THERMAL PROPERTIES AND HEAT TRANSFER STUDY OF DISPERSED FLUID WITH FUNCTIONALIZED MULTIWALLED CARBON NANOTUBE PARTICLES

FATIN NABILAHHUDA BINTI ZAHARI

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

Fakulti Kejuruteraan Mekanikal
Universiti Teknikal Malaysia Melaka

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SUPERVISOR DECLARATION

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

Signature : ....

Supervisor : IMRAN SYAKIR BIN MOHAMAD

Date : ....

DECLARATION

"I hereby declare that the work in this thesis is my own except for summaries and quotations which have been duly acknowledged"

Signature : ....

Author : FATIN NABILAHHUDA BINTI ZAHARI

Date : ....

This thesis was completed in dedication to both my beloved parents, Zahari bin Abu Bakar and Zaliha binti Abdul Rahman, siblings and also my friends.

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ABSTRACT

Nanofluids are gaining attention from industry as one way to improve the cooling processes because they have great characteristics in their thermal properties especially in thermal conductivity. The aim of this thesis is to form the stable nanofluids and study its thermal properties and heat transfer rate. This thesis was proposed due to the several problems in practical application of cooling agents especially in thermal properties and heat transfer rate. For this particular experiment, the nanoparticle that being used is functionalized Multi-walled Carbon Nanotube (fMWCNT). The stability of MWCNT in fluids was increased by introducing the hydroxyl groups towards its surface. Surfactant such as Polyvinylpyrrolidone (PVP) was used with deionized water as base fluid can make the nanofluids become more stable. Samples with different weight percentage (wt%) of fMWCNT and PVP was formulated to find a suitable ratio besides to analyze the thermal properties and heat transfer performance. The formulation of the nanofluids planning of the weight percentage and synthesizing of the samples (0.1 wt% - 1.0 wt%) was tested at different temperatures which is 6 °C, 25 °C and 40 °C. The performance improvement of nanofluids was compared with standard performance of deionized water in terms of thermal conductivity, viscosity and heat transfer performance. The highest enhancements of thermal conductivity of the nanofluids was succesfully recorded at 32.59% (0.7 wt% of CNT) at 40 °C while the highest enhancements of heat transfer coefficient is at 148.05% (0.5 wt% of CNT) at the temperature of 40 °C. It is determined that the 0.3 wt% of CNT exhibits the greatest improvement from the standard deionized water in terms of thermal conductivity and heat transfer coefficient. Unfortunately, 0.6 wt% and 0.7 wt% of CNT were not chosen because those samples have reduction in thermal conductivity at 6 °C and 25 °C. So they are not practical and not flexible to be applied at various temperatures.

ABSTRAK

Bendalir nano semakin mendapat perhatian daripada industri sebagai suatu penambahbaikan dalam proses penyejukan cecair kerana mereka mempunyai ciri-ciri yang bagus dalam sifat termal. Tujuan utama kajian ini adalah untuk menghasilkan bendalir nano yang stabil untuk dikaji sifat termalnya serta kadar pemindahan habanya. Eksperimen ini dicadangkan kerana terdapat beberapa masalah di dalam aplikasi praktikal bahan penyejuk ini terutamanya dalam sifat termal dan kadar pemindahan habanya. Untuk eksperimen ini, partikel nano yang digunakan adalah Tiub Nano Karbon Berbilang Dinding yang berfungsi (fMWCNT). Kestabilan MWCNT di dalam cecair meningkat dengan memperkenalkan kumpulan fungsian hidroksil terhadap permukaannya. Surfaktan seperti Polivinilpirrolidon (PVP) digunakan bersama air ternyah ion sebagai bendalir asas dapat membuatkan bendalir nano menjadi lebih stabil. Sampel yang terdiri daripada pelbagai peratusan berat (wt%) fMWCNT dan PVP telah dirumus untuk mencari nisbah yg sesuai disamping untuk mengkaji sifat termal dan prestasi pemindahan habanya. Penghasilan bendalir nano yang melibatkan perancangan peratusan berat dan mensintesiskan sampel (0.1 wt% - 1.0 wt%) telah diuji di berlainan suhu iaitu 6 °C, 25 °C dan 40 °C. Peningkatan prestasi bendalir nano akan dibandingkan dengan prestasi piawai air ternyahion dari segi kekonduksian termal, kelikatan dan prestasi pemindahan haba. Peningkatan terbanyak bagi kekonduksian termal bendalir nano yang berjaya direkodkan adalah sebanyak 32.59% (0.7 wt% dari CNT) pada 40 °C manakala peningkatan terbanyak untuk pekali pemindahan haba adalah sebanyak 148.05% (0.5 wt% dari CNT) pada suhu 40 °C. Ini menentukan bahawa 0.3 wt% dari CNT menunjukkan peningkatan yang lebih daripada piawai air ternyahion dari segi kekonduksian termal dan pekali pemindahan haba. Malangnya, 0.6 wt% dan 0.7 wt% dari CNT tidak akan terpilih kerana sampel tersebut menunjukkan pengurangan dalam kekonduksian termal pada suhu 6 °C dan 25 °C. Jadi, sampel tersebut adalah tidak praktikal dan tidak fleksibel untuk digunakan pada suhu yang pelbagai.

