solids	Silicon	148
Metallic liquids	Aluminium Sodium at 644K	40 72.3
Others	Water Ethylene glycol Engine oil R134a- tetrafluoroethane	0.613 0.253 0.145 0.0811

2.3 NANOFLUIDS

2.3.1 Definition of Nanofluids

There is a lot of definition of nanofluids but most of it has the same meaning. According to A.K. Singh (2008), nanofluids are a suspension mixture of suspended nanoparticles in a base liquid is usually referred to as a nanofluid. He also gives a few examples of natural nanofluids which are blood, a complex biological nanofluid where different nanoparticles (at molecular level) accomplish different functions, and functional components actively respond to their local environment.

Nanofluids also defined as engineered colloids made of base fluids and nanoparticles (L. Cheng, 2008). Base fluids; water, ethylene, oils are common or conventional fluids that been used as heat transfer fluids. The term of nanofluids has been proposed by Choi on 1995 of the Argonne National Laboratory (Choi, 1995). According to Wang and Mujumdar (2006), nanofluids has a much larger relative surface area of nanoparticles compared to conventional heat transfer fluid will not only increase the thermal conductivity but also the stability of the suspension. It also helps and improved abrasion-related properties as compared to the conventional solid/fluid mixture.

Theoretically, all nano-elements with high thermal conductivity can be dispersed in conventional heat transfer fluids but only a few can be used for nanofluids purposes. We can refer to table 2 to see the list of the materials that can be used for nanofluids.

Table 2.2 Materials that can be used for nanofluids

Material	**Form**
Oxides	Aluminium oxide, Al_2O_3 Copper oxide, CuO Titanium oxide, TiO_2 Silicon oxide, SiO_2
Metals	Copper, Cu Ferum, Fe Argentum, Ag Gold, Au
Carbides	Carbides, SiC
Carbon	Carbon nanotubes, CNT Diamond Graphite

From Table 2.2, we know that materials from carbon basically have higher thermal conductivity compared to other materials. This is why we choose carbon materials as the nanoparticles to be dispersed in the conventional heat transfer fluids.

2.3.2 Application of Nanofluids

For current application, nanofluids got the spotlight to replaced conventional heat transfer fluids; water, ethylene glycol,oil, etc. that have low thermal conductivity, hence it may be useful for industrial cooling applications. For U.S. industry, the replacement of cooling and heating water with nanofluids has the potential to conserve 1 trillion Btu of energy (O.D. Leon, et. al., 2009) where 1 Btu approximately equivalent to 1055.056 Joule.

The world's total geothermal energy resources were calculated to be over 13000 Zeta Joule (ZJ) in a report from MIT (2007). Currently only 200 ZJ would be extractable, however, with technological improvements, over 2,000 ZJ could be extracted and supply the world's energy needs for several millennia. When extracting energy from the earth's crust that varies in length between 5 to 10 km and temperature between 500°C and 1000°C, nanofluids can be employed to cool the pipes exposed to such high temperatures. When drilling, nanofluids can serve in cooling the machinery and equipment working in high friction and high temperature environment. As a "fluid superconductor," nanofluids could be used as a working fluid to extract energy from the earth core and processed in a PWR power plant system producing large amounts of work energy (K. V. Wong, et. al., 2009).

2.4 CARBON NANOTUBES (CNT)

Carbon-based materials such as diamond and in-plane graphite, display the highest measured thermal conductivity of any known material at moderate temperatures. Based on M. S. Dresselhaus et. al (2004) , carbon nanotubes (CNTs) are tubular structures that are typically of nanometer diameter and many micrometres in length.

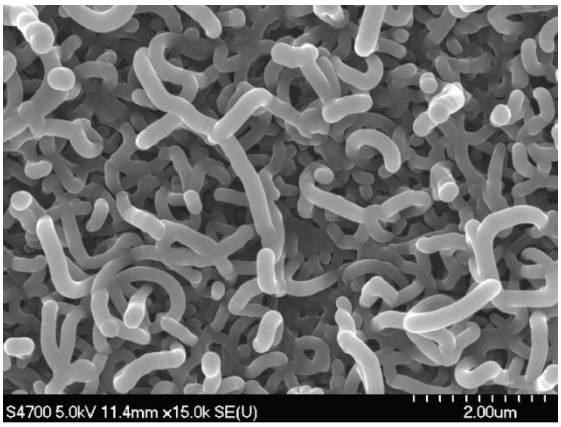

Figure 2.2: Fat CNT's

(Source: Y.K.Yap, 2006)

Apart from the well-known graphite, carbon can build closed and open cages with honeycomb atomic arrangement. This fascinating new class of materials was first observed by Endo (1975), and later by Iijima (1991) in the soot produced in the arc-discharge synthesis of fullerenes. Carbon nanotubes consist of rolled graphene sheets built from sp^2 hybridized carbon atoms. Nanotubes are categorized as single-walled nanotubes (SWNTs) and multi-walled nanotubes (MWNTs).

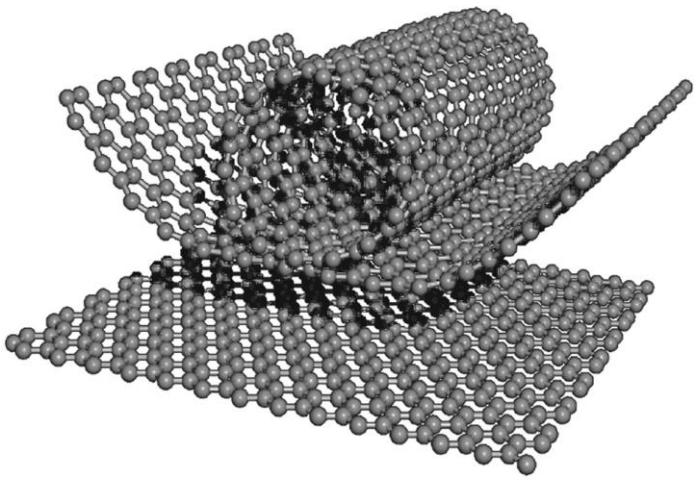

Figure 2.3: Schematic of an individual layer of carbon called graphene, and how this could be rolled in order to form a carbon nanotube.

(Source:M.Endo et. al, 2004)

2.4.1 Single-walled CNT (SWNT)

Most single-walled nanotubes (SWNT) have a diameter of close to 1 nanometer, with a tube length that can be many millions of times longer. The structure of a SWNT can be conceptualized by wrapping a one-atom-thick layer of graphite called graphene into a seamless cylinder.

