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"I hereby declare that 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)"

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ENHANCING THERMAL PROPERTIES OF FLUIDS WITH CARBON NANOPARTICLES

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This report is submitted to the Faculty of Mechanical Engineering in partial fulfillment of the requirement for the award of Bachelor of Mechanical

Engineering (Thermal-Fluids)

Faculty of Mechanical Engineering Universiti Teknikal Malaysia Melaka

JUNE 2015

DECLARATION



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ACKNOWLEDGEMENT

First and foremost, I would like thank my supervisor, Mr. Imran Syakir Bin Mohamad for his guidance from the very beginning. He is always there to guide us and to share his knowledge with us while listening to the problems faced by me. Without his guidance and assistance, I would not even know where to start my report, let alone my research for my final year project. Furthermore, I would like to extend my gratitude to my co-supervisor Dr. Norli Abdullah for her input throughout the project and always there to clear our doubts.

Secondly, I would like to thank my family for their support. To thank them for listening to my problems from time to time and still care for me and love me for who I am. Their unconditional support throughout this whole time meant a lot for me and it has been my beacon of hope in rough times.

Third of all, I would like to thank the lecturers that has been pouring their knowledge in the lectures selflessly. The same goes to the teachers I have had since young. Without them building up my knowledge foundation, I would not reach where I am. Although there were times where homework were not perfectly done, lectures and classes were not paid attention to, your effort in making me better than yesterday will not be forgotten.

Last but not least, I would like to send my utmost appreciation to all my friends for sharing all the joyous and strenuous moments throughout the study life in Universiti Teknikal Malaysia Melaka together. The laughter we had together will not be forgotten and the help and guidance all this time are all deeply appreciated.

ABSTRACT

Nanofluid is the product of mixing base fluid and nanoparticle. For this experiment, the base fluid chosen is deionized water while the nanoparticle is industrial-grade multi-walled carbon nanotube (MWCNT) with -OH functionalize. Due to the hydrophobic characteristic of the MWCNT, polyvinylpyrrolidone (PVP) was added into the nanofluid as a dispersing agent to stabilize the nanofluid for tests. This is because unstable nanofluid can cause clogging in operating system and ultimately rendering the system useless. Multiple sample between ratio 0.1wt% to 1.0wt% MWCNT were made to identify the best ratio for 100 hours stability. The best ratio nanofluid then underwent a series of tests including viscosity test, heat transfer test and specific heat test to determine the improvement of the nanofluid compared to normal water. The tests were all carried out in 6 °C, 25 °C and 40 °C to compare the performance of the nanofluid in different temperature. For thermal conductivity test, the three samples that has the overall best results were 0.1wt%, 0.5wt% and 0.8wt% with an average improvement of 7.34%, 4.73% and 5.13% respectively. As for viscosity test, since in terms of viscosity test the preferred result would be low viscosity, the results that showed the least increment in viscosity are considered better. The samples with the least increment in viscosity are 0.1wt%, 0.5wt% and 0.8wt%. with an average increase of 45.14%, 69.53% and 70.26% respectively. Lastly, for heat transfer test, the three samples that has shown promising results in previous were used to choose the overall best sample of them and is was found that 0.1wt% sample has the highest changes in temperature at an average of 4.68 °C while 0.5wt% and 0.8wt% sample has an average of 4.07 °C and 4.65 °C temperature changes respectively. In conclusion, 0.1wt% is the best sample in term of thermal conductivity, viscosity and

heat transfer. It is the most preferable sample throughout this project.

ABSTRAK

Bendalir-nano adalah hasil daripada percampuran cecair asas dan nanopartikel. Untuk kajian ini, cecair asas yang dipilih adalah air ternyah ion manakala nanopartikel yang digunakan adalah tiub karbon nano tiub dinding berganda gred-industri (MWCNT) dengan kumpulan berfungsi -OH. Disebabkan oleh ciri-ciri hidrofobik MWCNT, polivinilpirrolidon (PVP) telah ditambah ke dalam bendalir-nano tersebut sebagai ejen penyurai untuk menstabilkan bendalir-nano untuk dijalankan ujian. Pelbagai sampel telah disediakan untuk mengenal pasti nisbah terbaik untuk kestabilan selama 100 jam. Catuan bendalir-nano yang terbaik kemudian menjalani satu siri ujian termasuk ujian kelikatan, ujian pemindahan haba dan haba tertentu ujian untuk nenentukan peningkatan ciri-ciri terma bendalir-nano berbanding dengan air biasa. Kesemua ujian dijalankan dalam 6°C, 25°C) dan 40°C unluk membandingkan prestasi, bendalir-nano dalam suhu yang berbeza. Untuk ujian pemindahan haba, sampel 0.1wt%, 0.5wt% dan 0.8wt% mempunyaikeputusan yang terbaik, dengan purata 7.34%, 4.73% dan 5.13% masing-masing. Untuk ujian kelikatan, sampel yang berkelikatan rendah dianggap lebih baik. Sampel yang mempunyai peningkatan kelikatan yang terendah ada 0.1wt%, 0.5wt% dan 0.8wt% juga, dengan purata peningkatan sebanyak 45.14%, 69.53% dan 70.26%. Akhir sekali, tiga sampel yang mempunyai keputusan terbaik daripada ujian sebelum ini diguna untuk menjalani ujian kekonduksian termal. Sampel 0.1wt% didapati mempunyai perbezaan suhu yang tertinggi, sebanyak 4.68 °C manakala 0.5wt% dan 0.8wt% hanya mempunyai purata perbezaan suhu sebanyak 4.07 °C dan 4.65 °C sahaja. Keseluruhannya, sampel 0.1wt% adalah sampel yang terbaik antara sampel-sampel dan ujian yang telah dijalankan dan merupakan sampel yang mempunyai keputusan yang terbaik dalam projek ini.

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CHAPTER I

INTRODUCTION

1.0 INTRODUCTION

Carbon nanotube (CNT) was brought into the awareness of the scientific community in 1991 by Sumio Iijima of NEC. However, the production as well as the observation of carbon nanotube were made long before 1991. There are two main categories of CNT, namely single-walled nanotubes (SWNT) and multi-walled nanotubes (MWNT). CNTs are known for their thermal and electrical conductivity. Other than the element that made up the components, one major factor that affects thermal conductivity is the state of the element and the best state to transfer heat is solid state as the particles are closely packed in solid state. Also, the size of the solid will affect the thermal conductivity as the effective surface area would decrease as the size of the solid increases. CNTs are basically nano-sized solid that would act as medium that transfer the heat energy.

1.1 PROBLEM STATEMENT

Water is one of the most widely used medium for heat transfer mechanism around the world throughout human history. Water itself is considered to have low thermal conductivity. However, by introducing carbon nanotube will improve the thermal conductivity of the solution. Common carbon nanotube (CNT) are hydrophobic, however, the carbon nanotube that was chosen, industrial-grade multiwalled carbon nanotube (MWCNT) with –OH functionalize can improve the stability and dispersion of the carbon nanotube. Hence to produce a nanofluid with the ingredient as stated above would be a challenge as we need the nanofluid to be stable in order to conduct the viscosity, specific heat and thermal conductivity test. To achieve stability, we then introduce a dispersing agent, polyvinylpyrrolidone (PVP) to stabilize the nanofluid. And the amount required for us to produce the optimum stability are yet to be determine. At optimum weight ratio, we would then identify how much were we able to enhance the thermal conductivity compared to regular water.



The main objectives for this research are:

- To produce nanofluid with improved thermal conductivity using MWCNT-OH and deionized water with polyvinylpyrrolidone (PVP) as dispersing agent.
- To identify the weight percentage of MWCNT-OH and PVP to deionized water that would produce the best dispersion stability.
- iii) To find out the range of improvement of thermal properties of the nanofluid.

1.3 SCOPE

i) The material used are limited to MWCNT-OH and deionized water while using PVP as dispersing agent.

ii) A range between of 0.1wt% - 1.0wt% of CNT are used.

iii) The nanofluid stability test are limited to 100 hours only.

iii) Thermal conductivity, viscosity test, specific heat test and heat transfer test will be carried out.