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CHAPTER I

INTRODUCTION

1.0 INTRODUCTION

The twenty first century is an era of technological development and has already seen many changes in almost every industry. Carbon Nanotube (CNT) is an example of nanotechnology. We call it „nano" because their sizes are less than 100 nm in diameter and can be as thin as one or two nm. They are molecules that can be manipulated chemically and physically in very useful ways. They open an incredible range of applications in material science, electronics, chemical processing, energy management and many other fields. Some properties include extraordinary electrical conductivity, heat conductivity, and mechanical properties, they are probably the best electron field-emitter due to their high length-to-diameter ratios and last but not least, as pure carbon polymers, they can be manipulated using the well known and the tremendously rich chemistry of that element. Some of those properties provide opportunity to modify their structure and to optimize their solubility and dispersion. Besides that, CNT also have a range of electrical, thermal and structural properties that can change based on the physical design of nanotubes.

Nanoparticles of CNT can be mixed together with the base fluids such as water, engine oil and ethylene glycol (EG) to perform as transport fluid for various scientific and engineering applications also known as nanofluids. Nanofluids have some uncommon features those make them very special in engineering applications. The size of the nanoparticles imparts some unique characteristics to base fluids including greatly enhanced energy, momentum and mass transfer as well as reduced tendency for sedimentation and erosion of the containing surfaces. Nanofluids are being investigated for numerous applications including transportation, cooling, manufacturing, chemical and pharmaceutical processes, medical treatments, cosmetics and many more.

1.1 PROBLEM STATEMENT

Some applications of nanofluids are to improve heat transfer and energy efficiency in several areas such vehicular cooling and power generation. Many great phenomena involving nanofluids have been reported and mostly the researchers give more attention to the thermal conductivity and the heat transfer characteristics. The Multi-walled Carbon Nanotube (MWCNT) based nanofluids have hydrophobic surface area. A feature of such materials is instability of thin wetting water layers on their surfaces. To get better stability and thermal conductivity, the PVP surfactant need to add together with MWCNT based nanofluids. But the problem is when in static condition and there is PVP surfactant in that nanofluids, presence of hydrophobic solvent will affects the surfactant self-arrangement and results in porous microstructures. So, some of functional group such as OH (hydroxyl group) and COOH (carboxyl group) are needed in MWCNT surface area to prevent the surfactant self-arrangement from occur. Besides that, the surface functionalization of MWCNT also plays an essential role for improving the solubility and dispersion of the nanotubes in aqueous solutions. So, this research will focused on how functionalized MWCNT improve their practical application especially in their thermal properties and heat transfer rate.