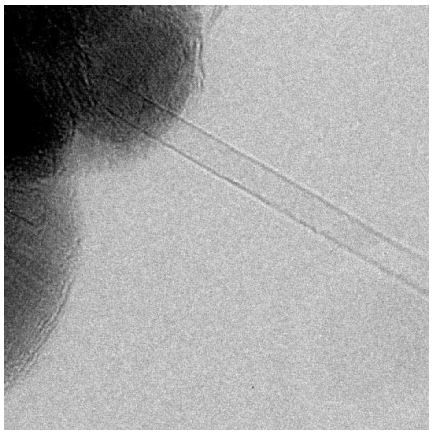

Figure 2.4: Scanning electron microscope (SEM) image exhibiting web-like SWNT structures

(Source: M. Endo et. al, 2004)

Single-walled nanotubes are an important variety of carbon nanotube because they exhibit electric properties that are not shared by the multi-walled carbon nanotube (MWNT) variants.

2.4.2 Multi-walled CNT (MWNT)

Multi-walled nanotubes (MWNT) consist of multiple rolled layers (concentric tubes) of graphite. Such cylindrical graphitic polymeric structures have novel or improved properties that make them potentially useful in a wide variety of applications in electronics, optics and other fields of materials science (A. Hajar, et. al.2009).

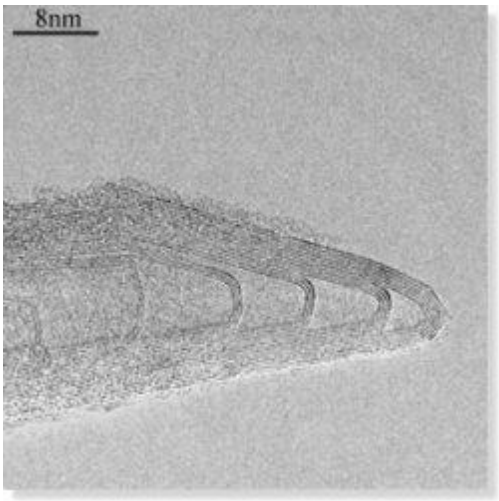

Figure 2.5: Tip of MWNT

(Source: M. Endo et. al, 2004)

Carbon nanotubes are endowed with exceptionally high material properties, very close to their theoretical limits, such as electrical and thermal conductivity, strength, stiffness, and toughness. Moreover, MWCNTs are polymers of pure carbon and can be reacted and manipulated using the rich chemistry of carbon.

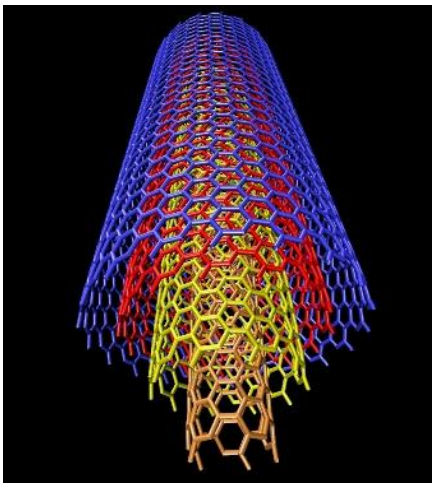

Figure 2.6: Conceptualize picture of MWNT

(Source: C. Ross, 2008)

2.4.3 Synthesis of Carbon Nanotubes

Due to its impressive properties, the demand of using CNT has increased all over the world. The needs of CNT increased, hence its need to be produced more. The technique of producing CNT has been develop and increased including the method arc discharge, laser ablation and chemical vapor deposition (CVD).

2.4.3.1 Arc Discharge Method

This arc discharge method was first and commonly used to produce CNT (M.Cadek et. al, 2002). Because nanotubes were initially discovered using this technique, it has been the most widely-used method of nanotube synthesis. For this method, production yields are in general poor while purity can be as low as 10% with the rest of the carbon in the form of species such as turbostratic graphite and carbon onions. The yield for this method is up to 30 percent by weight and it produces both single- and multi-walled nanotubes with lengths of up to 50 micrometers with few structural defects (P.G.Collins, 2000).

2.4.3.2 Laser Ablation Method

In the laser ablation process, a pulsed laser vaporizes a graphite target in a high-temperature reactor while an inert gas is bled into the chamber. Nanotubes develop on the cooler surfaces of the reactor as the vaporized carbon condenses. A water-cooled surface may be included in the system to collect the nanotubes. Laser ablation is one of the superior methods to grow SWNTs with high-quality and high-purity (M. Kusaba, Y. Tsunawaki, 2005).

This method was introduce in 1995 and the optimization for high quality and purity of SWNTs by manipulating numerous experimental variables such as; the composition target, gas pressure, gas flow rate, ambient temperature.

2.4.3.3 Chemical Vapour Deposition (CVD) Method

CVD is a common method for the commercial production of carbon nanotubes. Chemical vapour deposition or CVD is a generic name for a group of processes that involve depositing a solid material from a gaseous phase and is similar in some respects to physical vapour deposition (PVD). Precursor gases (often diluted in carrier gases) are delivered into the reaction chamber at approximately ambient temperatures. As they pass over or come into contact with a heated substrate, they react or decompose forming a solid phase which and are deposited onto the substrate. The substrate temperature is critical and can influence what reactions will take place (S.N.Bondi, et. al, 2006)

2.4.4 Mechanical Properties

The carbon nanotubes are expected to have high stiffness and axial strength as a result of the carbon sp^2 bonding (D.H. Robertson et al., 1992). According to Wong et. al (1997) Young modulus of nanotubes produced by the catalytic decomposition of hydrocarbons was determined and giving values in the range 10–50 GPa. The effective bending modulus corresponds to the standard Young modulus if the nanotube bends by stretching in the outer arc and by compression in the inner arc. This appears to be the case for nanotubes with diameter d < 12 nm, where the effective bending modulus was found to have a value of 1 TPa, in good agreement with the values previously obtained for Young's modulus.

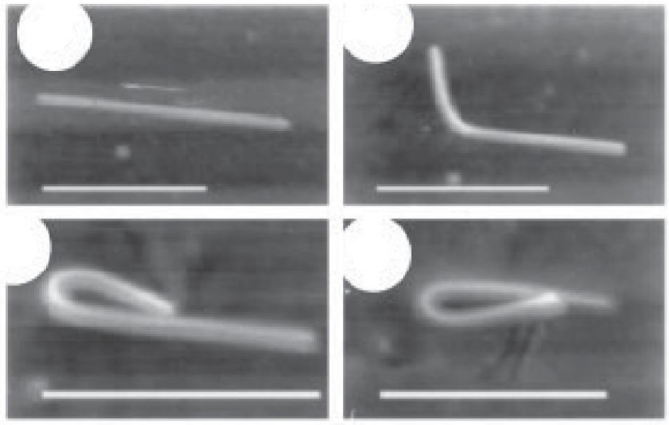

Figure 2.7: Series step of deformation of a MWNT

(Source: M.Endo, 2004)

However, for MWNTs of larger diameters, it was found that the effective bending modulus dropped dramatically to values of 100 GPa (M. S. Dresselhaus, et. al, 2004). This was shown in figure where the value of bending modulus was inversely proportional to the diameter of the MWNT.

