NUMERICAL SIMULATION OF NANOFLUID FORCED CONVECTION HEAT TRANSFER

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ABSTRACT

The thesis deals with the numerical simulation of nanofluid forced convection heat transfer under the turbulent flow with different volume concentrations. The objective of this thesis is to study the heat transfer coefficient of nanofluid at various volume concentrations and Reynolds number using Computational Fluid Dynamic (CFD) software. This thesis describes the CFD analysis techniques to predict the heat transfer coefficient using FLUENT software. Aluminum Oxide, Al_2O_3/Water with 0.02%, 0.1% and 0.5% of volume concentration were studied in this thesis which commonly available nanofluid in market. The structural three-dimensional solid modelling of plain pipe tube was developed using the computer aided-drawing software, SolidWorks. The strategy of validation of CFD model was developed by comparing the result from water simulation with the available equation in the study of forced convection heat transfer. The CFD analysis was then performed using FLUENT with nanofluid as the working fluid. The CFD model of components was analyzed using the pressure based solver and k-epsilon viscous model. Finally, the bulk temperature and wall temperature of the working fluid obtained from the simulation are used to calculate the heat transfer coefficient of the fluid. From the result, it is observed that the heat transfer coefficient of base fluid, water is increased about 20% in the presence of nanoparticles when Reynolds number and volume concentration are increase. But, increase in heat transfer coefficient by increasing volume concentration of nanofluid is valid when Reynolds number below 10,000. Results obtained from simulation were then compared with the experiment and it is observed that a close agreement between simulation and experiment is achieved. Both simulation and experiment results concluded that the heat transfer coenfficient increase when nanofluid is used as the working fluid. These results are significant to improve today cooling fluid in the way of increasing the heat transfer coefficient.

ABSTRAK

Tesis ini berurusan dengan simulasi numerik konveksi paksa perpindahan panas bendalirnano di bawah aliran gerlora dengan kepekatan isipadu yang berbeza. Tujuan tesis ini adalah untuk mempelajari pekali perpindahan panas bendalirnano pada pelbagai kepekatan isipadu dan bilangan Reynolds dengan menggunakan perisian Bendalir Dinamik Berkomputer (BDB). Tesis ini membincangkan teknik-teknik analisis BDB untuk mengagak pekali pemindahan panas menggunakan perisian FLUENT. Aluminium Oksida, Al_2O_3/Water dengan kepekatan isipadu 0.02%, 0,1% dan 0,5% tela dipelajari dalam tesis yang merupakan bendalirnano yang biasa terdapat di pasaran. Pemodelan padat struktur tiga-dimensi untuk tabung paip polos dibangunkan dengan menggunakan komputer perisian dibantu-rekabentuk, SolidWorks. Strategi untuk mengesahkan model BDB yang dibangunkan adalah dengan membandingkan dengan hasil dari simulasi air dan dengan persamaan yang terdapat dalam kajian konveksi paksa perpindahan panas. Analisis BDM kemudian dilakukan dengan menggunakan FLUENT dengan nanofluid sebagai bendalir kerja. Model komponen BDB dianalisis menggunakan penyelesai bersaskan tekanan dan model kelikatan k-epsilon. Akhirnya, suhu massa bendalir kerja dan suhu dinding paip yang diperolehi daripada simulasi digunakan untuk mengira pekali perpindahan panas dari bendalir. Dari hasil tersebut, dilihat bahawa pekali perpindahan panas bendalir asas, air meningkat sebanyak 20% dengan kehadiran partikel nano apabila bilangan Reynolds dan kepekatan isipadu meningkat. Namun begitu, peningkatan pekali perpindahan panas dengan meningkatkan kepekatan isipadu bendalirnano ketika bilangan Reynolds di bawah 10,000. Keputusan yang diperolehi daripada simulasi kemudian dibandingkan dengan eksperimen dan diamati bahawa terdapat persetujuan yang erat antara simulasi dan eksperimen. Daripada hasil simulasi dan eksperimen dapatlah disimpulkan bahawa pekali pemindahan panas meningkat disaat nanofluid digunakan sebagai bendalir kerja. Hasil daripada keputusan ini dapatlah digunakan untuk meningkatkan cairan pendingin hari ini dengan cara meningkatkan pekali perpindahan panas.