1.2 OBJECTIVES

The objectives of this research are

i. To prepare nanofluids consists of functionalized MWCNT in water-based fluids with addition of surfactant.
ii. To identify the most stable and homogeneous nanofluids with different weight percentage (wt%) of nanoparticles.
iii. To investigate the thermal properties of nanofluids such thermal conductivity and viscosity.
iv. To study the heat transfer properties of the stable nanofluids.

1.3 SCOPE OF RESEARCH

i. To prepare the formulation of the nanofluids sample which is consists of functionalized MWCNT, PVP (polyvinylpyrrolidone) as surfactant and deionized water (DI) as water-based fluids.
ii. To identify the stability and homogeneity of the nanofluids using physical approach such as homogenizing and ultrasonication process.
iii. To analyzed the efficiency of functionalized MWCNT dispersed inside the base fluid without any sedimentation formation with addition of different PVP weight percentage.
iv. To undergo the thermal properties testing such as thermal conductivity test and viscosity test towards the nanofluids and also heat transfer testing to the best three of nanofluids samples.
v. To conduct all the testing at three different temperature which is 6 °C, 25 °C and 40 °C.

CHAPTER II

LITERATURE REVIEW

2.0 INTRODUCTION

Heat transfer plays major role in many fields of industry such as transportation, air conditioning, power generation, electronic and others. Moreover, high performance cooling is widely needed in industrial technologies. Due to this fact, various studies and researches are aimed to increase cooling performance of working fluids. Nanofluids have drawn vast attention due to recently claimed high performance in heat transfer in the literature. In heat transfer, one of the major parameters is thermal conductivity of working fluid. Currently, most prevailing fluids utilized for cooling are water, ethylene glycol (EG) and engine oil which have much lower thermal conductivity. This fact was starting point of an idea which was creating mixture of solid and fluid in order to improve the thermal conductivity of fluid and to have better heat transfer performance consequently.

2.1 HISTORY AND DEVELOPMENT OF NANOFLUIDS

The twenty first century is an era of technological development and has already seen many changes in almost every industry. The introduction of nanoscience and technology is based on the famous phrase "There‟s Plenty of Room at the bottom" by the Nobel Prize winning physicist Richard Feynman in 1959. Feynman proposed the concept of micromachines. He also made his famous waver challenging the young scientist to make a working motor no more than 1/64 of an inch on all sides (Sreelakshmy *et al.* 2014). In 1974, Scientist Norio Taniguchi first used the term „Nanotechnology". After that, in 1995, Scientist Choi of Argonne Laboratory (USA) successfully prepared nanofluid (Mukherjee and Paria, 2013). The term nanotechnology was used by Drexler in 1986 book "Engines of creation : The coming era of nanotechnology". Drexlers idea of nanotechnology is referred to as molecular nanotechnology (Sreelakshmy *et al.* 2014). After the establishment of such a landmark in the history of nanoscience, nanofluids grab the attention of the most of the researchers around the world. In recent years the craze about nanofluid research has gone to such a hype that in the year 2011 with nearly 700 research papers where the term nanofluid was used showing the rapidly growth from 2002 until 2010 as shown in Figure 2.1.