CHAPTER II

LITERATURE REVIEW

2.0 INTRODUCTION

Nanoscience can be defined as the study of phenomena and manipulation of materials on nano-sized scale, from 1 nm up to a maximum of 100 nm. Therefore, nanotechnology would be focusing on the production, design, characterization and application of components in nano size (*S.K. Sahoo et al.* 2007) Due to the complex interplay between surface and quantum effects, each and every nanostructure can display a range of unique potential characteristics even with a slight modification onto the system, so specific discussion are required for each individual nanosystem. (Uskokovic, 2007). This technology base was initially discussed technically by Fynman in 1960 (Fynman, 1960) and commercially by Drexler in 1986 (Drexler, 1986). Nanotechnology is the first in history research initiative on a worldwide scale that can serve as general purpose technologies like biotechnologies, computational sciences. Physical sciences. Communication technologies, cognitive sciences, social psychology and other social sciences. (Mangematin, 2012)

2.1 NANOFLUIDS

2.1.1 Introduction to Nanofluid

Nanofluids are actually solid-liquid composite materials, made of solid nanoparticles or nanofiber with size between 1 nm to 100 nm, suspended in liquid known as base liquid (*Obaid et al. 2013*). By adding nano-sized solid into the liquid, the characteristic of solid can be utilized and improve the overall characteristic of the compound mixture. Figure 2.1 shows a sample of TEM pictures of traditional nanofluid and functionalized nanofluid. However, when the amount of solid added is too much, the system might clog and cause the entire system to fail. Hence a vast amount of research has to be done to acquire the optimum ratio for the system to work while avoiding system failure.



Figure 2.1 : TEM pictures of (a) traditional nanofluid and (b) functionalized nanofluid (Yang & Liu, 2011)

With different base fluid and different nanomaterial, the enhanced characteristic would be different. For example, the electrical conductivity of water and ethylene glycol-based nanofluids rose almost linearly with particle volume fraction but there is no significant changes when the temperature rises (*Sarojini et al. 2012*). However, the situation is absolutely different for thermal conductivities using CuO and Al₂O₃. The thermal conductivity rose 9.4% to 24.3% when the temperature

increased from 21 °C to 51 °C (*Das, et al. 2007*). This means that there would be a very wide range of application that could be applied on using nanofluid alone.

2.1.2 Application of Nanofluid

With enough data carried out by researchers from around the world, nanofluid has slowly been used into a wide range of technology, all by utilizing characteristics like thermal and electrical properties to viscosity of the nanofluid.

2.1.2.1 Automotive Industry

Engine oils, coolants, lubricants, automatic transmission fluids and other synthetic heat transfer fluids that works under high temperature found in conventional vehicle thermal system such as radiator, engine, HVAC (Heating, Ventilation and Air-conditioning) have inherently poor heat transfer properties (Wong & Leon, 2009). With an improved heat transfer in radiator, a smaller and fighter radiator can be used for the same effect of a traditional radiator and the space saved could be used for other use. Similarly, when the temperature of engine and radiator can be easily controlled, vehicle engine can run at optimum temperature and hence, uses less fuel for the same power output, hence a higher efficiency.

When a vehicle is moving at high speed and required to come to a stop, the kinetic energy of the car body is converted to heat energy, and in some extend, sound energy as well. The heat energy is then dissipated through the brakes as well as the brake fluid. It is then safe to say that, an efficient heat dissipation mechanism is crucial while determining the quality of the brake system of a vehicle.

2.1.2.2 Electronic Devices

Temperature control has always been the issue when it comes to computers. Using the same computer, running the same program would sometimes makes the computer seems slower at warmer surrounding temperature. This is due to the rise of temperature of the microchips in the CPU. Some computer users perform overclock on their computer system processor and hence a very good cooling system must be used to avoid overheating. At particle concentration of 6.8%, heat transfer coefficient increased by 40% when using Al₂O₃ nanoparticle (*Nyugen et al. 2007*).

2.1.2.3 Application in Other Field

Nanofluid has also been applied in medical field. Electrically activated microchip was delivered into the body of the patient to monitor the internal part of the body that could not be scanned using X-ray scan. There is also initiative that takes advantage of iron-based nanofluids to be used in cancer imaging and drug delivery for cancer therapeutics.

Nanofluid has also been in solar cell research. By enhancing the amount of sunlight trapped within the cell, the efficiency of the conversion between solar energy to chemical energy to electrical energy could be increased. Furthermore, by synthesizing elements in nanoscale the desired characteristic can be easily manufactured compare to conventional method.

2.1.3 Synthesis of Nanofluid

To produce nanofluid, nanoparticle has to mix with the base fluid. However, nanoparticle tend to clog together and form sedimentation instead of suspending evenly throughout the solvent. In order to synthesis a stable nanofluid with nanoparticle dispersed evenly suspending in the base fluid, dispersing agent will be added to help the nanofluid attain stability.

2.1.3.1 Single Step Method

Single step method is one of the simplest method to produce nanofluid, by mixing two chemical substances together along with dispersing agent of choice, then followed up by magnetic stirring. After stirred, the mixture is then placed into a microwave oven and allowed to react. After some time, the mixture will be allowed to cool back to room temperature. The nanofluid is officially done when the temperature reach room temperature.

2.1.3.2 Two Step Method

Although single step method is a more direct method of obtaining nanofluid, the use of two step method is more widely seen as nanoparticle in powder form is easily attained. The desired nanoparticle is mixed with the base fluid together with the dispersing agent. The mixture is then mixed with a homogenizer before being checked for the pH value. At the desired pH, the mixture is then inserted into ultrasonicator. The nanofluid is considered complete after it has finished the ultrasonication process.

2.1.3.3 Laser Ablation Method

Laser ablation method is a more sophisticated method of producing nanofluid. The solid metals or polymer is ablated with laser beam while submerged in a liquid. As the laser focuses on the surface of the solid, the temperature at the specific point and the liquid on the surface reaches very high temperature and vaporizes. As the vapor expands, the metal splashes into nano-sized drops and is then super cooled by the surrounding liquid before it reaches surrounding atmosphere. Figure 2.2 shows a simple description of the laser ablation method that is being used in most cases.



Figure 2.2: Laser Ablation Method (*Phuoc et al. 2007*)

2.2 CARBON NANOTUBE (CNT)

Carbon nanotubes (CNTs) are unique tubular structures of nanometer diameter and with a large length to diameter ratio (*Milone et al. 2014*). CNTs can exist in rolled shell of sp² carbon. This is known as single wall carbon nanotubes, SWCNT. CNT can

also exist in tens of co-axial shells of carbon layer with 0.34 nm adjacent shell separation, also known as multi wall carbon nanotubes, AWCNTs. Example of SEM images of carbon nanotubes can be seen in Figure 2.3. Carbon nanotubes are gaining popularity at a rather fast pace due to their unique structure and arrangement. These unique characteristics are the reason why CNTs have electrical, (*Chakraborty et al.* 2012) thermal (*Choi et al.* 2001) and mechanical (*JP Salvetat et al.* 1999) properties.



Figure 2.3: (a) SEM image of carbon nanotube and (b) TEM image of carbon

nanotube (*Ding et al. 2006*)

2.2.1 Single Wall Carbon Nanotube (SWCNT)

Single wall carbon nanotube (SWCNT) is basically a wrapped rolled up of a single piece of graphene into a tube shape as shown in Figure 2.4 (a). SWCNTs is a superb conductor of electrons and they show semiconducting behavior, depending on the diameter and atomic structure of the nanotubes. Even the very high thermal conductivity of isotopically pure diamond is expected to be exceeded by that of CNTs (*Vidu, et al, 2014*)



2.2.2 Multi Wall Carbon Nanotube (MWCNT)

MWCNTs are similar to that of SWCNTs but the difference in structure is that the MWCNTs are made up of a few layers of graphene instead of just one layer of graphene as shown in Figure 2.4 (b). Due to the fact that the number of layers of graphene found in MWCNT is not always the same, the use of MWCNT in field that require material used to be very precise is rarely seen. To produce SWCNT has its difficulties compared to MWCNT as the stability of MWCNT is largely affected by the increase of atom. Under heavy chemical surrounding, MWCNT is relatively more stable than SWCNT as well. Figure 2.5 show the SEM micrograph of MWCNT.



