STABILITY AND THERMAL CHARACTERISTICS OF CARBON NANOFIBER (CNF) WATER-BASED NANOFLUIDS

NOR SALIHAH BINTI ZAINI

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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-Fluid) with Honours"

Signature: ....

Supervisor: IMRAN SYAKIR BIN MOHAMAD

Date: ....

DECLARATION

"I hereby, declare this project entitled
'Stability and Thermal Characteristics of Carbon Nanofiber (CNF) water based nanofluids' is the result of my own research except as cited in the reference".

Signature : ....
Authors name: NOR SALIHAH BINTI ZAINI
Date : ....

Special tribute to my beloved parents;

Zaini bin Ahmad Nawawi and Khairiah binti Mohd Nor,

Family and Friends.

ACKNOWLEDGEMENT

With the name of Allah, the Most Gracious and the Most Merciful, I am most grateful to Allah the Almighty who has given me strength, determination and patience to complete the final year project report. First of all, I would like to thank my family for giving words of encouragement to me in order to pursue my studies. I would like to express my special gratitude to Mr. Imran Syakir bin Mohamad as supervisor and Dr Norli binti Abdullah as co-supervisor for giving a very useful guidance to me regarding the nanofluid research, nanotechnology development, report writing guidelines and support in order to complete this report. Furthermore, I would like to thank my friends for giving me moral support in the completion of this report. Lastly, I would like to express my gratitude to Universiti Teknikal Malaysia Melaka (UTeM) for giving me chance to complete this report as one of the task to accomplish my degree in Bachelor of Mechanical Engineering specifically in Thermal-Fluid.

ABSTRACT

Carbon nanofiber (CNF) is one of the nanoparticles which have a superior thermal conductivity. However, the major problem when using CNFs is their stability and dispersion in nanofluids system. Agglomeration can lead to inaccurate and non-reproducible data. Hence, this experiment was conducted to study the stability, dispersion and thermal characteristics of Carbon Nanofiber (CNF) water-based nanofluids thus, identifying the most stable CNF water-based nanofluid formulation with enhanced performance. The experiment is conducted by setting the variable of weight percentage of CNF from 0.1 wt% to 1.0 wt% and the dispersing agent used is Polyvinylpyrrolidone (PVP). After conducting the stability test, then the experiment were proceed for the thermal properties test which includes thermal conductivity test, viscosity test and heat transfer test. The thermal properties test was conducted at 6 °C, 25 °C and 40 °C because those temperatures are the temperature applied in the chiller. From the results obtained, the optimum percentage for the formulation of the stable CNF water-based nanofluid was from 0.1 wt% of CNF with the 50% dispersing agent of CNF. The preliminary resulted shows that, the presence of dispersing agent completely stabilize the CNT water-based nanofluid. For thermal conductivity test, the results show an increment as the weight percentage of CNF increase and the trend is roughly similar with the heat transfer results. Apart of that, the viscosity test also recorded an increment in its value as the weight percentage values were added. The increment of thermal properties does give the pleasant effect on the nanofluid heat transfer application but the increment in viscosity will cause the flow resistance during the heat transfer process. Therefore, the most suitable ratio selected for this experiment is 0.7 wt% of CNF due to its enhanced performance in thermal properties and relatively low viscosity.

