CONVECTIVE HEAT TRANSFER PERFORMANCE OF NANOFLUIDS IN CONCENTRIC TUBE HEAT EXCHANGER

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DEDICATION

This thesis is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

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ABSTRACT

This research studied the convective heat transfer performance of nanofluids in a concentric tube heat exchanger. Nanofluids is a new technology for heat transfer in cooling systems and suspension stability of nanofluids is a major issue since it will affect the performance of nanofluids in heat exchanger. The addition of surfactant will increase the dispersion of nanoparticles in the base fluids and increase its stability. The objectives of this research were to formulate the stable nanofluids with addition of surfactant and to investigate the stability, properties, and heat transfer performance of the nanofluids in concentric tube heat exchanger. Aluminium oxide (Al_2O_3) and titanium dioxide (TiO_2) nanoparticles were added to the base fluid, ethylene glycol (EG), with addition of polyvinylpyrrolidone (PVP) as surfactant by two-step method. First, the optimum stability ratio of nanoparticles to surfactant was determined by preparing 5 samples of 0.50 vol% nanoparticles with addition of different concentration of surfactant. Thus, each sample had different ratio and was observed for a few weeks by visual observation. Then, 4 samples of nanofluids (0.25, 0.50, 0.75 and 1.00 vol %) were prepared based on the optimum stability ratio. The properties and heat characteristics of nanofluids were analyzed at different concentration (0.25, 0.50, 0.75 and 1.00 vol%) of nanofluids and at 4 different temperatures which were, 30, 45, 60 and 75 °C. From the observation, the Al_2O_3 nanofluids was stable with the addition of 0.1 vol% surfactant, while TiO_2 nanofluids was stable with 0.4 vol% surfactant. The thermal conductivity of nanofluids was higher than the base fluids and increased as the temperature and concentration increased. Nevertheless, thermal conductivity for Al_2O_3 nanofluids was slightly higher compared to TiO_2 nanofluids. As known, viscosity of nanofluids increases with increasing nanoparticles concentration and reducing nanofluids temperature. Viscosity of these nanofluids was the highest at 1.00 vol% and at 30 °C temperature for both. The heat transfer performance was enhanced by using nanofluids as compared to base fluids alone. Heat transfer coefficient was increased by increasing nanoparticles concentration and temperature. All nanofluids gave the highest heat transfer enhancement at 1.00 vol% and 75 °C. However, heat transfer enhancement by Al_2O_3 nanofluids was higher compared to TiO_2 nanofluids due to the high thermal conductivity of Al_2O_3 nanofluids. Thus, the research proved that nanofluids can be used to replace the traditional working fluids as coolant or thermal fluids.

ABSTRAK

Penyelidikan ini telah mengkaji prestasi pemindahan haba bendalir nano di dalam penukar haba tiub sepusat. Bendalir nano ialah satu teknologi baharu untuk pemindahan haba di dalam sistem penyejukan dan kestabilan bendalir nano menjadi isu utama kerana masalah ini akan mempengaruhi prestasi bendalir nano dalam penukar haba. Penambahan bahan surfaktan akan meningkatkan penyebaran nanopartikel dalam bendalir asas dan meningkatkan kestabilan bendalir nano. Objektif kajian ini adalah untuk menghasilkan bendalir nano yang stabil dengan penambahan surfaktan dan untuk mengkaji kestabilan, sifat-sifat, dan prestasi pemindahan haba bendalir nano di dalam penukar haba tiub sepusat. Nanopartikel aluminium oksida (Al_2O_3) dan titanium dioksida (TiO_2) ditambah ke dalam etilena glikol (EG) sebagai bendalir asas dengan penambahan polivinilpirrolidon (PVP) sebagai surfaktan melalui kaedah dua-langkah. Nisbah kestabilan optimum nanopartikel kepada surfaktan ditentukan dengan penyediaan 5 sampel, 0.5% isipadu nanopartikel dengan penambahan kepekatan surfaktan yang berbeza. Oleh itu, setiap sampel mempunyai nisbah yang berbeza dan diperhatikan selama beberapa minggu secara visual. Kemudian, 4 sampel bendalir nano (0.25, 0.50, 0.75 and 1.00% isipadu) dihasilkan berdasarkan nisbah kestabilan yang optimum. Ciri-ciri dan prestasi pemindahan haba bendalir nano dikaji pada kepekatan nanopartikel yang berbeza (0.25, 0.50, 0.75 and 1.00 % isipadu) dan pada 4 suhu yang berbeza iaitu 30, 45, 60 dan 75 °C. Berdasarkan pemerhatian, bendalir nano Al_2O_3 stabil dengan penambahan 0.1 % isipadu surfaktan, sementara bendalir nano TiO_2 stabil dengan 0.4 % isipadu surfaktan. Kekonduksian haba bendalir nano lebih tinggi daripada bendalir asas dan semakin meningkat apabila suhu dan kepekatan nanopartikel meningkat. Walau bagaimanapun, kekonduksian haba untuk bendalir nano Al_2O_3 sedikit lebih tinggi berbanding dengan bendalir nano TiO_2. Seperti diketahui kelikatan bendalir nano meningkat dengan peningkatan kepekatan nanopartikel dan pengurangan suhu bendalir nano. Kelikatan bendalir nano ini didapati tertinggi pada 1.00 % isipadu dan pada suhu 30 °C untuk kedua-dua bendalir nano. Prestasi pemindahan haba telah meningkat dengan menggunakan bendalir nano berbanding dengan bendalir asas. Pekali pemindahan haba meningkat dengan peningkatan kepekatan nanopartikel dan suhu bendalir nano. Semua bendalir nano memberikan peningkatan pemindahan haba tertinggi pada 1.00 % isipadu dan 75 °C. Walau bagaimanapun, peningkatan pemindahan haba oleh bendalir nano Al_2O_3 adalah lebih tinggi berbanding dengan bendalir nano TiO_2 kerana kekonduksian habanya yang lebih tinggi. Oleh itu penyelidikan ini telah dapat membuktikan bahawa bendalir nano boleh menggantikan bendalir tradisional sebagai cecair penyejuk atau cecair haba.