Figure 2. 5: Typical SEM micrograph of MWCNTs (Liu et al. 2011)

2.2.3 -OH Functionalized Carbon Nanotube

Carbon nanotubes, without any treatment, are highly insoluble. The insolubility of CNT makes the manipulation highly difficult and has greatly limited the uses of this product in all aspects. The two main approaches to this matter developed throughout the years, are based on non-covalent and covalent functionalization of CNT (*Cecilia Menard Moyon, 2010*). The -OH functionalized group allows the formation of hydrogen bond between the CNTs as well as with the base fluid which ultimately helps with the dispersing mechanism.

2.3 DISPERSING AGENT

Dispersing agents are used especially when a solid material dispersed in a liquid. The addition of the dispersing agent is to make the dispersion process easier and more stable. Due to the different surface tension of the liquid and the solid, the dispersing process may take a long time. With the use of dispersing agent, the amount of solid that can be dispersed in the liquid can be increased without the risk of unstable viscosity dispersion throughout the mixture. Dispersing agent is crucial to the equation when producing stable formulation with storage stability.

2.3.1 Polyvinylpyrrolidone (PVP)

Polyvinylpyrrolidone or PVP in short, is white with a slight pale yellow in color. PVP is a hydrophilic polymer with wide variety application in medicine, food and even cosmetics (*Xie et al, 2014*) However, PVPs are not ideal for storage over a long period of time as the polymer is very hygroscopic. As shown on Figure 2.6, the chemical formula of PVP is shown. Previous research regarding CNTs and poly(vinylidene fluoride) (PVDF) on crystalline behaviors showed that the presence of PVP did not change the crystalline structure of the PVDF however it has greatly improved the dispersion of CNT throughout the structure. In other words, the presence of PVP has allowed a greater and denser network of CNT in the PVDF matrix (*Zhang et al. 2015*)



(Source: Harke Group, n.d.)

2.3.2 Sodium Dodecyl Sulphate (SDS)

Apart from PVP, sodium dodecyl Sulphate (SDS) too can be used as a dispersing agent. SDS can provide a layer of coating on the nanoparticle which would create a repulsion in the form of electrostatic. Being repulsive of each other, the surfactant-coated CNTs will have reduced particle agglomeration.



Figure 2.7: Structural formula of SDS

2.4 THERMAL CHARACTERISTICS OF NANOFLUID

Thermal conductivity is the ability of an object to transfer heat from one location to the other. The thermal conductivities of solid is generally better than that of liquid, even more so that of air as the heat energy that is being transferred by solid via conduction and to some extent, convection and radiation as well. However, heat transfer via conduction method is not applicable in fluids. Hence it is obvious that a mixture of solid and liquid would provide a better heat transfer than that of pure liquid.

Due to the very small size of nanoparticle, with the suspension of nanoparticle in fluids, the nanoparticle-fluid mixture could be suitable as heat transfer fluids in many existing heat transfer device (Wang & Xu, 1999).

2.4.1 Thermal Conductivity

Heat energy can only be transferred from a notter system to a colder system. This is one of the basic principle that pillar to the First Law of Thermodynamic. From investigations that has been conducted since the past decade, it is found that even with a very low concentration of nanoparticle (less than 5%), the thermal properties especially thermal conductivity are substantially higher (*Murshed et al. 2008*). The thermal conductivity of nanofluid consists of CNT and 0.3% copper nanoparticle concentration shows an increase in 70% of thermal conductivity (*Jana et al. 2007*). However, classic thermal conductivity models like those attributed to Maxwell, Hamilton-crosser (HC) and Bruggeman were found unable to predict the absurdly high thermal conductivity of nanofluids as these classic models do not take into consideration the effect of the particle size, distribution and also the interfacial layer between the nanoparticle and base fluid interface which are all considered as very important mechanisms for studying the thermal conductivity of nanofluid (*Murshed et al. 2008*).. Figure 2.8 shows the effective thermal conductivity of nanofluids as a function of CNT concentration at three temperatures (*Ding, et al., 2006*).



Figure 2. 8: Thermal conductivity of CNT nanofluids under different conditions: (*Source: Ding et al. 2006*)

2.4.2 Viscosity



CHAPTER III

METHODOLOGY

3.0 INTRODUCTION

In this chapter, the ingredients used and the apparatus used will be discussed. The procedure from the preparation of the nanofluid to the experimental would also be briefed. The importance of the methodology is to ensure the repeatability of the experiment should anyone felt the need to carry out this experiment again. The flow chart in subsection 3.1 served a brief guide for the general flow of the process while the subsequent sub-topics go into more details about the experiment.

3.1 FLOW CHART



Figure 3.1: Flow chart of research.

3.2 APPARATUS AND MATERIALS

Figure 3.2 shows the materials and apparatus required to prepare the nanofluid. Within Figure 3.2, there are homogenizer, pH meter, ultrasonicator, CNT, PVP, sodium hydroxide and hydrochloric acid.



Figure 3.2: Apparatus and material used for nanofluid preparation

3.2.1 Digital Analytical Balance

Digital analytical balance is used to measure the desired amount of CNT and PVP required for the sample. This type of balance is chosen due to the high sensitivity of this device. The digital analytical balance used was manufactured by Mettler Toledo, with sensitivity up to 0.0001 gram. Such high sensitive device is used because the CNTs and PVP used are all in powdered form. Hence such sensitive device is needed to obtain accurate reading.

3.3.2 Homogenizer

Homogenizer is used to stir up the mixture. In this experiment, the homogenizer is set to 10000 rpm and allowed to run for 5 minutes. Figure 3.3 shows the image of a homogenizer while Figure 3.4 (a) and Figure (b) shows the homogenizer stirring up the mixture and the setting of 10000 rpm respectively.



Figure 3. 4: (a) Nanofluid undergoing homogenizing process; (b) setting of homogenizer at 10000 rpm

3.2.3 Ultrasonicator

Ultrasonicator is used to ensure a good dispersion of the nanoparticle throughout the nanofluid. The ultrasonicator is set at maximum frequency of 37 kHz and run for 30 minutes. Figure 3.5 shows the ultrasonicator in work.



Figure 3. 5: Two sample of CNT with different PVP concentration undergoing

ultrasonication The ultrasomicator used in this project is the Elmasomic S model manufactured by Elma Hans Schmidbauer GmbH & Co. KG, with an effective 37 kHz ultrasonic high performance

3.2.4 pH Meter / Litmus Paper

pH meter and Litmus paper were used to measure the pH value of the mixture after homogenizing process, before continuing to ultrasonication process. Litmus paper too can be used to double-check the reading in case in doubt of the reading shown by the pH meter.

3.2.5 CNT Nanoamor

CNT Nanoamor is the nanoparticle used in this experiment. Table 3.1 shows the component content in the CNT used in this experiments.

Components	Contents (%)
Multi-walled carbon nanotubes (excluding -OH)	>90
-OH	2.36-2.60
Al	4.21
Fe	0.18
Ni	0.97
S	0.16

Table 3.1: COA of MWCNT used in the experiment

(Nanostructured & Amorphous Materials Inc, n.d.



PVP is the dispersing agent selected to be used in this experiment. The hydrophilic nature of PVP would work well with CNT Nanoamor which is hydrophobic. The presence of PVP in the nanofluid sample is crucial as it affects the stability of the nanofluid and the storage life. Figure 3.6 shows two samples of CNT, one without the use of PVP and one with PVP. Bear in mind that both sample were synthesized together as shown in Figure 3.6, hence sharing the same time span of being left alone for stability test.