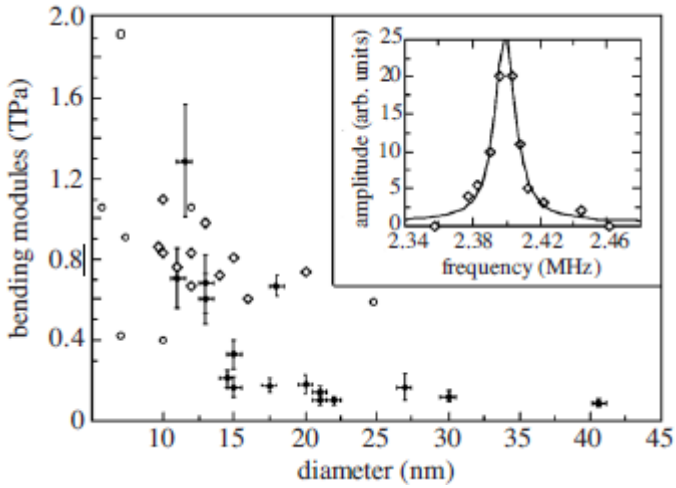

Figure 2.8: Graph of bending modulus versus diameter

(Source: A.K.Singh, 2007)

Figure 2.8 shows that effective bending modulus of MWNTs as a function of tube diameter obtained from electromechanical resonance experiments (Poncharal et al. 1999). For small-diameter tubes (less than 12 nm), the bending modulus is high (approaching 1 TPa) and can be associated with Young's modulus.

2.4.4 Electrical Properties

In theory, metallic nanotubes can carry an electric current density of 4 × 109 A/cm^2 which is more than 1,000 times greater than metals such as copper. Multiwalled carbon nanotubes with interconnected inner shells show superconductivity with a relatively high transition temperature Tc = 12 K. In contrast, the Tc value is an order of magnitude lower for ropes of single-walled carbon nanotubes or for MWNTs with usual, non-interconnected shells (Hong et. al, 2007).

2.4.5 Thermal Conductivity of Carbon Nanotubes

From D.J. Yang et. al. (2002), they estimated that the range of CNT either single-walled or multiwalled, the thermal conductivity is from 600 to 6000 W/mK. From their research, they used the photothermal reflection method and they have measured the thermal conductivity of MWNT films with film thickness or CNT length from 10 to 50 mm. The average thermal conductivity is found to be about 15 W/mK and independent of the CNT length. Taking the volume-filling fraction of CNT's into account, the effective thermal conductivity for the MWNT's is about 2 × 10^2 W/m K. With different approach and technique, each of this researchers obtained different value of thermal conductivity of CNT.

This thermal conductivity may caused by a lot of factor and a lot of theories presented by researchers and scientist around the globe. One of the theories that came is the role of Brownian motion in enhanced thermal conductivity of nanofluids. S.U.S Choi and S.P. Jang (2004) came out with theoretical model based on kinetics, Kapitza Resistance and convection. The first mode is collision between base fluid molecules which is physically represents the thermal conductivity of the base fluids. Nanoparticle collision due to Brownian motion is a very slow process.

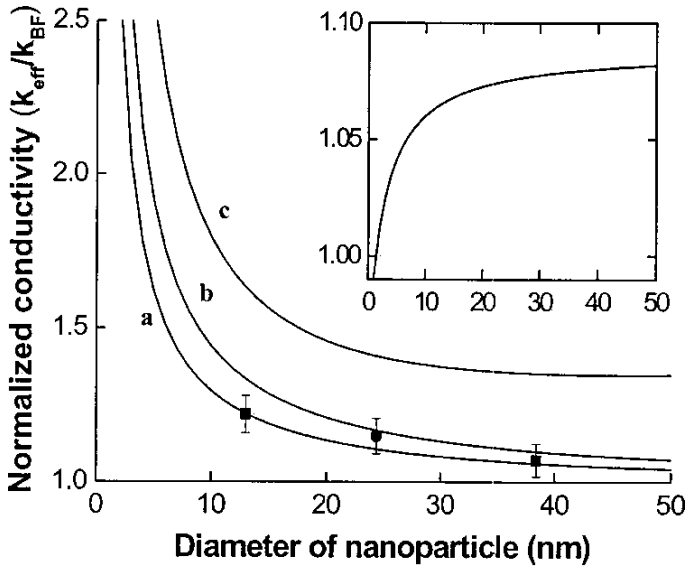

Figure 2.9 Graph of normalized conductivity versus diameter of nanoparticle

(Source: S.P. Jang & U.S.Choi)

This shows that the smaller diameter of nanoparticles that submerged inside the base fluid, the better for increasing the conductivity. Vice versa for solid or solid composites that is decreasing of thermal conductivity with decreasing of particle size.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Based on previous researches that have been conducted on the thermal conductivity test, the parameters that involved and give significant impact are;

i. Types of base fluid: water

ii. Types of CNT

iii. Surfactant dispersing agent

iv. Weight percentage of CNT and dispersing agent

Each of these parameters will affect the stability and also the thermal conductivity of the nanofluids. The project must be conducted according to the identified processes and is elaborated below:

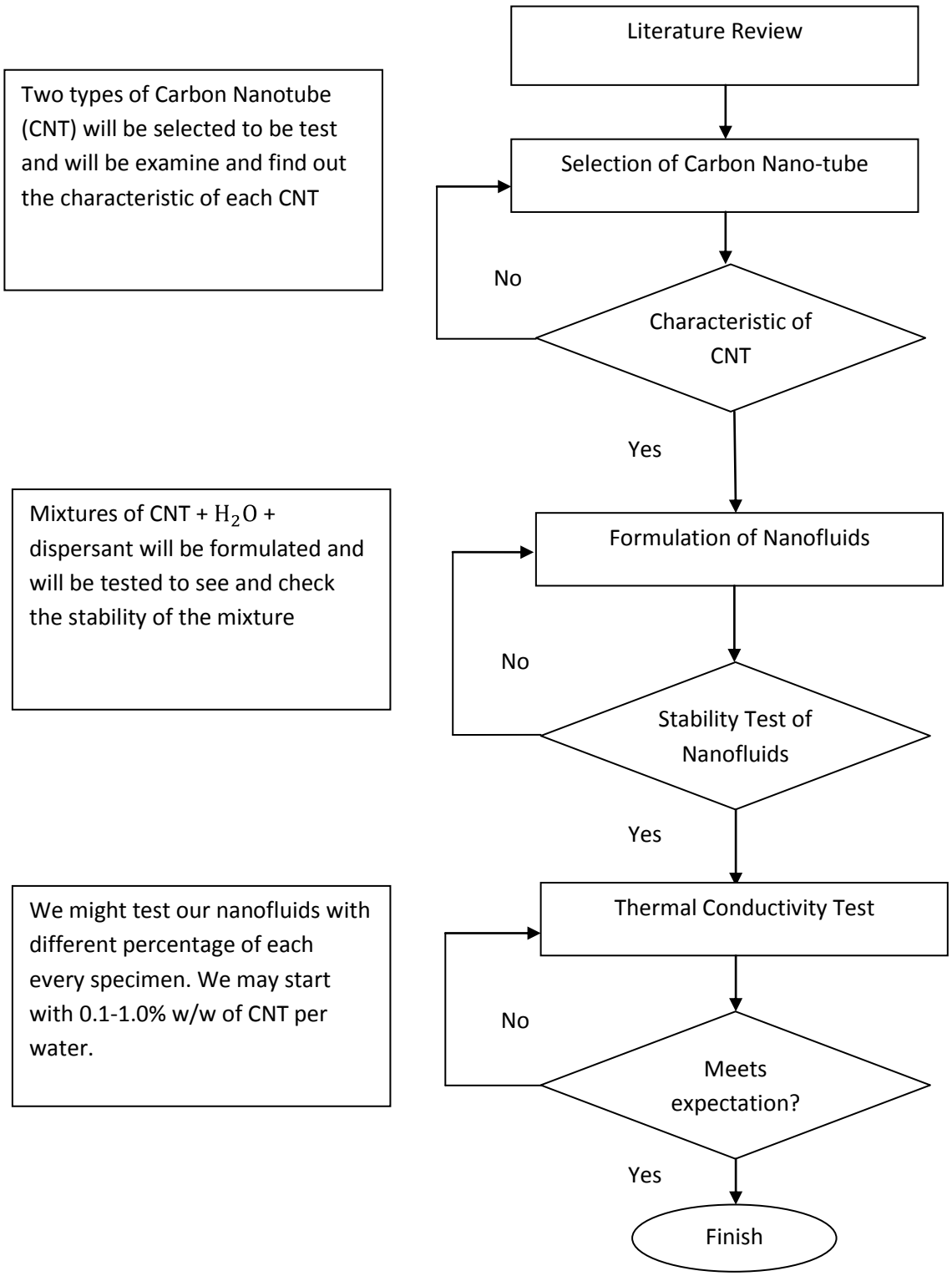

Figure 3.1: Flow Chart

3.2 PROPERTIES OF EACH PARAMETER

3.2.1 Base Fluids

The base fluids that will be used for this research is distilled water (DI). The excellent thermal conductivity properties compared to other conventional heat transfer fluids, widely used in the industries, and easy to get makes it favorable choice as the heat transfer fluids. In table 3.1, we list down the parameter of our based fluids.

Table 3.1: Properties of DI

Parameter	**Value**
Density	Liquid: $1000 kg/m^3$ Solid: $917 kg/m^3$
Melting point	0°C
Boiling point	100°C
Specific heat	4180 J/kg °C
Latent heat	333.55 kJ/kg
Viscosity	$893 \times 10^{-6} kgs/m$
pH	Approximately 7.0

3.2.2 Carbon Nanotubes

We tested and created nanofluids based on these carbon nanotubes that we purchased from vendor. There are two types of carbon nanotubes that we test for the thermal conductivity test of nanofluids that is Materials and Electrochemical Research Corporation (MER) and Pyrograf Products Incorporated (Pyrograf). CNT from MER are single-walled nanotube and CNT from Pyrograf are carbon nanofiber (CNF). Both of these products are purchased from USA (United States of America).

Table 3.2: CNT Properties

CNT	**CNT Types**	**Density**	**Purity**	**Diameter**
MER	SWNT	3.5 g/cm³	100%	-
Pyrograf	CNF	2.0 g/cm³	> 98%	0.2 microns

3.2.3 Dispersing Agent

Dispersing agent or surfactants are compounds that lower the surface tension of a liquid, allowing easier spreading, and lowering of the interfacial tension between two liquids, or between a liquid and a solid. Hence, in this experiment we will use sodium dedocyle sulphate (SDS) as our surfactant because from previous research it shows that SDS can be a suitable surfactant compare to others. This SDS was purchased from Systerm GmbH, Germany and has 99% purity. Furthermore, SDS is in form of white powder and soluble in water.

3.3 EQUIPMENT DESCRIPTION

Physical dispersion can be achieved using mechanical device such as mechanical homogenizer and ultrasonicator.

3.3.1 Mechanical Homogenizer

This homogenizer was manufactured by LabGenius company and use for homogenize the surfactant, CNT into the distilled water. This unit can speed up until 27000 rpm.

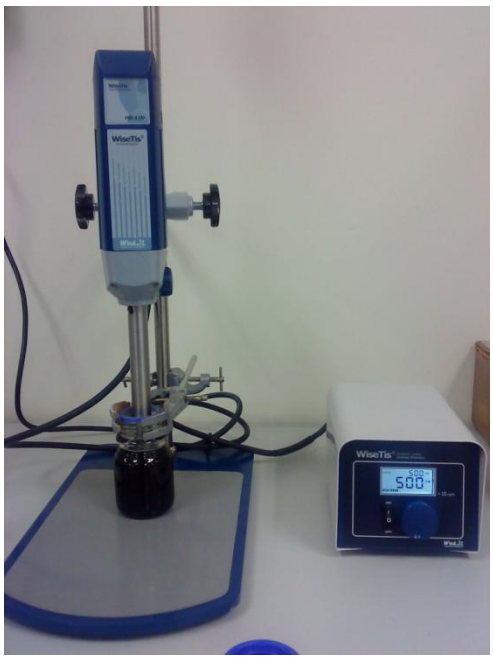

Figure 3.2: Mechanical Homogenizer

3.3.2 Ultrasonicator

Elmasonic S ultrasonic was manufactured by Elma Hans Schmidbauer GmbH & Co. KG, a German company. This ultrasonicator can be used to dispersing the CNT with high ultrasonic power.

