INVESTIGATION OF THERMAL CONDUCTIVITY AND VISCOSITY OF NANOFLUIDS CONTAINING CARBON NANOTUBE AND SURFACTANTS

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ABSTRACT

Conventional coolants such as water, oil and ethylene glycol are commonly used in thermal systems. However, they offered poor thermal characteristics such as low thermal conductivity. The developments in nanotechnology have introduced heat transfer fluids with improved thermal conductivity known as nanofluids. Addition of highly conductive particles like MWCNT can increase the thermal conductivity of heat-transfer fluids. Therefore, the objectives of this study are investigation on thermal conductivity and viscosity characteristics of MWCNT based water/ethylene glycol nanofluid. Apart from that the stability of nanoluids was measured via observation and zeta potential methods. KD2-Pro thermal analyser and Brookfield R/S rheometer were used to measure the thermal conductivity and viscosity of the samples, respectively. Based on observation method, the particle sedimentation and coagulation occurred at 0.01 wt. % and 0.05 wt. % of MWCNT. However, the nanofluids samples remained stable when added with surfactants namely GA, PVP, and CTAB. This experimental result concluded that sample added with 0.01 wt. % of MWCNT and CTAB exhibited highest zeta potential value compared to that of other type of surfactants. The thermal conductivity increase up to 18.4% for PVP, 25.67 % for GA and lastly 16.03% for CTAB for 0.05 wt. % of MWCNT based nanofluid compared to that of base fluid. The viscosity results indicated that for high particle content, the nanofluids behaved as shear-thinning. Finally, statistical mathematical equations were developed for thermal conductivity and viscosity of MWCNT based nanofluids in the present study.

ABSTRAK

Bahan penyejuk konvensional seperti air minyak dan ethylene glycol lazimnya digunakan di dalam sistem terma. Walau bagaimanapun, mereka menawarkan ciri-ciri haba yang lemah seperti mempunyai konduktiviti haba yang rendah. Perkembangan dalam bidang nanoteknologi memberi pengenalan mengenai cecair pemindahan haba yang dikenali sebagai nanofluids. Penambahan partikel yang sangat konduktif seperti MWCNT boleh meningkatkan keberaliran haba dalam cecair pemindahan haba. Oleh itu, objektif kajian ini adalah untuk menyiasat kekonduksian haba dan kelikatan MWCNT berasaskan air/ ethylene glycol nanofluid. Selain itu kestabilan nanoluids diukur melalui pemerhatian dan kaedah pengukuran potensi zeta. KD2-Pro terma analisis dan Brookfield R/S reometer digunakan untuk mengukur kekonduksian terma dan kelikatan sampel. Berdasarkan kaedah pemerhatian, pengenapan partikel dan pengumpalan berlaku pada 0.01 wt. % dan 0.05 wt. % daripada MWCNT. Walau bagaimanapun, sampel nanofluids stabil apabila ditambah dengan surfactant iaitu GA, PVP, dan CTAB. Hasil ujian eksperimen menunjukkan bahawa sampel yang ditambah dengan 0.01 wt. % daripada MWCNT dan CTAB memberi nilai potensi zeta tertinggi berbanding dengan lain-lain jenis surfactant. Kekonduksian haba meningkat sehingga 18.4% untuk PVP, 25.67% untuk GA dan akhir sekali 16.03% untuk CTAB untuk 0.05 wt. % daripada MWCNT nanofluid berdasarkan berbanding dengan bendalir asas. Keputusan menunjukkan bahawa dalam keadaan kandungan partikel tinggi, nanofluids berkelakuan kelikatan jenis penipisan ricih. Akhir sekali, persamaan matematik statistik telah dibangunkan untuk kekonduksian terma dan kelikatan nanofluids MWCNT berdasarkan pada kajian ini.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

CNT	-	Carbon Nanotube
CTAB	-	Cethytrimethylammoniumbromide
DOE	-	Design of Experiment
DTAB	-	Dodecyltrimethylammoniumbromide
DVLO	-	Derjaguin, Verway, Landau, Overbeek
DW	-	Distilled Water
EG	-	Ethylene Glycol
GA	-	Gum Arabic
HCTAB	-	Hexadodecyltrimethylammoniumbromide
MWCNT	-	Multi-Walled Carbon Nanotube
NIPAAm	-	N-isopropylacrylamide
PVA	-	Polyvinyl Alcohol
PVP	-	Polyvinylpyrrolidone
SEM	-	Scanning Electron Microscopy
SDS	-	Sodiumdodecylsulfate
SDBS	-	Sodiumdodecylbenzinesulfate
SOCT	-	Sodium Octanoate
SWCNT	-	Single-Walled Carbon Nanotube
TEM	-	Transmission Electron Microscopy
V_A	-	Attractive Contribution
V_R	-	Repulsive Contribution
V_S	-	Potential Energy Due to Solvent
V_T	-	Balance of Several Competing Contribution

min.	-	Minute
μm	-	Micrometer
Nm	-	Nanometre
mV	-	milivolt
k	-	Thermal Conductivity
ID	-	Inside Diameter
OD	-	Outside Diameter
L	-	Length
k_{bf}	-	Thermal Conductivity of Base Fluid
k_{nf}	-	Thermal Conductivity of Nanofluids
k_{eff}	-	Effective Thermal Conducvity
T	-	Temperature
Ps	-	Particle Sizes
Ut	-	Ultrasonication Time
V%	-	Volume Percentage
S	-	Surfactant
Br	-	Brinkman Number
Cp	-	Specific Heat Capacity
N	-	Empirical Shape Factor
Z	-	Zeta Potential
K	-	Function of Ionic Composition
A	-	Particle Radius