Figure 3.6: Comparison of samples (a) unstable and (b) stable

3.2.7 Deionized Water

Deionized water is basically water that has most of the ions removed from it. Normal water usually has some metallic ion found in them such as iron magnesium and calcium. By using deionized water, the experimental result is more precise and has higher repeatability as we can reduce the amount of impurities found within the liquid, unlike tap water which the amount of impure ions cannot be controlled.

3.2.8 Acid and Base

The acid used in the experiment is nitric acid while the base used is sodium hydroxide. These chemical is essential as throughout the experiment, the pH value that has decided fixed is pH value 9 with an allowance of ± 0.2 pH value. This is to ensure the accuracy of the data as nanofluids and dispersing agent tend to have different qualities at pH values that are too far apart. Hence, the acid and base is used to adjust the pH value to as close to pH value 9 as possible.
3.2.9 Stability Test

The stability test can be conducted via two method, one is through simple visual confirmation while the other is through a device. If the sample shows obvious failure as the sample without PVP in Figure 3.6, a simple visual confirmation would be sufficient. However, in some cases the sedimentation can only be seen under focused light as shown in Figure 3.7(a). Hence a device should be used to determine the quality of stability of the sample as shown in Figure3.7 (b). When a sample inserted could fully block the passing light, 3 lights will be turned on, indicating absolutely no lights passes through the sample.



Figure 3.7: (a) early stages of sedimentation that could only be seen under focused light and white background and (b) a simple device made to check the stability of the sample.

3.3 SYNTHESIS OF NANOFLUID

Start off the experiment by measuring the CNT, PVP and 40 g of deionized water to the desired weight using the digital analytical balance. The ingredients were mixed together into a container.

Container is clamped to the stand below the homogenizer and set the homogenizer to 10000 rpm and allowed to run for 5 minutes. Note that the stirring rod of the homogenizer must not touch the wall nor the bottom of the container.

After homogenizing, the mixture was poured into a 40 ml container tube and tested the pH value using pH meter. If the pH meter showed the value is too low (< pH 8), a few drops of sodium hydroxide were added. However if the pH value is too high (> pH 10), a few drops of nitric acid were added instead. The range of pH accepted in this experiment is pH 9 with the allowance of ± 0.2 pH value.

When the pH of the nanofluid is within range, the ultrasonicator is set up and the sample were bathed in the ultrasonicator at maximum frequency of 37 kHz for 30 minutes. After ultrasonication process, the container tube was covered up and and labelled. The sample were left to sit in up to 100 hours. Visual confirmation were used before 100 hours to determine early failure of sample. At the end of 100 hours, the sample were put into the stability testing device. If all 3 lights are lit up, the sample is acceptable.

The experiment was repeated with a different ratio of CNT-to-PVP to determine the best ratio for 100 hours of stability. After obtaining the best CNT-to-PVP ratio, using the same CNT-to-PVP ratio, 10 more sample with different concentration of CNT-to-deionized water were produced

For each of the 10 samples, thermal characteristic tests were conducted at 6 °C, 25 °C and 40 °C respectively.

3.4 THERMAL CHARACTERISTIC TEST

Thermal characteristic test in this experiments include viscosity test, specific heat test and heat transfer test.

3.4.1 Thermal Conductivity Test

The thermal conductivity test will be carried out using KD2 Pro as shown in Figure 3. 8.



Figure 3. 8: KD2 Pro

Before carrying out the test, the water bath temperature was set to 6 °C and all the sample were inserted into the water bath. While waiting for the temperature to reach the desired level, the KD2-Pro device was switched on and sensor KS-1 was inserted. KS-1 sensor is designed for liquid samples and insulating material. KS-1 sensor is a long single needle wich is 6 cm long and a diameter of 1.3 mm.

Once the temperature of the water bath reaches 6 °C, the experiment begun. The sensor was inserted into the sample without lifting the sample from the water bath and the 'Enter' button on the KD2-Pro was pressed. The testing took 1 minute to complete and the result can be seen on the display once the testing is completed. The testing for all the 10 samples were repeated. At the end of all 10 samples, another experiment with the base fluid alone was tested. This reading served as the datum when comparing the data. After getting the first reading from the 11 samples, the experiment were repeated for two more times at the same temperature to obtain a more accurate data. Once the data are all collected, the experiment was repeated again at 25 °C and 40 °C

3.4.2 Viscosity Test

. The viscosity test in this experiment is to be carried out using viscometer as show in Figure 3.9



Figure 3. 9: Viscometer

Set up the viscometer. Make sure the screws are screwed on correctly. The EZlock Spindle Coupling was attached to the spindle and made sure the tubes were tightly inserted to the inlet and outlet pipe. The water from the water bath was directed into the chamber through the inlet and outlet pipe which in turn regulated the temperature of the sample.

The water bath was turned on and set to 6 °C. 6.7 ml of the desired sample was poured into the chamber. The chamber was inserted into the viscometer slowly. The experiment began once the water bath temperature reached 6 °C. The rotation of spindle was set to maximum (100 rpm) and the final result were shown on the display. At the end of all 10 samples, another experiment with the base fluid alone were tested. The reading will serve as the datum when comparing the data. Similar to viscosity test, the test ran for 3 times to obtain consistent data.

In between each sample, the chamber was cleaned so that the sample would not mix and also to avoid any impurities. Once the experiment at 6 °C are done, the experiment was repeated again at 25 °C and 40 °C.

3.4.3 Heat Transfer Test

Three samples with the best overall data from thermal conductivity test and viscosity test was chosen for heat transfer test. The three samples were formulated again at 500 ml volume each instead of 40 ml as before. This is because the sample has to run through coils and pumps as shown in Figure 3.10



Figure 3.10: Set up for heat transfer test

The water bath was set to 6 °C. The 500 ml sample as poured into the large container and inserted thermocouple at both the inlet and outlet of the coil.

At 6 °C, the pump was turned on. The reading from the thermocouple were taken at one minute interval. After six minutes, the experiment ended and proceeded with the experimenting of other two samples. While changing sample, the sample in the coil and pump were made sure that they were poured back to the sample to avoid wastage. The coil and pump were washed thoroughly before starting with the next sample. At the end of all three samples, another experiment with the base fluid alone was tested. This reading will serve as the datum when comparing the data. The experiment was repeated again at 25 °C and 40 °C.

3.5 SAFETY MEASUREMENTS

As this experiment revolved around nanoparticle, a protective mask must always be worn. Similarly, rubber gloves too has to be worn through the experiment. This is because the nanoparticle in this experiment, CNT Nanoamor, is carcinogenic.

While handling devices that involves electricity, please ensure that it is not managed using wet hands. In case of spilling, refrain from cleaning with bare hand. Always use tissue or cloth to wipe it clean. By the end of every session, please remember to wipe the tables used with wet cloth so as not to endanger other users later on with the possible exposure of CNTs. Before leaving the laboratory, please rearrange the apparatus and furniture used back to the original position to reduce the chances of tripping of accidental spilling of samples.



CHAPTER IV

RESULTS AND DISCUSSION

4.0 INTRODUCTION

This chapter consists of the data gathered from stability test, thermal conductivity test and heat transfer test. The data collected were tabulated into graphical and table format for a better reading and easier understanding of the nature of the results. Each table and graph will be explained briefly in this chapter A more detail discussion will be made in the following chapter. The results gathered are arranged in accordance with the completion time of the experiment.

4.1 STABILITY TEST

The stability test is the first of a series of test. Samples with a fixed amount of CNT and varying PVP are made to identify the optimum ratio of CNT: PVP. The ratio is then used to formulate other samples with varying CNT concentration. Samples that have failed in this stage are automatically discarded from the other test as a measure to reduce cost and to reduce unproductive waiting time. The stability were set for 100 hours long. Any sedimentation throughout the 100 hours span would disqualify the sample.

4.1.1 Stability Test Results

At the end of the 100 hour test, the samples were put into test in the stability test device as shown in Figure 3.7 (b) for a final testing. Table 4.1 shows the amount of PVP and their performance throughout the stability test duration.