Figure 3.3: Ultrasonicator Unit

3.3.3 KD2-Pro

KD2-Pro is a device manufactured by Decagon Services. It can be used fully portable field and lab thermal properties analyzer. This device are using line heat source method to measure all thermal properties including thermal diffusivity, specific heat, thermal conductivity and thermal resistivity.

Figure 3.4: KD2-Pro device

3.4 EXPERIMENTAL PROCEDURE

This are the following procedure was build for the preparation of nanofluids

1. Optimum value of SDS concentration was determined

2. Using the concentration of SDS, the weight percentage of CNT was also determined then both SDS and CNT were placed directly inside the distilled water and the mixture was set pH at 9.

3. These samples then will be homogenized using homogenizer at 10000 rpm. The propeller of the homogenizer was place slightly few centimeters from the bottom of the beaker to avoid cavitation and foaming at the surface. This process will take about approximately one minute. The propeller of this homogenizer we need to wrap it to avoid the fluid from splashed out from the bottle.

Figure 3.5: Plastic was used to wrapped bottle to avoid splashing

4. The mixture then dispersed again using ultrasonicator at temperature 25°C at highest frequency to ensure the carbon nanotube and the surfactant was dispersed evenly inside the base fluid. This process took 60 minutes to complete.

Figure 3.6: Waterbath or ultrasonicated

5. Then, the mixture was homogenized again by using mechanical homogenizer at 10000 rpm and just like before, the propeller of the homogenizer wast placed few centimeters from the bottom of the beaker. Approximately, this process took about five minutes.

6. For the stability test to see whether the CNT was totally dispersed inside the distilled water, it will start right after the mixture was produce and it may take a week to check if any agglomerate occurs inside the beaker. These stability tests were checked periodically within 1 to 100 hours.

Figure 3.7: One of the samples after passed the stability test

7. Thermal conductivity test conducted right after the nanofluid was passed the stability test and we tested it at three different temperatures that is 6°C, 25°C and 45°C using KD2-Pro

3.5 SAFETY PRECAUTIONS

Both sodium dedocyle sulphate and CNT are in powder form. For CNT, skin and eye contact may cause irritation. Inhalation of CNT may cause lung damage or disease. Hence, usage of dust respirator is of a face mask is a must and in case the CNT powder is spilled, remove it by using sweeper or vacuum cleaner or spray with water.

CHAPTER 4

RESULT AND DISCUSSION

4.1 RESULTS

Result is the final consequence of a sequence of actions. In term of this project, we gained results or outcome from our experiment and we will present it in tabular and graphical format.

4.1.1 Thermal Conductivity Test

After testing the nanofluid using KD2-Pro device, we have obtained results which wil be explained below. Figure 4.1 shows thermal conductivity of different weight percentage of MER CNT inside the based fluids for three different temperatures that is at 6℃, 25°C and 45°C. There are slight differences between each of weight percentage but from these results, this figure shows that the addition of MER CNT inside base fluid that is distilled water enhanced the thermal

conductivity of the based fluid. Table 4.1 shows precise number of thermal conductivity for each sample that was gained from the experiment.

Table 4.1: Thermal Conductivity of MER CNT

CNT	**Weight percentage, wt%**	**Code**	**Thermal conductivity (W/mK) at temperature**		
			6°C	**25°C**	**45°C**
MER	0.4	N001	0.597	0.62	0.671
	0.6	N002	0.583	0.61	0.697
	0.8	N003	0.576	0.604	0.622
	1.0	N004	0.575	0.63	0.645

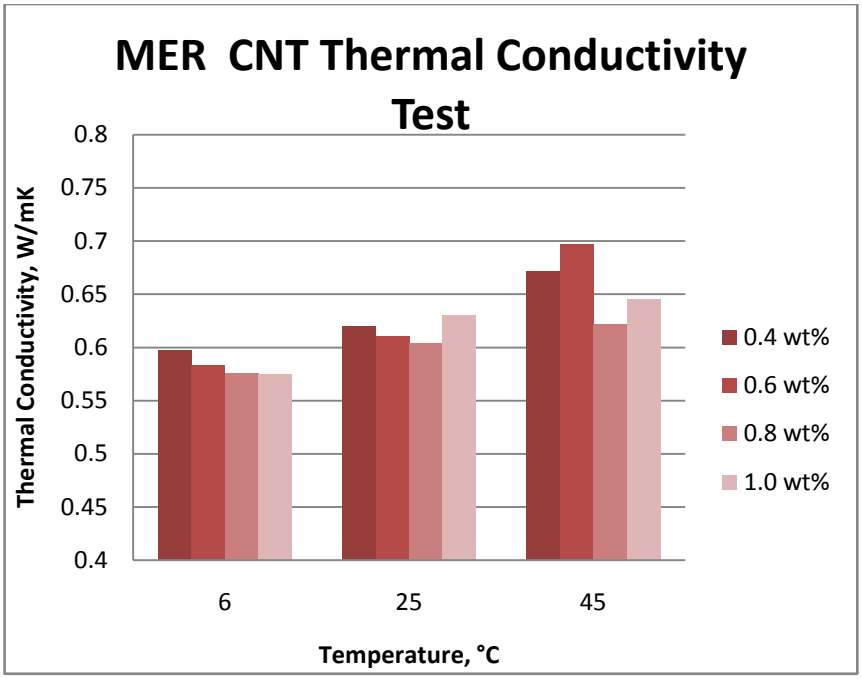

Figure 4.1: MER Thermal Conductivity Graph

Based on figure 4.1, the highest thermal conductivity at 6C is 0.4% with 0.597 W/mK followed by 0.6% and the lowest thermal conductivity at 6°C is 1.0% with 0.575 W/mK. At 25°C, the highest thermal conductivity is 1.0%; 0.63 W/mK and the lowest is 0.8%; 0.604 W/mK. While at the highest temperature testing; 45°C, N002 or 0.6% shows tremendous result with the highest thermal conductivity with 0.697 W/mK.