GREEK SYMBOL

ρ	-	Density (kg/m^3)
Π	-	Solvent Permeability
μ	-	Dynamic Viscosity
Φ, v	-	Volume fraction

CHAPTER 1

INTRODUCTION

1.0 Introduction

Conventional coolants such as water, engine oil, ethylene glycol are widely used in thermal systems. These types of fluids are cheap and easily available. However, they offered poor thermal characteristics such as low thermal conductivity which will hinder their performance in the thermal system. Technological advancement has seen the introduction of electronic devices, automotive engine and other inventions which require higher efficiency of heat dissipation. One of the possible options to address this problem is to increase heat transfer area but this is not preferable since it will make devices bulkier. The second alternative is by improving the thermal conductivity of the coolants.

The developments in nanotechnology have provided opportunities to introduce heat transfer fluids with improved thermal conductivity. In the Argonne Laboratory, thermal scientists have developed a novel heat transfer fluid known as nanofluid. It is a suspension of nanoparticles in base fluid. Nanofluids offered several advantages including high thermal conductivity, long term stability and minimal fluid clogging problem (Choi, 1995; Yu et el., 2007). The potential application of nanofluids can be seen in microelectronic, transportation, and Heating, Ventilation & Air Conditioning (HVAC) industries. Quite a number of researchers have found that nanofluids offer superior thermal conductivity compared to that of base fluid (Eastman et al., 2001; Murshed et al., 2008; Ghadimi et al., 2011). Eastman et al. (2001) found that 40 % of thermal conductivity enhancement can be achieved for ethylene glycol based copper nanofluids containing 0.3 % volume fraction of copper nanoparticles. There are also studies reported by Ghadimi et al. (2011) and Murshed et al. (2008) that found nanofluids offer augmented thermal conductivity behaviour compared to base fluids. Hence, it can be said that nanofluids have enormous potential to replace conventional coolants as heat transfer fluids in thermal systems.

1.1 Background of Problem

The addition of particles into base fluid will increase the performance of thermal conductivity. However, in depth investigation is needed before introducing nanofluid applications to the industries. Basically, the common types of nanoparticle used in the nanofluids related researches are alumina, copper and titanium dioxide (Eastman et al., 2001; Teng et al., 2010; Yu et al., 2012). It should be noted that there are limited studies focused on the carbon nanotube (CNT) although it was proven that CNT has a high thermal conductivity. The value of thermal conductivity for CNT ranges from 2000 W/mK and can reach up to 6000 W/mK (Fisher, 2006; Pierson, 1993). The limited studies utilizing CNT may be due to the price of CNT which is more expensive compared to other nanoparticles. Another reason could be that the hydrophobic characteristic of CNT which tends to agglomerate in the base fluid. There are several researchers who found that CNT-based nanofluids exhibit better thermal conductivity characteristic. For instance, Garg (2008) reported a 20% of enhancement in thermal conductivity in nanofluids compared to base fluid.

Meibodi et al. (2010) used statistical analysis to investigate the factors affecting thermal conductivity of water-based CNT nanofluids. The considered factors in their study included: size and volume fraction of nanoparticles, types of surfactant, pH, power used for ultrasonication and time taken after the sonication process. Apart from that, Phuoc et al. (2011) measured the characteristic and thermal conductivity of Multiwall Carbon Nanotubes (MWCNT) which was stabilized by a surfactant namely cationic chitosan. The study implied that there is enhancement in the thermal conductivity that ranged between 2.3 % to 13 % for 0.5 wt. % to 3 wt. % of MWCNT. Although this novel fluid possesses better thermal property, its stability remains a major concern. Besides thermal conductivity, viscosity behaviour also plays an important role in determining the suitability of nanofluids as heat transfer fluids. Heat transfer fluids with lower viscosity are preferred in order to minimize pressure drop. Ghadimi et al. (2011) posited that pressure drop and pumping power are inter-related. Several studies have indicated that nanofluids viscosity will increase with the increase of particles' volume fraction. Duangthongsuk and Wongwises (2009) found that the nanofluids viscosity is inversely proportional to the operating temperature; however it increases with particle volume fractions.