T at	le 4.1 2 St	ability of r	nanofluid v	with diffe	erent dis	persant	concentra	tion
	CNT	PVP	Base			Stabili	ity	
Sample	(g)	(g)	Fluid (g)	24 hr	48 hr	72 hr	96 hr	100 hr
1	0.04	0.040	39.920	Pass	Pass	Pass	Pass	Pass
2	0.04	0.032	39.928	Pass	Pass	Pass	Pass	Pass
3	0.04	0.024	39.936	Pass	Pass	Pass	Pass	Pass
4	0.04	0.016	39.944	Pass	Pass	Pass	Pass	Pass
5	0.04	0.008	39.952	Pass	Pass	Pass	Failed	Failed
6	0.04	0.012	39.948	Pass	Pass	Pass	Pass	Pass

Table 4.1 shows a total of 6 samples. The samples are made with a decrement of 0.2 ratio of CNT: PVP. At sample 5, the CNT: PVP ratio is at 0.2. With failure at 96 hour mark, sample 6 were made with CNT: PVP of 0.3. As shown in the table, Sample 6 has passed the stability test. Hence the ratio of CNT: PVP at 0.3 will be used in the formulation of other samples with different CNT concentration as this ratio uses the least amount of PVP while still being able to maintain the stability of the nanofluid after 100 hours.

After deciding upon the CNT to PVP ratio, ten samples were made, however, with increasing CNT to deionized water ratio and. All the ten samples underwent the stability test again and the result can be seen in Table 4.2.

	CNT	DVD	Base			Stability		
Sample	(wt%)	(wt%)	Fluid (g)	24 hr	48 hr	72 hr	96 hr	100 hr
1	0.1	0.030	39.948	Pass	Pass	Pass	Pass	Pass
2	0.2	0.060	39.896	Pass	Pass	Pass	Pass	Pass
3	0.3	0.090	39.844	Pass	Pass	Pass	Pass	Pass
4	0.4	0.012	39.792	Pass	Pass	Pass	Pass	Pass
5	0.5	0.015	39.740	Pass	Pass	Pass	Pass	Pass
6	0.6	0.018	39.688	Pass	Pass	Pass	Pass	Pass
7	0.7	0.021	39.636	Pass	Pass	Pass	Pass	Pass
8	0.8	0.024	39.584	Pass	Pass	Pass	Pass	Pass
9	0.9	0.027 0.030	39.532 39.480	Pass Pass	Pass Pass	Pass Pass	Pass Pass	Pass Pass

Table 4.2: Stability test result of all the sample made

4.1 2 Stability Test Analysis

The main material used in this project, carbon nanotube (-OH CNT Nanoarmor) is a hydrophobic material. In order to obtain consistent and accurate results in the upcoming test, the nanofluid must be stable. However, as the material used is hydrophobic, a dispersant must be introduced. According to (Fendler, 2001), by using PVP as a surfactant, the Van der Waals forces between surfactant-coated nanoparticle will increase, thus would greatly reduce the particle agglomeration that causes the CNT to not be able to disperse evenly.

Sample 5 from Table 4.1 showed sedimentation after 96 hours, this means that there were not enough surfactant to coat the particles, hence after a period of time, the CNTs started to clog together due to gravity, hence forming sedimentation at the bottom of the sample. After increasing the CNT: PVP ratio from 0.2 to 0.3, the sample

was able to maintain stable even after 100 hours. This means that at a 100 hours test duration, the amount of PVP particle was sufficient to maintain the stability of the nanofluid, avoiding agglomeration of particles.

According to Table 4.2, all the sample were stable at the end of 100 hour. This means that there were enough PVP to coat the CNT particle which improved the overall Van der Waals forces and greatly reduce the agglomeration of CNT (Fendler, 2000).

4.2 THERMAL CONDUCTIVITY TEST

Thermal conductivity test was carried out after the stability test of the samples at different CNT concentration (0.1wt%, 0.2wt%, 0.3wt%, 0.4wt%, 0.5wt%, 0.6wt%, 0.7wt%, 0.8wt%, 0.9wt%, 1.0wt%). The test was carried out in three temperatures, which are 6 °C, 25 °C and 40 °C. To maintain the sample at desired temperature, a water bath is used.

4.2.1 Thermal Conductivity Test Result

Table 4.2 shows the average value of thermal conductivity of each sample collected at the different temperatures. A detail version of each reading can be found in Appendix C.

Sampla		Temperature	
Sample	6°C	25°C	40°C
Standard	0.5463	0.5789	0.5983
1	0.573	0.630	0.648
2	0.568	0.594	0.634
3	0.561	0.595	0.627
4	0.560	0.595	0.637
5	0.565	0.600	0.641
6	0.551	0.617	0.635
7	0.557	0.615	0.639
8	0.553	0.610	0.651
9	0.561	0.592	0.633
10	0.569	0.601	0.619

Table 4.3: Average thermal conductivity of each sample at 6°C, 25°C and 40°C



Figure 4.1: Graph of thermal conductivity of samples at 6 °C, 25 °C and 40 °C

The thermal conductivities of the sample can be seen to increase as the temperature rises as shown in Figure 4.1. At 6 °C, sample with 0.1wt% of CNT has the highest thermal conductivity at 0.573 W/m.K, followed by 1.0wt% CNT sample at

0.569 W/m.K and 0.2wt% CNT sample recording thermal conductivity of 0.568 W/m.K. At 25 °C, the sample with the highest thermal conductivity is still 0.1wt% at 0.630 W/m.K, then followed by 0.6wt% with thermal conductivity of 0.617 W/m.K and 0.7wt% with thermal conductivity of 0.615 W/m.K. However, at 40 °C, the sample that shows the highest thermal conductivity is 0.8wt%, at 0.651 W/m.K. Sample with the second highest thermal conductivity is 0.1wt% at 0.648 W/m.K and thirdly, 0.5wt% with thermal conductivity 0.641 W/m.K.

4.2.1.1 Thermal Conductivity at 6 °C

In order to identify samples with the highest enhancement, the samples are tabulated into graphs classified using the temperature in which the experiments were carried out in. The percentage of increment of each sample is calculated using Equation 4.1. A sample in calculation can be found at Appendix B.





Based on Figure 4.2, all the sample can be seen to have higher conductivity than the standard. Sample 0.1wt% has the highest thermal conductivity enhancement among all the sample, at 0.573 W/m.K, or a 4.89% enhancement. Sample 1.0wt% has a thermal conductivity of 0.569 W/m.K, 4.16% increment. Sample 0.2wt% came in third with 0.568W/m.K, scaling a 3.97% thermal conductivity enhancement.

4.2.1.2 Thermal Conductivity at 25 °C

Similarly, the results at 25 °C were tabulated into a graph for easier understanding. The graph is classified using the concentration of CNT in which the experiments were carried out in and the thermal conductivity results.



Figure 4.3: Graph of thermal conductivities of each samples at 25 °C with reference to deionized water as datum.

At 25 °C, all the sample experience thermal conductivity enhancement of at least 2.2%. Sample 0.1wt% has the greatest enhancement in term of thermal

conductivity, at 0.63 W/m.K, a total of 8.83% improvement. Sample 0.6wt% came in second at 0.617 W/m.K. In other words, 0.6wt% sample underwent an improvement of 6.58% from the standard. The sample that has the third highest enhancement is sample 0.7wt%, which has thermal conductivity of 0.615 W/m.K.

4.2.1.3 Thermal Conductivity at 40 °C

As the experiment proceed to 40 °C, the results were tabulated into a graph for easier understanding. The graph is classified using the concentration of CNT in which the experiments were carried out in and the thermal conductivity results



Figure 4.4: Graph of thermal conductivities of each sample at 40 °C with deionize water as standard

All the 10 samples has shown improved thermal conductivity at 40 °C. Sample 0.8wt% shows an improvement of 8.8% in thermal conductivity, reaching 0.651 W/m.K. Sample 0.1wt% shows second highest increment, at 0.648 W/m.K. Placed at third is sample 0.5wt%, at 0.641 W/m.K. sample 0.1wt% and 0.5wt% has an improvement of 8.3% and 4.14% respectively.