Table 4.2: Thermal conductivity of Pyrograf CNT

CNT	**Weight Percentage, wt%**	**Code**	**Thermal conductivity (W/mK) at temperature**		
			6°C	**25°C**	**45°C**
Pyrograf	0.4	N011	0.588	0.623	0.679
	0.6	N012	0.594	0.645	0.732
	0.8	N013	0.616	0.639	0.689
	1.0	N014	0.645	0.662	0.812

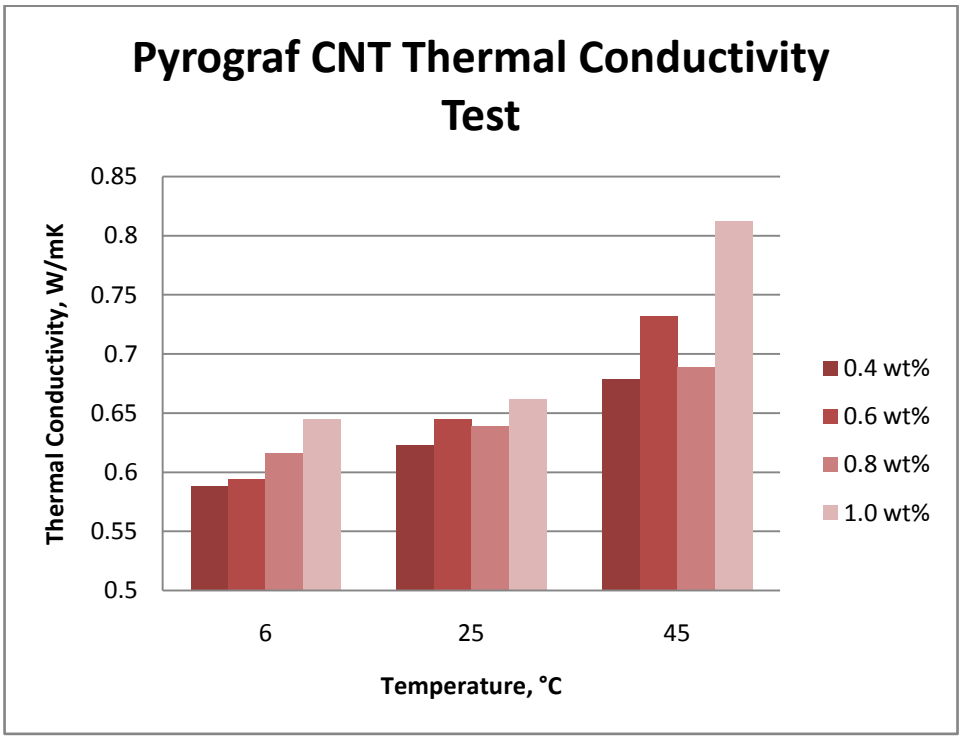

Figure 4.2: Pyrograf Thermal Conductivity Graph

Similar pattern was also shown by Pyrograf CNT but in figure 4.2, the thermal conductivity of each nanofluid increased with the weight percentage. At 6°C, the highest thermal conductivity is 1.0% or N011 at 0.645 W/mK. Same goes at 25°C and 45°C, N011 gave the highest thermal conductivity among other samples. By comparing both CNT that we tested, the highest thermal conductivity was obtained by N011 and second highest was N003.

4.1.2 Percentage of Enhancement of Thermal Conductivity

In percentage of enhancement of thermal conductivity of each nanofluid that we tested, we compare the result that we obtained in 4.2.1 with thermal conductivity of distilled water at each temperature.

Table 4.3: Percentage of enhancement for MER and Pyrograf

CNT	**Weight Percentage, wt%**	**Code**	**Percentage of enhancement (%) at temperature**		
			6°C	**25°C**	**45°C**
MER	0.4	N001	3.98%	5.44%	11.48%
	0.6	N002	1.84%	2.41%	12.51%
	0.8	N003	-0.47%	0.33%	-0.61%
	1.0	N004	0.48%	5.79%	4.14%
Pyrograf	0.4	N011	2.34%	5.95%	12.82%
	0.6	N012	3.73%	8.29%	18.81%
	0.8	N013	6.46%	6.19%	10.15%
	1.0	N014	12.67%	11.27%	31.15%

From our observation, it is clearly shown that at three different temperature, Pyrograf show great enhancement compared to MER. At 45°C, the enhancement of thermal conductivity for MER is 12.51% but Pyrograf is 31.15%. This shows a huge difference between MER and Pyrograf CNT with 18.64% differences. From this data, we can conclude that nanofluids that contain 1.0 wt% of Pyrograf CNT gave the best enhancement at all temperatures.

4.2 DISCUSSION

We conclude that between Pyrograf CNT gave better enhancement of thermal conductivity compared to MER CNT. But there is explanation why Pyrograf gave such amazing results.

4.2.1 Types of CNT

Types of CNT may affect the thermal conductivity of each CNT. From data that we have collected from each of manufacturer, Pyrograf and MER are two different types of CNT

Table 4.4: Types of CNT

CNT	**Type**
MER	Multi-walled nanotube (MWNT)
Pyrograf	Carbon nanofiber (CNF)

MER consist of multi-walled nanotubes but Pyrograf consist of carbon nanofiber. Here we can see that Pyrograf have surplus value compared to MER. The advantage of Pyrograf is the length of the tubes.

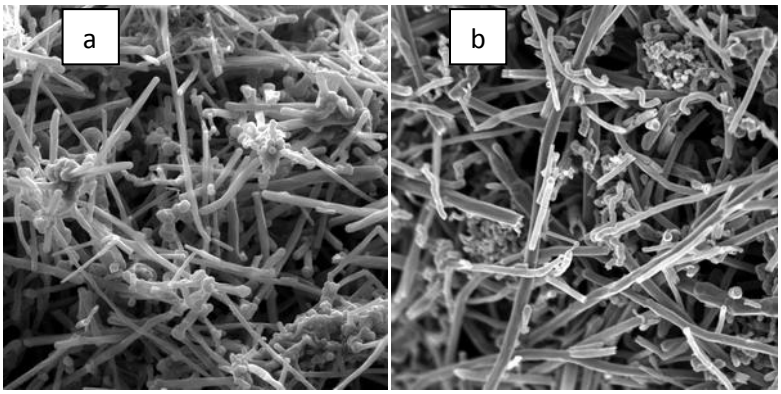

Figure 4.3: Scanning electron microscope (SEM) image of MER (a) and Pyrograf (b) at 2 micron

From figure 4.3 above, we can see difference between MER and Pyograf. MER consist of short length of tubes but Pyrograf have longer and continuous length of tubes. Length of tubes may affect the thermal conductivity of each nanofluids in terms of absorption area of nanotubes. The longer the tubes, the higher surface area of CNT, hence the higher thermal conductivity will be obtained.

4.2.2 Surface Area

Surface area can affect the thermal conductivity of CNT. Smaller particle have a bigger surface area than larger particle for the same mass. This explanation is based on the “Bread and Butter” theory. Each time we cut a new slice of bread we got a new extra surface. The thinner we cut a new slice, we got a higher extra surface. We used BET surface area testing method to calculate the surface area of CNT that we used to produce nanofluids. BET surface area testing is the most popular method to check surface area of certain compound and can give the most accurate surface area for the compound.