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LIST OF ABBREVIATIONS

CTAB	-	Cetyl Trimethylammonium Bromide
EG	-	Ethylene glycol
GA	-	Gum Arabic
PVP	-	Poly Vinly Pyrrolidone
SDBS	-	Sodium Dodecylbenzene Sulfonate
TEM	-	Transmission Electron Microscopy

LIST OF SYMBOLS

m_x	-	Mass of component x
V_x	-	Volume of component x
ρ_x	-	Density of component x
$_x$	-	Nanoparticles
$_y$	-	Base fluids
k_r	-	Effective thermal conductivity
k_{nf}	-	Thermal conductivity of nanofluids
k_{bf}	-	Thermal conductivity of base fluids
Ø	-	Specific volume concentration of nanoparticles
Q	-	Heat transfer rate
Cp	-	Specific heat capacity
T	-	Temperature
T_{lm}	-	Log mean temperature
h	-	Heat transfer coefficient
A	-	Surface area

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Heat transfer is one of the most important processes in various fields of engineering industries and consumer products. Thus heat transfer fluids play a vital role in many processes such as heating and cooling processes, power generation and chemical processes. The inherently poor thermal conductivity of conventional fluids puts a fundamental limit on heat transfer.

In the past few years, scientists and researchers have been attempting and finding the solution to develop good equipment having enhanced heat transfer properties of working fluids. This is because of the fluids may have better efficiency in transferring heat especially in cooling applications system. Previously, the conventional fluids that have been used for heat transfer application did not give high heat transfer efficiency due to lower thermal conductivity. Thus, researchers need to develop a new type of fluids that is effective in terms of heat transfer performance. According to Anoop, Cox and Sadr (2013), in 1995, Choi and his team were the first to introduce the ability of this breed of fluids, known as nanofluids.

Nanofluids by definition is fluid that contains nanometer-sized (1-100 nm) nanoparticles that suspended into base fluids such as water, ethylene glycol (EG) and engine oil (Kumar,Tiwari and Ghosh, 2015). By introducing small size solid particles into fluids, they seem to increase the thermal conductivity of that fluid. Due to their significantly improved thermal properties, nanofluids are a new type of compound material in nano-technology industry to provide better heat transfer performance in cooling system (Nazari, Karami and Ashouri, 2014). Thus a lot of ways have been engaged on producing a better heat transfer fluids system. According to Singh (2008), there is not any standard method for preparation of stable nanofluids. However, there are two basic or fundamental methods to obtain stable nanofluids which are single-step method and two-step method. For single-step method employs chemical approach by using wet technology. Meanwhile for two-step method, the nanoparticles are first produced as a dry powder, and then will be dispersed into a base fluids.

In studying nanofluids, preparation of the stable nanofluids still remains as the main challenge. There are two situations where both are critical to the stability of nanofluids which are aggregation and sedimentation. Therefore, preparation to get stable nanofluids is important due to achieve higher heat transfer performance of fluids. According to Singh (2008), research has proved that with only small amount of dispersed particle of up to 5 vol%, the thermal conductivity can be enhanced. Due to their significantly improved thermal properties, nanofluids could have applications in many fields such as transportation, medical and manufacturing.