4.2.2 Thermal Conductivity Test Analysis

According to Figure 4.2, Figure 4.3 and Figure 4.4, the graph do not follow any specific trend or pattern. This made the analyzing of the data complicated. The only trend that could be made clear is that for all the sample, even for the standard, the thermal conductivity increases with the rise of temperature. Generally, there are several factors that has been identified that would affect the thermal conductivity of a nanofluid, they are basically the nanoparticle used, the concentration of nanoparticle and the operating temperature.

4.2.2.1 Effect of Temperature

The thermal conductivity of an object is carried out through the collision of particle, hence transferring the energy from one particle to another. At higher temperature, the rate of collision is higher as the particles move at a higher average velocity. These increased rate of random collision is known as Brownian motion. The Brownian motion will result in aggregation of particle which in turn would cause the occurrence of thermal conduction (*Li. 2009*). The phenomenon shown in Figure 4.1 is exactly similar with this finding as the reading shows increased thermal conductivity with increased temperature.

4.2.2.2 Effect of Nanoparticle

By introducing carbon nanotube with functionalized –O group from Nanoarmor into the base fluid, the thermal conductivity showed improvement. This is because the CNT particle works as extra particle that would transfer the energy in addition to the particle of the base fluid. However, the results in Figure 4.2, Figure 4.3 and Figure 4.4 shows total random improvement rate. This phenomenon is known as the anomalous enhancement. It was suggested that Brownian motion of nanoparticles would set off a convection-like effects by dragging the fluid, which enhance the thermal conductivity (*Jang, 2004*). Hence, it is believed that the Brownian motion of

particle, effect of nanoparticle clustering, the nature of heat transport in nanoparticle itself and the molecular level layering at the liquid-solid particle interface affects the thermal conductivity directly (*Keblinski*. 2002).

4.3 VISCOSITY TEST

Viscosity test was carried out after a 1 hour long ultrasonic process to remove the sedimentation of CNT. The viscosity test were carried at 6 °C, 25 °C and 40 °C for all the sample. A water bath was used to control the temperature of the samples.

4.3.1 Visocity Test Result

Table 4.4 shows the average viscosity of each sample at different temperatures. A detailed table of each reading for all ten samples at three different temperature can be found at Appendix C.

	verage viscosi	ity of samples at 6 °C, 25 °C	Cand Q.C				
Samula	Viscosity (cP)						
Sample	6 °C	25 °C	40 °C				
Standard	7.04	5.77	5.14				
1	7.13	9.48	8.73				
2	7.67	13.40	10.80				
3	7.97	13.60	12.90				
4	6.23	11.80	13.00				
5	7.19	9.87	12.10				
6	8.69	10.20	13.90				
7	7.13	10.10	12.80				
8	6.59	10.60	12.00				
9	6.56	11.10	12.40				
10	7.40	10.90	13.40				

 $1 \text{ cP} = 0.001 \text{ Pa} \cdot \text{s}$



Figure 4.5: Graph of viscosity of samples at 6 °C, 25 °C and 40 °C

Deionized water was used as datum for the experiment and it shows that the viscosity decreases as the temperature increases. However, all the samples has increased viscosity as the temperature increases as opposed to the standard which has lower viscosity as temperature rises. There are three samples with an exception of having lower viscosity at 40 °C than at 25 °C, which are sample 0.1wt%, 0.2wt% and 0.3wt%. Sample 0.1wt% has a viscosity of 9.48 cP at 25 °C but dropped to 8.73 cP at 40 °C. Sample 0.2 wt% recorded viscosity of 13.4 cP at 25 °C and 10.8 cP at 40 °C. Sample 0.3wt% at 25 °C has viscosity of 13.6 cP and dropped to 12.9 cP at 40 °C. Other than the three samples mentioned, the rest exhibit a trait of increasing viscosity as the temperature increases.

4.3.1.1 Viscosity vs Concentration (wt%) at 6 °C

Figure 4.6 shows the deviation of each sample from the datum made using deionized water.



Figure 4.6: The deviation of viscosity of each sample at 6 °C with reference to deionize water as datum

As solids are added into the base fluid, the viscosity of the solution is expected to increase and Figure 4.6 has shown that the samples with added CNT generally does have higher viscosity than the standard except for 3 samples, which are 0.4wt%, 0.8wt% and 0.9wt%. Sample with the highest increment in viscosity is 0.6 wt% with a viscosity of 8.69 cP. However, the sample with the least increment was tied between 0.1wt% and 0.7wt%, both at 7.13 cP, with an increment of 0.013% in viscosity.

4.3.1.2 Viscosity vs Concentration (wt%) at 25 °C

Similarly, the reading for 25 °C were tabulated into Graph 4.7 for better understanding of the results.



Figure 4.7: Deviation of viscosity of each samples from deionized water at 25 °C

At 25 °C, the reading indicates the viscosity of all the sample are higher than that of deionized water. Sample 0.1wt% has the lowest viscosity among all the sample at 25 °C, which is 9.48 cP. Sample of CNT concentration 0.5wt% has the second lowest increment in viscosity from the standard, which is 9.87 cP Sample that came in third place with the lowest increment in viscosity is 0.7wt%, with viscosity of 10.1 cP. In terms of percentage, 0.1wt% sample has an increment of 64.3%, 0.5wt% sample has an increment of 71.1% and sample 0.7wt% has an increment of 75% in viscosity with reference to the standard.

4.3.1.3 Viscosity vs Concentration (wt%) at 40°C

At 40 °C, all the reading were also tabulated into graph format as shown in Figure 4.8 for better understanding of the results.



Figure 4.8: Increment of viscosity of each sample at 40 °C with deionized water as standard

Similar to the reading at 25 °C, all the reading obtained at 40 °C shows increment in viscosity with reference to the standard. Sample that has the lowest increment is 0.1wt%, with viscosity level of 8.73 cP, or 69.8% increment from the standard. Sample 0.2wt% came in as the second lowest in increment at viscosity of 10.8 cP, an increase of 110% from the standard. The sample that ranked third in the least increment from standard is 0.8wt%, with viscosity level of 12 cP. In terms of

percentage, 0.8wt% has an increment of 133% from the datum.

4.3.2 Viscosity Test Analysis

The viscosity in a nanofluid is preferred to remain as low as possible as high viscosity means that the nanofluid would clog together easily and stick to the wall of the container, the pipe and all the parts that the nanofluid came in contact with. According to Figure 4.5, the base fluid (standard solution) has higher viscosity at low temperature and decreased viscosity at higher temperature. All the sample behave exactly opposite to the base fluid, having lower viscosity at low temperature and higher temperature.

4.3.2.1 Effect of Temperature on Viscosity

When a solution is being heated, the molecules that is inside the solution is given energy to move around. At excited state, the energy is high enough to cause movement that can overcome the Van de Waals forces and the hydrogen bond that bind the solution together. Overcoming the binding forces, the solution becomes more fluid like hence having lower viscosity. This is particularly true for the standard solution which uses deionized water.

4.3.2.2 Effect of Nanoparticle on Viscosity

As nanoparticles are being added to the base fluid, theoretically, the viscosity would increase due to the nanoparticle structuring (*Chen. 2008*) However, based on Figure 4.6, there were a total of 3 samples that has lower viscosity despite having nanoparticles added to the solution. The possible explanation would be that there were erfor when the experiment for those particular sample were carried out. Due to the limited resources available, the apparatus used for the viscosity test is a Brookfield DV-II+ Pro Viscometer with spindle SC4-18. The sensitivity of the spindle is only useful for range 1.5 cP to 30000 cP while the viscosity of water starts at 8 cP only. Hence it is possible that the readings were on the edge and not absolutely accurate.