Table 4.5: Data from BET surface area testing

CNT	BET Surface Area, m²/g	Total pore volume, cc/g
MER	1.015×10^{2}	8.816×10^{-2}
Pyrograf	1.718×10^{3}	1.078

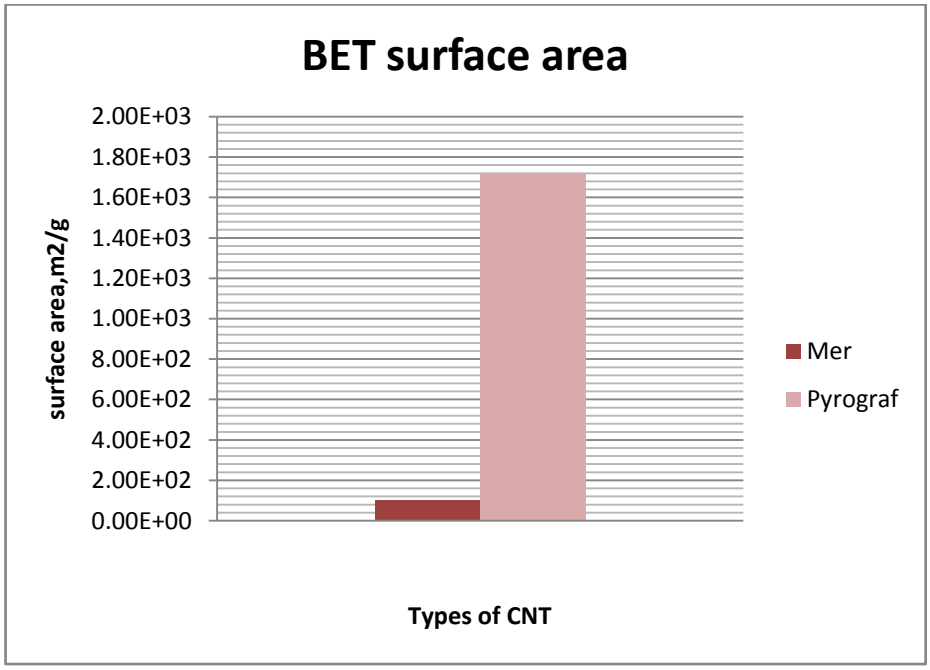

Figure 4.4: BET surface area

From the data that was collected from BET testing, Pyrograf has the largest surface area compared to MER. The high surface area is due to high distribution of micropores in this sample. Note that high surface area is good for thermal conductivity.

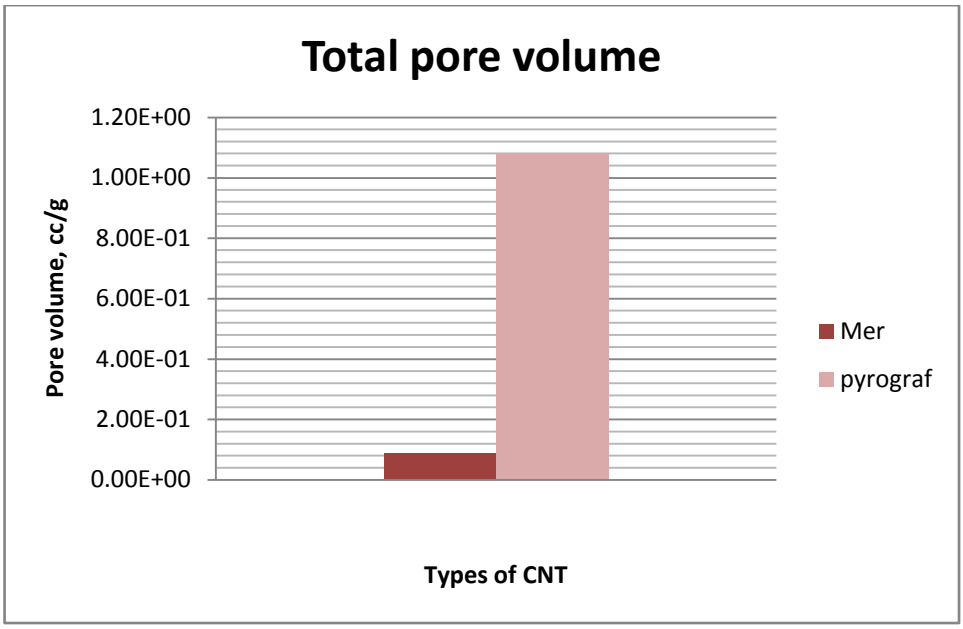

Figure 4.5: Total pore volume

Porosity plays important role because from porosity of a substance, we can determine the absorption capacity of the substance. We can also determine the porosity by calculating the total pore volume, which is combination of micro, meso and macro pores. In this case, once again Pyrograf gave enormous result by obtaining the highest pore volume leaving MER a huge difference of pore volume.

4.3 CONCLUSION

As a conclusion for this chapter, the results clearly showed that each of CNT that was tested gave slight enhancement of thermal conductivity of the based fluid. This indicates that CNT was proven to have capacity to enhance the thermal conductivity of distilled water even though there are differences between CNT that were tested. In our case, Pyrograf have a better thermal conductivity at 45C, 1.0 wt% with 0.812 W/mK and it enhanced the based fluid as high as 31.15%. With high number of surface area and total pore volume, this shows that Pyrograf CNT have a brighter usage to be commercialized and be used as nanoparticles to be suspended inside conventional heat transfer fluids.

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

The thermal conductivity of two different nanofluids based on CNT has been investigated. Nanofluids with different weight ratio of CNT from 0.4 wt% until 1.0 wt% has been tested and analyzed. Using KD-2 Pro thermal properties analyzer, thermal conductivity each of nanofluids has been tested at three different temperature; 6℃, 25°C and 45°C. Basically, all the nanofluids shows enhancement of thermal conductivity. Somehow, the highest thermal conductivity of nanofluids based on Pyrograf was recorded at 45°C with 1.0 wt% at 0.812 W/mK with enhancement 31.15%. The second highest enhancement of thermal conductivity recorded with 1.0 wt% at 6°C with 12.67% at 0.645 W/mK and the third highest is MER at 45°C with 0.6 wt% at 0.697 W/mK with enhancement 12.51%. Textural analysis of Pyrograf shows that this sample has the highest surface area and has highest total pore volume. The morphology of Pyrograf indicates that average diameter of the CNT from 20 nanometer (nm) to 40 nm.

5.2 RECOMMENDATION

Aside from investigating CNT's thermal conductivity, in future research we shall investigate other properties such as CNT mechanical properties or electrical properties. In terms of this project, maybe we can propose for developing our own facility or method to grow CNT and test it compare to other purchased CNT. Even though it will use a lot of funding but this research may give benefit in the future if we know the potential of CNT

The high thermal conductivity of carbon nanotubes can produce and change a lot of things. The current heat transfer fluids may be irrelevant to the industries in the future because the demand of power increase in year after year. If this technology cannot expand, we may have a bigger chiller, or heat exchanger, or even bigger cooling tower because we need a lot of water or other conventional heat transfer fluid for cooling processes. If we manage to explore and enhance this technology, we can miniaturize the size of heat exchanger or even a lot of other things.