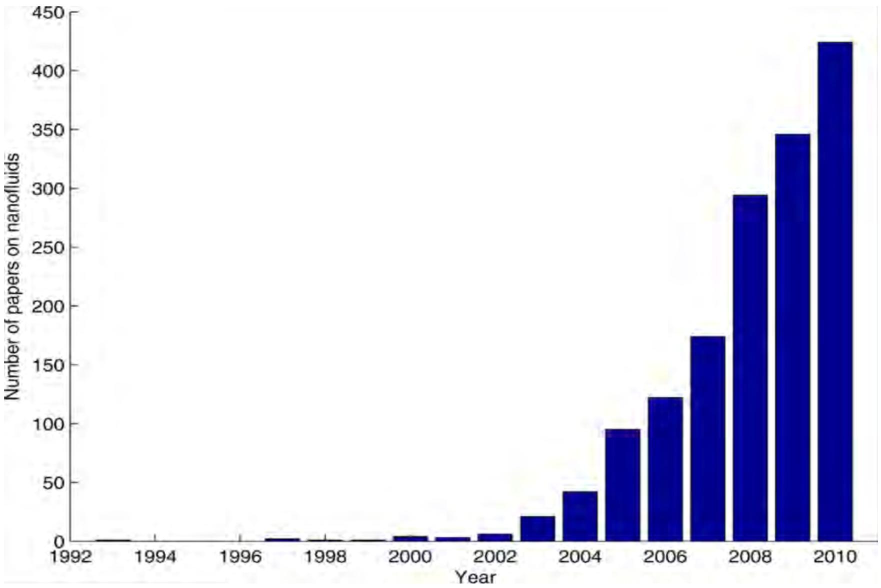

Figure 2.1 : Year wise research papers on nanofluids

(Source : Sreelakshmy *et al.* 2014)

2.2 ABOUT NANOFLUIDS

Heat transfer plays major role in many fields of industry such as transportation, air conditioning, power generation, electronic and so on. Moreover, high performance cooling is widely needed in industrial technologies. Due to this fact, various studies and researchers are aimed to increase cooling performance of working fluids. Nanofluids are defined as suspended nanoparticles with the size of 1 to 100 nm inside fluids, have drawn vast attention due to recently claimed high performance in heat transfer. It also defined as colloidal suspension of solid particles with the size of less than 100 nm and the solid particles concentration of lower than 5 vol%. In heat transfer, one of major parameters is thermal conductivity of working fluid. Currently, most prevailing fluids utilized for cooling are water, EG and engine oil which have much lower thermal conductivity compared to lots of solids including metallic ones; such as silver, copper and iron or non-metallic materials; like alumina, CuO, SiC and CNTs. This fact was starting point of an idea, which was creating mixture of solid and fluid in order to improve thermal conductivity of fluid and to have better heat transfer performance consequently (Ozerine *et al*. 2010).

Maxwell was the first one who initiated the use of small sized solid particles inside fluids to increase thermal conductivity. His idea was based on suspension of micro- or milli-sized solid particles inside the fluids on that time (Maxwell, 1873). However, large size of particles in scale of milli- or even micro-sized particles causes several technical problems such as faster settling time, clogging micro-channels of devices, abrasion of the surface, erosion of pipelines and increasing pressure drop (Wang *et al*. 2003). The importance of nano-sized particles and their benefits compared to micro-sized particles has been investigated and it could be stated that nanoparticles possess longer suspension time (more stable), much higher surface area, higher thermal conductivity, lower erosion and clogging, lower demand for pumping power, reduction in inventory of heat transfer fluid and significant for energy saving (Sarit *et al.* 2008).

Higher performance of heat transfer, in both conduction and convection heat transfer modes, was reported by several researchers afterward. Increment in thermal conductivity of fluid was one of the first features investigated by Eastman *et al.* (2001). They observed 40% increment of thermal conductivity after adding 0.3 wt% of copper nanoparticles into EG. Moreover, convection heat transfer of nanofluids was also investigated by different researchers and based on that, significant improvement was reported in heat transfer rate. From heat transport point of view, various results with great disparities have been reported in recent years. For instance, it has been claimed that improving thermal transport properties of nanofluids would have several advantages such as improving the efficiency of heat exchanging, reducing size of the system, providing much greater safety margins and reducing costs (Han 2008).

2.3 NANOFLUIDS SUSPENSION

Nanofluids are not simply liquid-solid mixtures. Some special requirements are essential such as even and stable suspension, durable suspension, negligible agglomeration of particles, no chemical change of the fluid and so on. As shown in Figure 2.2, nanofluids are produced by dispersing nanometer-scale solid particles with a typical size less than 100 nm (Ghadimi *et al*. 2011) such as Al_2O_3, CuO, SiO_2, CNT and others into base fluids such as distilled water (DW), deionized water, EG and engine oils. Besides that, nanofluids also can be added with surfactant. Addition of surfactant can improve the stability of nanoparticles in aqueous suspensions. Popular surfactants that have been used in literature can be listed as sodium dodecylsulfate (SDS), sodium dodecylbenzene sulfonate (SDBS), salt and oleic acid and PVP. But this technique cannot be applicable for nanofluids working in high temperature on account of probable damage of bonding between surfactant and nanoparticle, causing hindrance to stability of nanofluids (Mishra *et al*. 2013).