Besides, while the standard solution shows viscosity that is inversely proportional to the temperature, all the sample shows increase in viscosity directly proportional to temperature rise. As the base fluid for all the samples are the same, it is highly possible that it is the characteristics of the nanoparticle that causes the viscosity to increase with temperature. Despite being unlikely, it is not impossible. Large excess of counter ions over cationic surfactant solution shows a fairly substantial increase in viscosity with temperature rise (*Gokul C. Kalur, 2005*). Hence according to Figure 4.5, it is likely that the use of PVP as surfactant in this project might promote the growth wormlike micelles which causes the viscosity to increase with temperature.

4.4 HEAT TRANSFER TEST

The heat transfer test were carried out in three different temperature using water bath as temperature controller. The temperature in which the experiment took place in are 6 °C, 25 °C and 40 °C. Three samples were chosen to run the heat transfer test based on the 3 highest thermal conductivity and 3 lowest viscosity at 6 °C, 25 °C and 40 °C. This is because generally an object with higher thermal conductivity has higher heat transfer rate while having low viscosity will reduce the burden placed on the pump used during the heat transfer test.

4.4.1 Heat Transfer Test Results

After considering all the factors, the three samples that was selected are 0.1wt%, 0.5wt% and 0.8wt%. In order to obtain a more accurate and consistent result, the reading are only taken into consideration after the third minute.

4.4.1.1 Heat Transfer at 6 °C

Each reading obtained during the experiment done in 6 °C were made into a table in order to obtain a clearing reading of the results.

Time	Standard		0.1 wt% CNT		0.5 wt%	% CNT	0.8 wt% CNT	
(min)	TIn	Tout	TIn	TOut	TIn	Tout	TIn	Tout
0	10.13	8.35	27.87	13.20	29.40	14.18	28.68	13.51
1	9.80	8.06	23.50	12.77	24.94	13.32	23.88	12.92
2	9.29	7.60	16.82	10.66	17.22	10.78	16.42	10.51
3	8.84	7.19	13.62	9.42	13.53	9.40	13.21	9.22
4	8.46	6.91	11.89	8.80	11.71	8.72	11.67	8.66
5	8.24	6.84	10.97	8.48	10.84	8.42	10.86	8.38

Table 4.5: The inlet and outlet temperature of three selected samples at 6 °C

Time	Standard	0.1 wt%	0.5 wt%	0.8 wt%
(min)				
0	-1.78	-14.67	-15.22	15.17
1	-1.74	-10.73	-11.62	-10.96
2	-1.69	-6.16	-6.44	-5.91
3	-1.65	-4.2	-4.13	-3.99
4	-1.55	-3.09	-2.99	-3.01
5	-1.4	-2.49	-2.42	-2.48

Table 4.6: Difference in temperature of selected samples at 6°C

Based on the Table 4.6, from the trend alone we can tell that the trend is the same for the three sample as well as the standard. At the third minute, 0.1wt% sample ranked the highest in temperature difference. Throughout the experiment at the fourth and fifth minute, although the gap difference in temperature reduces, 0.1wt% has the highest difference in temperature, a total of 9.78 °C in three minutes, with a total of 112.6% improvement compared to the standard.

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4.4.1.2 Heat Transfer at 25 °C

Each reading obtained during the experiment done in 25 °C were made into a table in order to obtain a clearing reading of the results. In the table, results that were negative in value were coloured in red while positive value are in black colour.

Time	Standard		0.1 wt% CNT		0.5 wt%	% CNT	0.8 wt% CNT	
(min)	TIn	Tout	TIn	Tout	TIn	Tout	TIn	Tout
0	28.42	25.81	22.46	25.24	21.95	25.09	21.96	25.06
1	27.83	25.72	23.14	25.13	23.06	25.02	22.80	25.01
2	26.66	25.46	24.90	25.76	25.13	25.87	24.96	25.81
3	26.10	25.32	25.75	26.11	25.98	26.21	25.86	26.17
4	25.81	25.23	26.17	26.28	26.36	26.36	26.21	26.30
5	25.65	25.20	26.40	26.36	26.51	26.41	26.44	26.38

Table 4.7: The inlet and outlet temperature flow at 25°C for heat transfer analysis

Time	Standard	0.1 wt%	0.5 wt%	0.8 wt%
(min)		∆Tempera	ature (°C)	
0	-2.61	2.78	3.14	3.1
1	-2.11	1.99	1.96	2.21
2	-1.2	0.86	0.74	0.85
3	-0.78	0.36	0.23	0.31
4	-0.58	0.11	0	0.09
5	-0.45	-0.04	-0.1	-0.06

Table 4.8: Difference in temperature of selected samples at 25 °C

From Table 4.8, it is clear that there are different trending of positive difference of temperature and negative difference of temperature. In order to analyze the data obtained, it was decided to ignore the negative sign of the values and use the absolute value. This would be further discussed in sub section 4.4.2.1.

At 25 °C, all of the samples has lower temperature difference than the standard. At the third minute, sample 0.1 wt% has only 0.36 °C difference while the sample has 0.78 °C changes in temperature. At the fourth minute, the standard has 0.58 °C changes while the sample 0.1 wt% has only 0.11 °C deviation. At the fifth minute, sample 0.5 wt% has a total of 0.1 °C change in temperature, however, the standard still have the higher temperature gap, at 0.45 °C. Overall, sample 0.1 wt% has a total changes of 0.51 °C, sample 0.5 wt% has a total change of 0.33 °C and sample 0.8 wt% has a total temperature changes of 0.46 °C while the standard recorded a total of 1.81 °C of

4.4.1.3 Heat Transfer at 40 °C

temperature changes.

Each reading obtained during the experiment done in 40 °C were made into a table in order to obtain a clearing reading of the results. As all the result in this chapter is positive, all the value are in black colour

Time	Standard		0.1 wt% CNT		0.5 wt%	% CNT	0.8 wt% CNT	
(min)	TIn	Tout	TIn	Tout	TIn	Tout	TIn	Tout
0	31.27	40.78	29.84	37.91	30.08	37.22	26.77	38.25
1	31.78	39.91	32.89	38.79	33.92	38.79	30.61	37.92
2	35.61	40.24	36.99	40.05	38.04	40.22	36.08	39.72
3	37.93	40.67	38.83	40.6	39.56	40.77	38.38	40.38
4	38.98	40.87	39.71	40.83	40.16	40.92	39.46	40.7
5	39.64	40.01	40.12	40.94	40.44	41	39.94	40.83

Table 4.9: The inlet and outlet temperature flow at 40°C for heat transfer analysis

Table 4.10: Difference in temperature of selected samples at 40 °C

Time	Standard	0.1 wt%	0.5 wt%	0.8 wt%
(min)		ΔTempera	ature (°C)	
0	9.51	8.07	7.14	11.48
1	8.13	5.9	4.87	7.31
	4.63	3.06 177 112		3.64 2 1.24
5	0.37	0.82	0.56	0.89

Based on Figure 4.11, at third minute, the standard has the highest changes in temperature at 2.74 °C, followed by sample 0.8wt% of 2 °C changes, 0.1wt% with 1.77 °C temperature changes and lastly 0.5wt% with 1.21 °C temperature change. At fourth minute, the ranking of temperature difference is still the same, datum at 2.74 °C, 0.8wt% at 1.24 °C, 0.1wt% at 1.12 °C and 0.5wt% at 0.76 °C. At fifth minute, sample 0.8wt% has the highest changes in temperature at 0.89 °C, followed by 0.1wt% with 0.82 °C temperature change, 0.5wt% with temperature change of 0.56 °C and the standard with 0.37 °C temperature difference.

Overall, at 40 °C, the standard still have the highest change in temperature, which is a total changes of 5 °C. The sample that came closest to the datum is 0.8wt% CNT, with a total of 4.13 °C, or -17.4% enhancement. Then followed by 0.1wt% CNT

with a total of 3.71 °C difference or -25.8% enhancement and lastly 0.5wt% with a total of 2.53 °C changes in temperature or -49.4% enhancement.