ABSTRAK

Karbon nanofiber (CNF) adalah salah satu daripada partikel nano yang mempunyai kekonduksian haba yang unggul. Walau bagaimanapun, masalah utama apabila menggunakan CNF adalah kestabilan dan penyebarannya dalam sistem bendalir nano yang boleh menyebabkan aglomerasi dan seterusnya menyebabkan ketidaktepatan data. Oleh itu, eksperimen ini dijalankan untuk mengkaji kestabilan, dispersi, dan ciri-ciri haba karbon nanofiber yang berasaskan air ternyahion dan seterusnya mengenal pasti rumusan yang paling stabil untuk bendalir nano CNF. Eksperimen ini dijalankan dengan menetapkan pembolehubah peratusan berat CNF dari 0.1 wt% hingga 1.0 wt% dan ajen pengurai yang digunakan adalah polivinilpirrolidon (PVP). Selepas menjalankan ujian kestabilan, eksperimen diteruskan dengan menguji sifat haba yang merangkumi ujian kekonduksian terma, ujian kelikatan dan ujian pemindahan haba. Ujian sifat haba telahpun dijalankan pada 6 °C, 25 °C dan 40 °C kerana suhu tersebut merupakan suhu yang digunakan untuk sistem penyejukan. Berdasarkan keputusan, peratusan optimum untuk pembentukan nanofluid berasaskan air ternyahion CNF yang stabil adalah dari 0.1 wt% CNF dengan ejen pengurai yang menggunakan 50% daripada peratusan CNF. Keputusan menunjukkan bahawa, kehadiran ejen pengurai menstabilkan bendalir nano CNF yang berasaskan air ternyahion. Keputusan ujian kekonduksian terma menunjukkan peningkatan selari dengan meningkatnya peratusan berat CNF dan trend itu adalah lebih kurang sama dengan keputusan pemindahan haba. Selain itu, ujian kelikatan juga mencatatkan kenaikan dengan bertambahnya nilai peratusan berat. Peningkatan daripada sifat haba memberikan kesan yang baik untuk proses pemindahan haba. Namun, kenaikan nilai kelikatan akan menyebabkan rintangan aliran semasa proses pemindahan haba. Oleh itu, nisbah yang paling sesuai untuk eksperimen ini adalah 0.7 wt% CNF disebabkan oleh ciri-ciri haba yang mengagumkan dan tahap kelikatan yang rendah.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

1.0 BACKGROUND

Nanofluids are dilute liquid suspensions contain nanometer-sized particles that have the dimension within 1-100 nanometers. This fluid has been engineered in order to enhance the thermophysical properties in a particular system. Thermophysical properties include thermal conductivity, thermal diffusivity, viscosity, and convective heat transfer coefficients. They are the main properties to be considered in industries nowadays since it is widely used for cooling process in engineering application. Basically the formation of nanofluid begins by the addition of nanomaterial to a based fluid like water, or oil. Carbon nanofiber (CNF) is type of nanomaterial that have excellent mechanical properties, high electrical conductivity and high thermal conductivity, which can be imparted to a wide range of matrices including thermoplastics, thermosets, elastomers, ceramics, and metals. The addition of CNF inside the based fluid will form the carbon nanofluid. However the selection of based fluid is varies and from the previous studies, water is one of the best based-fluid used in the formation of nanofluid.

Nanofluids have novel properties that make them potentially useful in many applications in heat transfer, including microelectronics, fuel cells, pharmaceutical processes, domestic refrigerator, chiller and heat exchanger. Nanofluids for industrial cooling could result in great energy savings and resulting emissions reductions (Routbort *et al.* 2008). Other than that, (Donzelli *et al.* 2009) stated that nanofluids can be used as a smart material working as a heat valve to control the flow of heat.

1.1 PROBLEM STATEMENT

Nanoparticles such as carbon nanofibers (CNF) can have superior thermal conductivity compared to other element such as aluminium oxide and titanium oxide. The addition of CNFs to a fluid could improve the heat transfer properties. However, the major problem when using CNFs is their stability and dispersion in nanofluids system. Agglomeration can lead to inaccurate and non-reproducible data. Therefore, it is important to conduct experiment to find the best method to overcome this problem.

1.2 OBJECTIVES

The objectives of the study are:

i. To study the stability, dispersion and thermal characteristics of Carbon Nanofibers (CNF) water-based nanofluids.
ii. To identify the most stable CNF Water-based nanofluid formulation with enhanced performance

1.3 SCOPE OF STUDY

The scopes of work are as shown;

i. Formulation of nanofluids which consists the mixture of Carbon Nanofibers (HHT-24), Polyvinylpyrrolidone (PVP) and deionized water.
ii. Identification of the optimum ratio of CNF, PVP and deionized water in order to achieve stability.
iii. Investigation of carbon nanofluids thermal characteristics by conducting the viscosity testing, thermal conductivity and heat transfer testing.