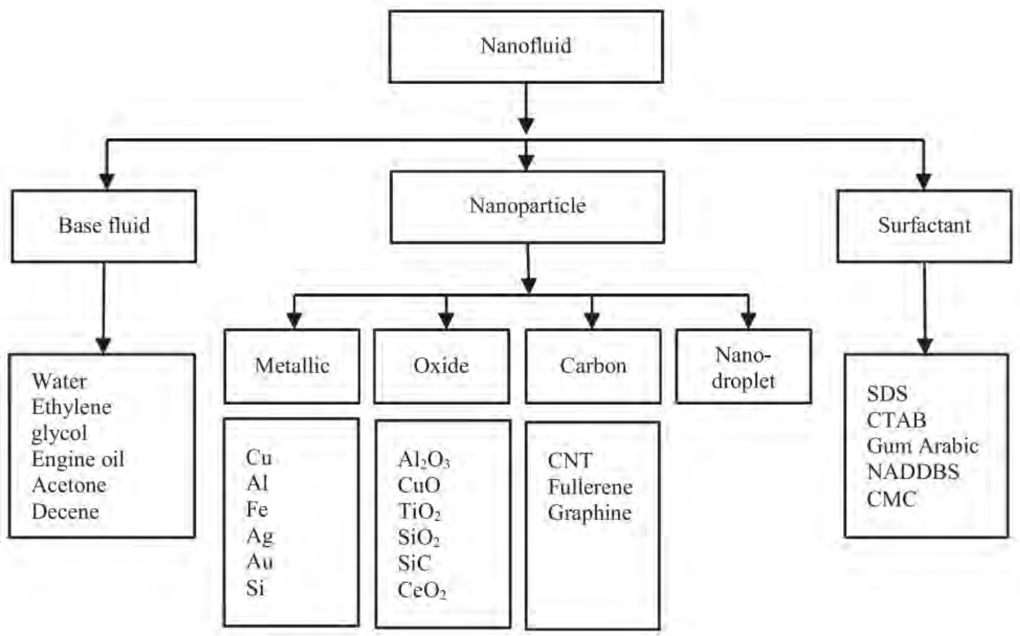

Figure 2.2 : Base fluids, nanoparticles and surfactants for synthesizing nanofluid (Source : Ghadimi *et al*. 2011)

2.3.1 Base Fluids

Base fluids also known as heat exchange fluids are fluids used to transport heat in a number of industrial applications. These fluids are employed to transport energy in the form of heat from the point where the heat is generated from burners, cores of nuclear reactor and solar farms to the system that is going to use it such as thermal storage systems, steam generators, chemical reactors and others. The most widely used base fluids are water, EG, molten salts and engine oils. Unfortunately, one of their characteristic is low thermal conductivity which is limits the efficiency of the heat exchange systems that use them. But we can overcomes these limitations and increases the thermal conductivity by adding an exact proportion of nanoparticles consisting on carbon and surfactant to the base fluid while maintaining the original range of operating temperatures of the base fluid, which can range from 15 °C to 400 °C. In this way, it becomes possible to obtain increases of up to 30% in the thermal conductivity of the base fluid (Asociación RUVID, 2014).

2.3.1.1 Water

Regular water from the tap, though not unhealthy to consume, can cause a great deal of problems when used with highly sensitive lab equipment. Impurities found in water include suspended particles, colloidal particles, dissolved organic and inorganic solids, dissolved gases and microorganisms. Besides that, because of distilled water are pure, it is valuable in research since it is a constant and does not interfere with any chemical processes. Distilled water is used primarily as a solvent for reagent preparation, as a calibration standard or analytical blank, for cleaning testing equipment and rinsing an analyte. Besides that, for deionized water, it is not only has impurities filtered out, but it also has ions removed. The pure water does not conduct electricity because there are no ions to allow electrons to flow. Therefore, the deionized water will not add any other unaccounted for reactions to the experiment. So it is important to remove ionic impurities and minerals from water to achieve precise results in any testing, formulations, calibrations or cleaning.