4.4.2 HEAT TRANSFER TEST ANALYSIS

The samples selected to undergo heat transfer test is based on high thermal conductivity test result and low viscosity test result. This is because generally, a solution with higher thermal conductivity would have a higher heat transfer coefficient. However, a solution with high viscosity would burden the pump used as the particles tend to clog together or stick to the wall or parts that it came in contact with as mentioned before in sub section 4.3.2. Hence three sample with the highest thermal conductivity and lowest viscosity were selected.



negative difference in temperature. However, in the calculation of heat transfer coefficient, the negative signs were ignored. This is because heat transfer is the transfer of heat from a location with higher temperature to another location with lower temperature. The temperature difference is calculated using the outlet temperature deducting the inlet temperature. At situations whereby the inlet temperature is higher than the outlet temperature, a negative value appeared. This simply means that the heat flows from the nanofluid to the surrounding. Having both positive value and negative value does not mean heat transfer does not occur but rather the heat flows in different direction. So, while calculating the total temperature difference, the negative sign is ignored.

4.4.2.2 Effect of Ultrasonication on Heat Transfer

Table 4.8 and Table 4.10 shows that all the heat transfer rate of the three selected samples at 25 °C and 40 °C are lower than the base fluid. At 6 °C, all the shows enhanced heat transfer rate compared to the base fluid. This is mostly caused by the sedimentation of CNT particle at nano-scale. All the samples underwent a 30 minutes long ultrasonication process before the heat transfer test at 6 °C. After that while the water bath and the sample returns back to room temperature, the samples did not underwent ultrasonication process again. The same situation happens at 40 °C as well. The long down time might be the main reason as to why the samples all have lower heat transfer rate than the base fluid at temperature other than 6 °C. The ultrasonication process, requires 40 minutes to reach the optimum effect, attributed to the breakup of CNT aggregates into smaller dimensions and eventually fully dispersed in the nanofluid (*Rad Sadri, 2014*). Without undergoing ultrasonication process, it is likely that the nanoparticle started sedimentation which resulted in the lower heat transfer



CHAPTER V

CONCLUSION AND RECOMMENDATION

5.0 CONCLUSION

In summary, the research proceeded rather smoothly despite a few bumps along the way. The production of nanofluid with improved thermal conductivity using MWCNT-OH and deionized water as base fluid with the use of PVP as dispersing agent was a success. It was found that the ideal ratio of CNT: PVP for optimum stability is 0.3. Authough having higher ratio of CNT: PVP does not decrease the stability, the ratio of 0.3 is sufficient for stability of 100 hours. In the aspect of thermal conductivity, the sample with 0.1wt% CNT has the highest range of improvement. Sample 0.1wt% CNT has an average improvement of 7.34% in all three temperature the experiment carried out in. As for viscosity, the ideal sample would be the one with the lowest increase in the viscosity. Again, the sample with the least increment in viscosity is sample with 0.1wt% CNT. The average increment of viscosity is 45.14% compared to the base fluid. For heat transfer test, sample 0.1wt% CNT has the highest heat transfer coefficient among all the three samples tested for temperature 6 °C and 25 °C. However at 40 °C, 0.8wt% CNT sample has the highest heat transfer ration. Overall, sample 0.1wt% CNT still has the highest heat transfer rate among the three sample. Combining the result from all the experiment, 0.1wt% CNT sample underwent the greatest thermal characteristic enhancement.

5.1 **RECOMMENDATION**

Throughout the research, there were a few hiccups on either procedure or equipment available. For future references on similar research, there are a few recommendation that I would like to suggest:

- i. For sample formulation process to find the ideal ingredient ratio, instead of dropping a few percent at a time, dropping the ratio by half would save more time and reduce the use of material in this procedure.
- ii. Before carrying out any experiment, carry out ultrasonication process of 1 hour long even if all the samples are to be tested on the same day. The experiment should only be carried out directly after ultrasonication process. This is to remove the possibility of aggregation of particle before the experiment took place.
- iii. For viscosity test, try acquiring a different viscometer meter model instead of using DV-II Pro+. The viscosity of water too near to the lower border range that can be detected by the model sensitivity and spindle sensitivity. Instead,



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APPENDIX A

APPENDIX B

Sample calculation of CNT: PVP ratio For ratio CNT: PVP = 0.1, At 0.1 wt% concentration of CNT at a 100 ml sample. CNT = 0.1 g PVP = 0.01 g Deionized Water = 100 g - 0.1 g - 0.01 g = 99.89 gConverting to 40 ml sample, divide all sample by 2.5, CNT = 0.04 g PVP = 0.004 gDeionized Water = 39.956 g

Sample Calculation of percentage of enhancement,

 $\frac{Sample Reading - Standard Reading}{x \ 100\%}$ *Percentage of Increment =* Standard reading Take reading of 0,1 wt% of Figure 4.2, 0.573 - 0.5463 *Percentage of Increment =* = 4.89% 0.5463

APPENDIX C

	wt%	6°C	average at 6°C	25°C	average at 25°C	40°C	average at 40°C	
		0.592		0.654		0.754		
	0.1	0.555	0.573	0.585	0.63	0.589	0.648	
		0.572		0.651		0.601		
		0.572		0.602		0.629		
	0.2	0.563	0.568	0.581	0.595	0.639	0.634	
		0.569		0.602		0.634		
		0.564		0.61		0.646		
	0.3	0.56	0.561	0.598	0.595	0.616	0.627	
		0.559		0.577		0.619		
		0.534		0.616		0.652		
	0.4	0.56	0.559	0.588	0.595	0.627	0.637	
		0.583		0.581		0.632		
	0.5	0.567	0.565	0.598	0.6	0.651	0.641	
		0.559		0.599		0.618		
$\overline{)}$		0.569	5	-0.603	$\approx \sqrt{2}$	-0-654		
	0.6	0.535	0.551	0.567	0,617	/0.613//	0.635	
		0.554		0.662		0.63/		
2 <u> </u>		0.564		0.622		0.655		
		0.554		0.619		0.651		
	0.7	0.562	0.557	0.606	0.615	0.627	0.638	
		0.555		0.62		0.636		
		0.476		0.616		0.658		
	0.8	0.576	0.553	0.603	0.61	0.644	0.651	
		0.607		0.611		0.651		
		0.558		0.605		0.596		
	0.9	0.561	0.561	0.582	0.592	0.659	0.633	
		0.564		0.589		0.644		
		0.557		0.584		0.617		
	1.0	0.563	0.569	0.611	0.601	0.619	0.619	
		0.587		0.608		0.621		

Detailed result of thermal conductivity test
APPENDIX D

Detail result of viscosity test

	wt%	6°C	average at 6°C	25°C	average at 25°C	40°C	average at 40°C	
	0.1	6.98	7.13	9.52	9.48	8.72	8.73	
		7.77		9.49		8.8		
		6.64		9.43		8.67		
	0.2	7.88	7.67	13.7	13.4	11.02	10.8	
		7.55		12.9		10.71		
		7.58		13.6		10.67		
	0.3	8.03	7.97	13.5	13.6	13.19	12.9	
		7.85		13.8		12.88		
		8.03		13.5		12.63		
	0.4	6.66	6.23	11.78	11.8	12.95	13	
		5.99		11.7		13.26		
		6.04		11.92		12.79		
	0.5	6.78	7.19	9.81	9.87	12.15	12.1	
		7.66		9.85		12.12		
		7.13		9.95		12.03		
	0.6	8.87	8.69	10.15	10.2	/13.87	13.9	
		8.75		10.07		14.06		
		8.45		10.38		13.75		
	0.7	7.45	7.13	10.07	10.1	12.82	12.8	
		7.05		10.16		12.72		
		6.89		10.07		12.86		
	0.8	6.69	6.59	10.66	10.6	11.91	12	
		6.62		10.54		11.98		
		6.46		10.6		12.11		
	0.9	6.51	6.56	11.23	11.1	12.43	12.4	
		6.61		11.12		12.39		
		6.56		10.95		12.38		
	1.0	7.29	7.4	10.83	10.9	13.47	13.4	
		7.6		11.03		13.33		
		7.31		10.84		13.4		