CHAPTER II

LITERATURE REVIEW

2.0 INTRODUCTION

Nanofluid is a fluid containing nanometer-sized colloidal particles with size typically within 1-100 nanometer suspended in liquid-based. The nanofluid is a liquid suspension of nano-meter sized solid particles and fibres (Cahill *et al.* 2005). The nanoparticles or nanomaterial used in nanofluids are usually made of oxides, carbides, carbon nanotubes or metal. Recently, nanofluid has attracted great interest among the researcher due to its significant enhanced in thermal properties at modest nanoparticle concentrations and many potential applications. The usage of conventional heat transfer fluid does not achieve the satisfied capability on heat transferring process due to it poor heat transfer properties. Thus, the discovery of nanofluid had improved the heat transfer capabilities of conventional heat transfer fluids. According to Özerinç (2012), nanofluids containing a small amount of metallic or nonmetallic particles, such as Al_2O_3, CuO, Cu, SiO_2, TiO_2, have increased thermal conductivity compared with the thermal conductivity of the base fluid. Choi (1995) reported that the nanofluids were proved to have high thermal conductivities compared to those of currently used heat transfer fluids, and leading to enhancement of heat transfer. Large surface area in nanoparticle causing the heat transfer process is much more efficient compared to microparticle. Better dispersion conduct attained where there is less stopping up and bigger add up to surface region (Yang *et al.* 2005).

2.1 NANOFLUID PREPARATION

Preparation of nanofluid is the crucial step in experimental studies of the nanofluid stability. The correct step should be considered since it affects the result on nanofluid studies. The primary step in nanofluid preparation involves single-step preparation process and two-step preparation process.

2.1.1 Single-Step Preparation Process

The single-step preparation process indicates the synthesis of nanofluids in one-step (Mukherjee *et al.* 2013). Several single-step methods have been performed for nanofluid preparation. The single-step process consists of simultaneously making and dispersing the particles in the fluid. In this method, the processes of drying, storage, transportation and dispersion of nanoparticles are avoided, so the agglomeration of nanoparticles is minimized and the stability of fluids is increased (Yanjiao *et al.* 2009). Akoh *et al.* (1978) have developed a one-step direct evaporation process while Zhu *et al.* (2004) have developed the single step chemical process. Single step direct evaporation methods have its own limitation where the process of separating nanoparticles form fluids is quite complex. Due to that, Eastman *et al.* (1997) reengineered the existed direct evaporation process technique, in which Cu vapor is directly condensed into nanoparticles by contact with flowing low vapor-pressure ethylene glycol. Zhu *et al.* (2004) proposed a single-step chemical process for the preparation of Cu nanofluids by reducing $CuSO_4.5H_2O$ with $NaH_2PO_2.H_2O$ in ethylene glycol under microwave irradiation. The influences of $CuSO_4$ concentration with the addition of NaH_2PO_2, together with the microwave irradiation on the reaction rate and the properties of Cu nanofluids were investigated by various methods which includes transmission electron microscopy, sedimentation measurements and infrared analysis. A benefit of one-step synthesis method is that nanoparticle agglomeration can be reduced. But the main problem is that not all the fluids are compatible with this process since it is only applicable for low vapor pressure fluid. Otherwise the cost required to develop this method is higher compared to two-step method. The Figure 2.1 shows the graphic of one step preparation process.

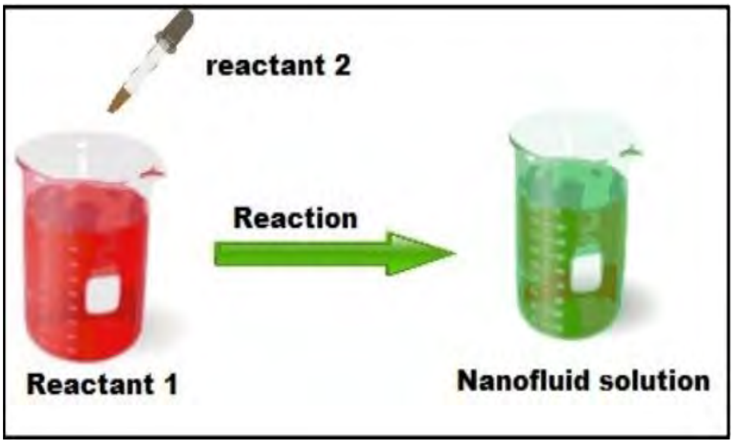


Figure 2.1: One-step preparation chemical process
(Source : Mukherjee *et al*. 2013)