2.3.1.2 Ethylene Glycol (EG)

EG is an important organic compound and chemical intermediate used in a large number of industrial processes. It also used as antifreeze in automobile radiators. EG can be produced by undergo sterilization process of ethylene oxide with water (John 1945) as shown in Figure 2.3. The addition of EG to water causes the freezing point of the mixture decrease thus the damage that would be caused by the water freezing in a radiator can be avoided by using a mixture of water and ethylene glycol as the coolant. In most heat transfer applications, EG as based fluids are the best choice because of their superior heat transfer efficiency as well as the temperature in the heat transfer fluid can be below 0 °C. This efficiency is largely due to the lower viscosity of EG solutions. Specific heat capacity, viscosity and specific weight of a distilled water and EG solution vary significantly with the percent of EG and the temperature of the fluid. Properties differ so much from distilled water that heat transfer systems with EG should be calculated thoroughly for actual temperature and solution.

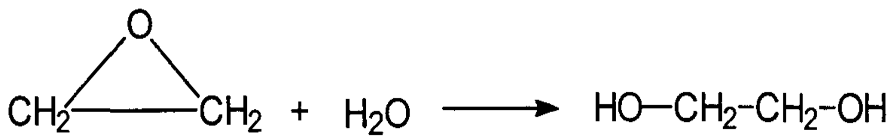

Figure 2.3 : Sterilization process of ethylene oxide with water to produce EG

(Source : John, 1945)

2.3.1.3 Engine Oils

Oil-based heat transfer fluids significantly high in thermal conductivity for energy efficient heat exchangers. Transformer oil, mineral oil, silicon oil, hydrocarbon fuels and some organic solutions are used as the base fluids for studying nanofluids (Choi *et al*. 2008). The dispersion and thermal conductivities of the oil-based nanofluids containing Cu, CuO, Ag, or Al_2O_3 particles have been recently reported (Zhu *et al*., 2007). When nanoparticles are introduced into oil, the particles are usually sediment within several minutes because of the poor compatibility between the base oil and nanoparticles. The agglomerated particles are gradually settled over time and this leads to the poor stability and low heat transfer capability of the suspensions. So the appropriate lipophilic modification process is needed for the formation of a stable oil-based nanofluid. Surface modification on metallic particles with hydrophobic ligands and surfactant addition can be employed to improve the compatibility between the nanoparticles and the oil-based fluid. It is because when the organic ligands with long hydrocarbon chains coordinated to the nanoparticles, it will prevent the particles from clustering (Choi *et al*. 2008).

2.3.2 Nanoparticles

Nanoparticles are of great scientific interest as they are effectively a bridge between bulk materials and atomic or molecular structures. The properties of materials change as their size approaches the nano-scale and as the percentage of atoms at the surface of a material becomes significant. Nanoparticles have a very high surface area to volume ratio. This provides a tremendous driving force for diffusion especially at elevated temperatures.

2.3.2.1 Metallic

Many metal and metalloid elements are able to form nano-scale structures. Some of the better known nanoparticles currently being investigated include those based on silver (Ag), which are known for their anti-microbial and anti-inflammatory properties. Silver nanoparticles have larger surfaces areas so that it can increase the area available for interactions especially in heat transfer. The heating effect is strong for metallic nanoparticles since they have many mobile electrons.

2.3.2.2 Carbon Nanotube (CNT)

CNT possess higher thermal conductivity than other types of metallic or non-metallic nanoparticles (Nasiri *et al*. 2012). Marquis and Chibante (2005) revealed that the thermal conductivity of CNT can reach 1800 to 2000 W/m.K. This provides