REFERENCES

Ahmadi M.K., Baghalha M. (2007) MWCNT Nano-Fluids Enhancement Of Copper Corrosion, Not published yet.

Biercuk M.J. et. al (2002).Carbon nanotube composites for thermal management. Applied Physics Letters, volume 80, page 2767-2779.

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

Choi E.S. et. al (2003). Enhancement of thermal and electrical properties of carbon nanotube polymer composites by magnetic field processing. Journal Of Applied Physics, Volume 94, Number 9, pp. 6034-6040.

Ci. L et. al (2008). Continuous Carbon Nanotube Reinforced Composites, Nano Letters. Not published yet.

Costa S. et. al (2007)Characterization of Carbon Nanotubes by Raman spectroscopy. Centre of Knowledge Based Nanomaterials and Technologies, Institute of Chemical and Environment Engineering, Not published yet.

Endo M. et. al.(2004). Applications of carbon nanotubes in the twenty-first century. Published online, pp. 2223-2239.

Fujii M. et. al (2005)Measuring the Thermal Conductivity of a Single Carbon Nanotube. PHYSICAL REVIEW LETTERS, 95, pp. 1-4.

Gowda R. et. al (2010). Effects of Particle Surface Charge, Species, Concentration, and DispersionMethod on the Thermal Conductivity of Nanofluids, Advances in Mechanical Engineering, Volume 2010, pp. 18-28.

Han Z.H. et al (2007). Application of hybrid sphere/carbon nanotube particles in nanofluids. Nanotechnology 18. 31 January 2007.

Huthala M. et. al (2002) Computational studies of carbon nanotube structures. Computer Physics Communications, 147, pp. 91–96.

J.A. Eastman (2005), Mechanisms of Enhanced Heat Transfer in Nanofluids, Materials Science Division, Argonne National Laboratory. Not published yet.

Jiang W. et. al (2009). Measurement and model on thermal conductivities of carbon nanotube nanorefrigerants. International Journal of Thermal Sciences, 48 , pp. 1108–1115.

Khare R. and Bose S. (2005)Carbon Nanotube Based Composites- A Review, Journal of Minerals & Materials Characterization & Engineering, Vol. 4, No.1, pp 31-46.

Ko G.H et al. (2007). An experimental study on the pressure drop of nanofluids containing carbon nanotubes in a horizontal tube. International Journal of Heat and Mass Transfer 50, pp. 4749–4753.

Manca O. et. al (2010). Heat Transfer in Nanofluids. Advances in Mechanical Engineering, Volume 2010, pp 1-2.

McEuen P.L (2000)Single-walled carbon nanotubes. Physics World. Pp. 31-37.

Mohorianu S. H., Agop M.(2006). A theoretical approach of the heat transfer in nanofluids. Journal Of Optoelectronics And Advanced Materials Vol. 8, pp. 1741 – 1743.

Murshed S.S.M et. al (2007). Convective Heat Transfer Of Nanofluids In Minichannel Under Laminar Flow Conditions. International Conference on Mechanical Engineering 2007 (ICME2007) 29- 31 December 2007.

Nygård J. et. al (1999)Electrical transport measurements on single-walled carbon nanotubes. Appl. Phys. A 69, pp. 297–304 .

Ryglowski B.K. (2009). Characterization Of Carbon Nanotube-Enhanced Water As A Phase Change Material For Thermal Energy Storage Systems. Naval Postgraduate School Monterey, California. Thesis Bchlr.

S. Choi (2006). Nanofluids for Improved Efficiency in Cooling Systems. Argonne National Laboratory – 362 Auditorium. 18-20 April, 2006. Not published yet.

Sundar L.S. et. al (2007) Experimental investigation of Heat Transfer Enhancements with Al2O3 Nanofluid and Twisted Tape Insert in a Circular Tube. International Journal of Nanotechnology and Applications. Volume 1, Number 2, pp. 21–28.

Tahery A.A. et. *al* (2010). Numerical Study of Heat Transfer Performance of Homogenous Nanofluids under Natural Convection. International Journal of Chemical Engineering and Applications, Vol. 1. pp 49-55.

Torii S. (2010). Turbulent Heat Transfer Behavior of Nanofluid in a Circular Tube Heated under Constant Heat Flux. Advances in Mechanical Engineering. Volume 2010, pp. 1-7.

Vandusberg L. et. al (2006). Surface Modification of Multi-Walled Carbon Nanotubes for Enhanced Dispersion and Stability Using a RF Glow Discharge. Heat Transfer in Nanofluids A Review, Heat Transfer Engineering 27, 3.

Vasu V. et. al (2008). Application of Nanofluids in Thermal Design of Compact Heat Exchanger. International Journal of Nanotechnology and Applications. Volume 2, Number 1, pp. 75–87.

Vekas L. et. al (2006). Magnetic Nanofluids Stabilized With Various Chain Length Surfactants. Romanian Reports in Physics, Vol. 58, No. 3, pp. 257–267.

Wang X.Q. and Mujumdar A.S (2007). Heat transfer characteristics of nanofluids: a review. International Journal of Thermal Sciences. 46. pp 1–19.

Wang X.Q. and Mujumdar A.S (2008). A Review On Nanofluids - Part Ii: Experiments And Applications. Vol. 25, No. 04, pp. 631 – 648.

Wong K.V. , Castillo M.J.(2010) Heat TransferMechanisms and Clustering in Nanofluids, Advances in Mechanical Engineering, Volume 2010, pp. 28-37.

Wong K.V. , Deon O. L. (2010). Applications of Nanofluids: Current and Future. Advances in Mechanical Engineering, Volume 2010, pp. 3-13.

Wu D. et. al (2009), Critical Issues in Nanofluids Preparation, Characterization and Thermal Conductivity. Current Nanoscience, 5, pp. 103-112.

Xue. Q and Xu W.M (2005). A model of thermal conductivity of nanofluids with interfacial shells. Materials Chemistry and Physics 90, pp. 298–301.

Zhou L.P. et. al (2010). On the Specific Heat Capacity of CuO Nanofluid, Advances in Mechanical Engineering, Volume 2010, pp. 14-18.

Zhu D. et. al (2009). Dispersion behavior and thermal conductivity characteristics of Al2O3–H2O nanofluids. Current Applied Physics, 9, pp. 131–139.