2.1.2 Two Step Preparation Process

This type of nanofluid preparation is frequently and widely used by the researchers. Nanomaterial used in this method is early produced as dry powders by chemical or physical method (Yu & Xie, 2012). With the help of intensive magnetic force agitation, ultrasonic agitation, and homogenizing, the nanoparticle will be dispersed into a based fluid. An ultrasonic vibrator is generally used to agitate nanopowders with based-fluids. The agglomeration of particle will reduce if this device is used frequently. Two-step method is the most economic method to produce nanofluids in large scale; because nanopowder synthesis techniques have already been scaled up to industrial production levels (Yu *et al*. 2012). Due to the high surface area and surface activity, nanoparticles have the tendency to aggregate. The important method to improve the stability of nanoparticles in fluids is the use of depressant. However, the functionality of the depressant under high temperature is also a huge concern, predominantly for high-temperature applications. The surface tension and bubble size decreased as the temperature increased (Sharma *et al*. 1985). The Figure 2.2 shows the graphic of two step preparation method.

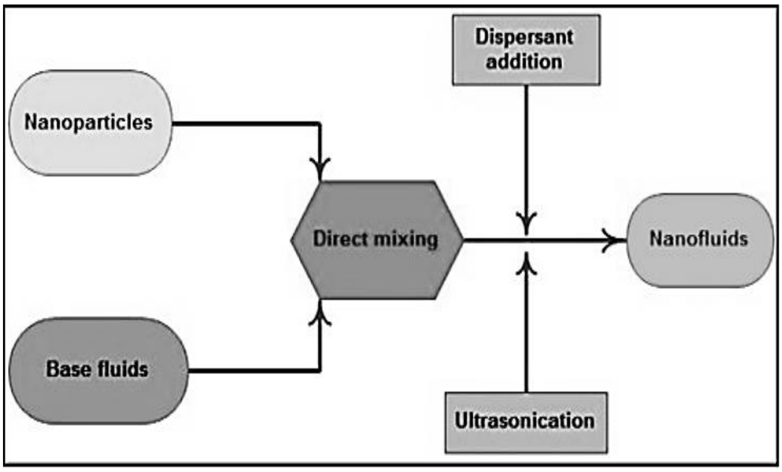


Figure 2.2: Two-step preparation process
(Source : Mukherjee *et al.* 2013)

2.2 NANOFLUID APPLICATION

There are many applications of nanofluid that has been used recently. These include the usage in industry, fuel application, power plant as well as medication. Its pleasant function in heat transfer application had caught the attention of the recent technologist and industrialist to broaden it usage and application on the other sector in the future. Other than that, the discovery of nanofluid also provides the contribution for the world sustainability.

2.2.1 Heat Transfer Application

The increases in effective thermal conductivity are important to enhance the heat transfer of fluids (Shivasanmugam, 2012). A number of other variables like viscosity, heat transfer capacity and several other variables also play key roles. Xuan and Li (2003) built an experimental rig to study the flow and convective heat transfer feature of the nanofluid flowing in a tube. They investigated convective heat transfer feature and flow performance of Cu-water nanofluids for the turbulent flow. The suspended nanoparticles do enhance heat transfer process and the nanofluid has larger heat transfer coefficient than the original base liquid under the same Reynolds number. Farajollahi *et al*. (2010), conduct a research on heat transfer of nanofluids in a shell and tube heat exchanger under turbulent flow condition. From the result obtained, adding of nanoparticles to the base fluid causes the significance enhancement of heat transfer properties. For the other types of heat exchanger, Huminic (2011) run a three-dimensional analysis to study the heat transfer characteristics of a double-tube helical heat exchanger using nanofluids in laminar flow condition. The result obtained shows the enhancement of heat transfer rate of the nanofluid approximately about 14% greater than of pure water at the same mass flow rate in inner tube and annulus. While the heat transfer rate of water from annulus than through the inner tube flowing nanofluids was approximately 19% greater than for the case which through the inner and outer tubes flow meter.