1.2 Problem Statement

A mechanism that can extract the heat produced by many electronic devices like laptops is highly demand in order to work in a secure working condition. Heat exchanger is a device that can best transfer all the heat that had been generated efficiently. However, the properties of working fluids in the heat exchanger play an important role in the heat transfer coefficient to enhance the absorption of heat produced by the devices. Heat transfer in heat exchanger using nano-scale materials has been investigated for the past decade by many researchers in order to find the best working fluid that can transfer heat efficiently in cooling systems. According to Khattak, Mukhtar and Afaq (2020), nanofluids is a coolant that enhances the heat transfer but one of the most important issues is the stability of nanofluids for industrial application. It remains a big challenge to achieve desired stability of nanofluids.

Nanofluids have been proven as the best working fluids that can replace the traditional working fluid in heat exchanger. Millimeter and micrometer size of particles will cause clogging and abrasion due to the large size of these particles. Therefore, smaller particles in size like nanoparticles is the best material for the heat transfer systems. According to Tawfik (2017), nanofluid gave better stability than the fluids with micrometer or millimeter particles and has higher thermal conductivity than that of base fluids. The stability of nanofluids is very important to increase the heat transfer performance in heat exchanger. The preparation method for nanofluids is the first thing that needs to be taken care to produce high stability of nanofluids to ensure the efficiency of the nanofluids as heat transfer fluid. Thus, it is very important to study and determine the stability of nanofluids.

Stability of nanofluids can be enhanced by adding surfactants and using ultrasonic vibrator to disperse nanoparticles in the base fluids. According to Zawrah, Khattab, Girgis, Daidamony and Aziz (2015), surfactants play a vital role in dispersion of nanoparticles in base fluids by ensuring higher stability of nanofluids for a long period of time. Most of the past researchers did not added any surfactants. By adding too much surfactant, the viscosity of nanofluids will increase, hence the thermal performance of heat transfer in heat exchanger will decrease. Enough surfactants will decrease the viscosity of the nanofluids, thus the friction factor of nanofluids also decreases. Thus, good formulation of nanofluids is essential to ensure the optimum properties and characteristics of nanofluids.

The suspended nanoparticles will improve the heat transfer properties and transport properties of base fluids in heat exchanger (Ganvir, Walke and Kriplani, 2017). Nanofluids absorb more heat in the cooling system compare to base fluids due to excellent thermal conductivity (Sandhu, Gangacharyulu and Singh, 2018). The properties of working fluids will determine the heat transfer performance of the heat exchanger. Among the properties that affect the heat transfer performance include thermal conductivity, heat transfer coefficient, viscosity and Reynolds number. Previous research mostly does not use concentric tube heat exchanger to study the performance of nanofluids as a coolant or thermal fluids.

Therefore, in the case of this challenge, the research was conducted to formulate the nanofluids that give the higher stability and their properties. The best ratio of nanoparticles to surfactant were identified to find the best condition of nanofluids for applying to concentric tube heat exchanger. The research will cover the thermal conductivity, viscosity and convective heat transfer coefficient based performance of concentric tube heat exchanger. Hopefully this can give the highest heat transfer performance of nanofluids for energy recovery in concentric tube heat exchanger.

1.3 Research Objectives

The aims of this research are:

i) to investigate the properties of nanofluids in term of thermal conductivity and rheological behavior,
ii) to analyze the heat transfer performance of nanofluids in concentric tube heat exchanger, and
iii) to compare effective heat transfer performance for different types of nanofluids

1.4 Scopes of Research

In order to achieve the objectives above, this research was conducted with several scopes which are:

i) Preparation of nanofluids by using nanoparticles aluminium oxide (Al_2O_3) and titanium dioxide (TiO_2), with ethylene glycol (EG) as the base fluid and poly vinly pyrrolidone (PVP) as a surfactant.
ii) Preparation of nanofluids at different concentration of nanoparticles (0.25, 0.50, 0.75 and 1.00 vol%) and different concentration of surfactant (0.10, 0.20, 0.30, 0.40 and 0.50 vol%).
iii) Stability observation is limited to visual observation.
iv) Morphology of raw material has been characterized by Transmission Electron Microscopy (TEM)
v) Measurement of thermal conductivity and viscosity of nanofluids at temperature range of 30 °C to 75 °C.
vi) Analysis for heat transfer performance of nanofluids in concentric tube heat exchanger at various temperature and concentration.

1.5 Organization of Thesis

This thesis consists of five chapters. It starts with Chapter 1 which is introduction of the thesis that included research background, problem statement, objectives and scopes of research. Chapter 2 is the literature review which discusses the facts, information and results from previous research. Next is research methodology in Chapter 3 that explain the procedure of research to be conducted. Chapter 4 is results and discussion which explain the findings from the research. Lastly, Chapter 5 concluded the thesis based on the results discussed and offers recommendations for improvements for this work in the future.

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