This study has focused on the effect of the surfactants on the thermal conductivity and viscosity of carbon nanotube based nanofluids. The factors considered were weight percentage of MWCNT, type of surfactant, and sonication time. The stability of MWCNT based nanofluids was considered because it is believed that the stability of nanofluids will improve with the addition of surfactant. The types of surfactants used in this study were Gum Arabic (GA), Cetyltrimethylammoniumbromide (CTAB) and Polyvinylpyrrolidone (PVP). Nanofluids with better stability are associated with higher thermal conductivity. In addition, there are limited studies which investigated the thermal conductivity and viscosity characteristics of carbon nanotube based nanofluids added with the three types of surfactant as mentioned above.

1.2 Objective of the Study

The purpose of this study is to achieve several objectives as follows:

a) To evaluate the stability of multi-walled carbon nanotube based nanofluids
b) To investigate the thermal conductivity and viscosity characteristics of multi-walled carbon nanotube based nanofluid
c) To develop thermal conductivity and viscosity empirical correlations for multi-walled carbon nanotube based nanofluids

1.3 Scope of the Study

The scope of this study is as follows:

a) Multi-walled carbon nanotube (MWCNT) was chosen from the other Carbon Nanotubes. This is because the price of MWCNT is cheaper than Single Wall Carbon Nanotubes (SWCNT). The specifications of the MWCNT are: outer diameter of 20-30nm, length of 10-30µm, and purity percentage of 95%.

b) 40 % of Ethanol Glycol (EG) and 60 % of Distilled Water (DW) mixture was used as the main base fluid in this study.

c) The thermal properties considered were thermal conductivity and viscosity, and the parameter considered were particles mass fraction, types of surfactants and sonication time.

d) Weight percentages of multi-walled carbon nanotube (MWCNT) were 0.01wt. %, 0.05wt. %, 0.1wt. %, 0.3 wt. % and 0.5 wt. %.

e) The types of surfactant were Gum Arabic (GA), Cetyltrimethylammoniumbromide (CTAB) and Polyvinylpyrrolidone (PVP). The weight percentages of the surfactants were 0.01wt. %, 0.05wt. %, 0.1 wt. %, 0.3 wt. % and 0.5 wt. %.

f) The method used to develop the empirical correlation using the design of experiment (DOE) was the Response Surface Method (RSM). The effective design utilized under the RSM was the Central Composite Design (CCD).

1.4 Contribution of Study

Heat transfer improvement in thermal systems such as automotive radiator and electronic cooling is done by adding fins and increasing the heat transfer surface. These innovations had reached a limit where they are no longer seen as effective. As a result, there is a need to develop a new generation of heat transfer fluids to further improve the thermal systems. The newly developed heat transfer fluids must exhibit a high thermal conductivity characteristic. MWCNT based nanofluid is one of the potential heat transfer nanofluids that can be used to replace the conventional fluids. In the present study, an investigation was done to evaluate the thermal conductivity and viscosity characteristic of MWCNT-based nanofluids subjected to various types of surfactants. The factors affecting the thermal conductivity and viscosity characteristic such as weight concentration, different types of surfactants and ulltrasonication time were included. With this knowledge, stable and improved MWCNT-based nanofluids can be developed. Consequently, the efficiency of a thermal system can be enhanced by using nanofluids. Moreover, there is also opportunity to reduce the size of the thermal system. For instance, the size reduction of automotive radiators will definitely reduce the weight of vehicles. This will directly improve aerodynamic features of cars.

Furthermore based on author's best knowledge, there are limited studies which focused on comparison of various types of surfactants on thermal conductivity and viscosity characteristics of MWCNT based nanofluids. Most of the researches mainly focused on single type of surfactant. In addition, the development of empirical correlations for MWCNT based nanofluid's thermal conductivity and viscosity is also very rare and given less attention from the reserachers. Therefore, it is hope that the present study will fill the gap available in this area.

1.5 Outline of The Thesis

This thesis comprises of five chapters. The first chapter, Chapter 1 begins with the introduction, background of problem, objectives of the study, scope of the study, outline of the study, and importance of the research. Chapter 2 presents an overview of the literature related to the CNT nanofluid researches and its connection to the present work. Next, Chapter 3 elaborates the methodology adopted in carrying out the experiments. Chapter 4 presents the results obtained from the thermal conductivity, viscosity and design of experimental measurements. Finally, the last chapter which is Chapter 5 concludes the overall findings and suggests the direction for future studies.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

The fundamental of nanofluids is described in this chapter. Subsection 2.1 elaborates nanofluids as heat transfer fluids followed by the synthesis of nanofluids in subsection 2.2. Subsection 2.3 discusses in detail the stability aspect of nanofluids. In the subsequent subsection which is subsection 2.4, the explanation on CNT based nanofluids is covered. Subsection 2.5 and subsection 2.6 meanwhile discuss the CNT based nanofluids preparation and the mechanism of thermal transport in nanofluids. Subsection 2.7 and subsection 2.8 explains the factors affecting the characteristic of thermal conductivity and theoretical formula for thermal conductivity, respectively. Subsection 2.9 and subsection 2.10 explains the viscosity of CNT based nanofluids and theoretical formula for viscosity, respectively. Subsection 2.11 describes the design of the experiment. The last subsection, which is subsection 2.12, is the summary for chapter 2.