2.2.2 Nuclear Reactors

Kim et al. (2007) do the research to determine the feasibility of nanofluids in nuclear applications by improving the performance of any water-cooled nuclear system that is heat removal limited. Possible applications include pressurized water reactor (PWR) primary coolant, standby safety systems and so forth. The using of nanofluids instead of conventional liquid based causes one of the components in PWR that is fuel rods become coated with nanoparticles such as alumina, which prevent any formation of bubbles and finally result in the elimination of a layer of vapor around the rod. The use of nanofluids as a coolant could also be used in emergency cooling systems, where they could cool down overheat surfaces more quickly leading to an improvement in power plant safety (Wong & Leon, 2010). The use of nanofluids in nuclear power plants seems like a potential future application (J. Boungiorno *et al.* 2007).

2.2.3 Cancer Therapeutics

The application of nanofluid also needed in medical sector. There is a new alternative which takes advantage of several properties of certain nanofluids to use in cancer imaging and drug delivery. This alternative includes the use of iron-based nanoparticles as delivery vehicles for drugs or radiation in cancer patients. According to J. Boungiorno (2007), magnetic nanofluids are to be used to guide the particles up the bloodstream to a tumor with magnets. It will allow medical officers to apply high local doses of drugs or radiation without damaging nearby healthy tissue.

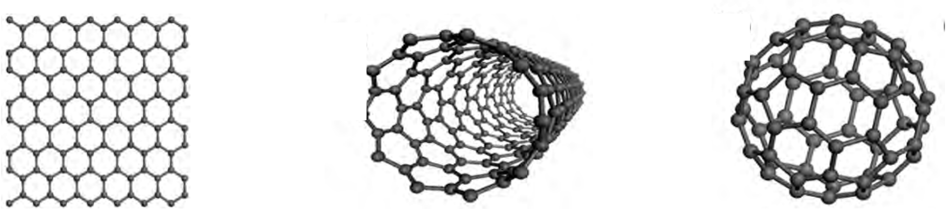
2.2.4 Automobiles

The nanofluid applications for automobiles are enormously wide. The applications involves are coolant, fuel additives, lubrication, shock absorber and brake fluids. Cooling process is very important in automotive sector because it directly related to engine performance. However the bulky size of the conventional radiator causes the rapid dissipation of heat to the surrounding otherwise, it requires some investment due to the complex manufacturing and the cost to consider the amount of material used. According to Mishra *et al.* (2011) high heat dissipation results in larger radiators and increase frontal areas leading to additional viscous drag and rise in engine fuel consumption. According to the statement, it clearly explained that the systems in automotives crucially need an efficient coolant to remove more engine heat from higher horsepower engines with a relatively small radiator. By the existence of nanofluid, this issue can be solved due to their large surface area that enhances the rate of heat transfer process in the radiator. Moreover, the size of the radiator can be much smaller than the conventional one and this created the flexibility for the movement of automotive vehicle.

2.3 NANOMATERIALS

Nanomaterials is the structured component where the size is at least one dimension less than 100 nm (Cristina *et al.* 2007). There are several nanomaterial structure such as graphene and nanotubes. Materials that have one dimension in the nanoscale (and are extended in the other two dimensions) are layers, such as graphene, thin films or surface coatings. Some of the features on computer chips come in this category. Materials that are nanoscale in two dimensions (and extended in one dimension) include nanowires and nanotubes.

Based on Agency (2013), there are commonly four types of currently used nanomaterial such as carbon based materials, metal based materials, dendrites and composite. Carbon based material shape have the long hollow shape which consists mainly of carbon. Most carbon based material taking the form of a hollow spheres, tubes, or ellipsoid. Spherical and ellipsoidal carbon nanomaterials are known as fullerenes, while cylindrical tubes form is called carbon nanotubes (Azo, 2013). Figure 2.3 shows the several structures of carbon based material.



(a) Graphene (b) Carbon Nanotubes (c) Fullerenes

Figure 2.3 : Several structures of carbon-based material.
(Source: Lulu *et al.* 2014)

2.3.1 Carbon Nanotubes

Carbon Nanotubes (CNTs) are long cylinders of covalently bonded carbon atoms which possess extraordinary electronic and mechanical properties (Choudhary & Gupta, 2011). There are two basic types of CNTs those are single-wall carbon nanotubes (SWCNTs) and multi-wall carbon nanotubes (MWCNTs) as shown in Figure 2.4. SWCNTs are the fundamental cylindrical structures while multi-wall carbon nanotubes is a multiple layer of SWCNTs. Carbon nanotubes are tiny little microscopic-sized tubes made of sheets of carbon atoms, rolled up into a tube like a paper towel roll. One roll is a single walled carbon nanotube and a few rolls will make a MWCNT (Sass, 2014). According to Choundary et al. (2011), MWCNTs are made of coaxial cylinders and having interlayered spacing close to that of the interlayer distance in graphite about 0.34 nm.

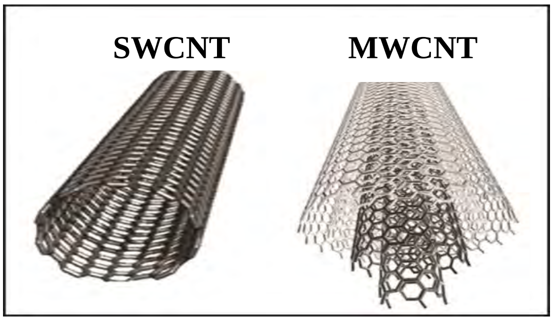


Figure 2.4: Graphical Structures of SWCNT and MWCNT

(Source: Choudhary & Gupta, 2011)

2.3.2 Carbon Nanofiber

Carbon Nanofibers (CNFs) is a novel carbon nanomaterial where the structure of graphene sheets are stacking in varying shape which then producing more edges sites on the outer wall of CNFs. The CNFs edges sites is more compared to CNTs edges sites. According to Huang *et al.* (2010) this advantage can facilitate the electron transfer of electroactive analytes. Carbon nanofibers (CNFs) have the similar conductivity and stability to carbon nanotubes (CNTs) however the primary differences between the materials are morphology, size, ease of processing and costs. Carbon nanofibers, also known as Stacked-Cup Carbon Nanotubes (SCCNT) have a unique morphology in that graphene planes are canted from the fiber axis, resulting in exposed edge planes on the interior and exterior surfaces of the fiber (Choundary *et al.* 2011). In other words, Stacked-Cup Carbon Nanotubes is morphological structures of Carbon Nanofibers. The Figure 2.5 illustrates the difference in CNF and CNT morphology.

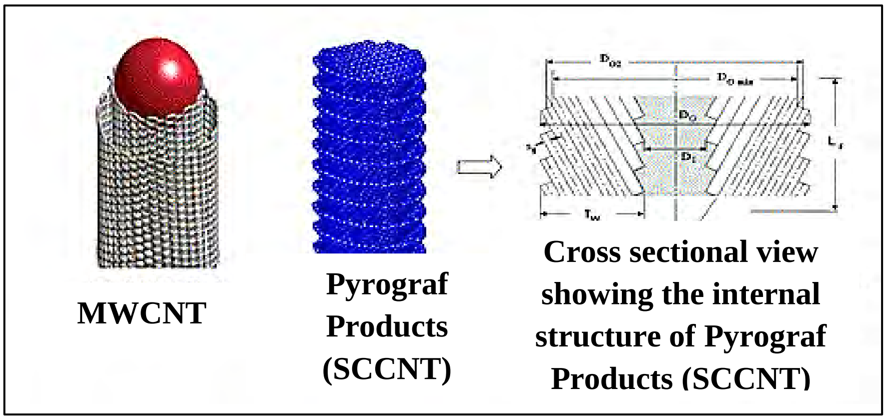


Figure 2.5: Morphology of Carbon Nanotube

(Source : Choundary *et al.* 2011)