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LIST OF SYMBOLS

ρ	Density
Re	Reynolds Number
Φ	Volume concentration
L	Length
Pr	Prandtl Number
Nu	Nusselt Number
T_b	Bulk Temperature
T_w	Wall Temperature
T_∞	Fluid Temperature
H_2O_3	Water
T_s	Surface Temperature
Cu	Copper
$\dot{m}$	Mass Flow Rate
A_C	Cross Sectional Area
f	Friction Factor
Al_2O_3	Aluminum Oxide
C_P	Specific Heat
V	Velocity
k	Dynamic Viscosity
h	Heat Transfer Coefficient
A_s	Heat Transfer Surface Area
$\dot{Q}_{conv}$	Heat Transfer for Convection
$u(r)$	Velocity Profile

d_p	Diameter Particle
d_{max}	Diameter Maximum
k_{nf}	Thermal Conductivity of Nanofluid
μ_{nf}	Dynamic Viscosity of Nanofluid
$C_{P_{nf}}$	Specific Heat of Nanofluid
k_w	Thermal Conductivity of Water
μ_w	Dynamic Viscosity of Water
C_{P_w}	Specific Heat of Water
g	Gravity

LIST OF ABBREVIATIONS

FYP	Final Year Project
CFD	Computational Fluid Dynamic
GUI	Graphical User Interface
CAD	Computer Aided Design
MMGS	Milimeter, gram and second
TI	Turbulent Intensity

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

In today's globalized and modern world, there are many products available for consumers to be used in all ranges, from food to clothing, electrical appliances to transportation. But do we know, lots of these products such as electronic devices (e.g., laptops, computers, and game consoles), heat exchangers (e.g., refrigerator, heater, and air conditioner) and transportation vehicles need to have a liquid coolant to prevent the overheating or to improve the rate of heat transfer. However, the liquid coolants or heat transfer fluids that we have today such as water, engine oil, and ethylene glycol generally has poor thermal properties. For more than 100 years, many scientists and engineers have made great efforts to improve the inherently poor thermal conductivities of these traditional heat transfer fluids (J.C. Maxwell, 1873).

An innovative way of improving the thermal conductivities of heat transfer fluids is to suspend small solid particles in the fluids. In order to achieve this, nanofluids have been used. Nanofluids are nanometer-sized particles (<100 nm) dispersed in a base fluid such as water, ethylene glycol or propylene glycol. Addition of high thermal-conductivity metallic nanoparticles (e.g., aluminum, copper, silicon and silver) increases the thermal conductivity of such mixtures; thus enhancing their overall energy transport capability. This term was made up by Choi in 1995 at Argonne National Laboratory of USA (S.U.S. Choi, 1995).

Nanofluids are thought to be the next-generation heat transfer fluids, and they offer exciting possibilities due to their enhanced heat transfer performance compared to ordinary fluids. Some of the advantages of these nanofluids are:

(i) Better stability and heat transfer ability compared to those fluids containing micro or mili sized particles.
(ii) Higher thermal conductive capability than the base fluids themselves because of large surface size for heat transfer due to smaller size of particles.

Nanofluids are proposed for various uses in important fields such as electronics, transportation, medical, and Heating Ventilating and Air Conditioning (HVAC). Hence, there is a need for fundamental understanding of the heat transfer behavior of nanofluids in order to exploit their potential benefits and applications. Nanofluids with metallic nanoparticles and oxide nanoparticles have been investigated by several researchers such as Choi, Yu, Maxwell, Das et al., Xuan et al., Eastman et al., Lee et al., Hester et al. and many other scientists and researchers.

1.2 PROBLEM STATEMENT

As we already known, energy costs have escalated rapidly in the last decade and there are tremendous needs for new kinds of heating or cooling fluids, which will increase heating system thermal performance, reduce the overall size and energy consumption. This is because many conventional coolant fluids today are poor in thermal conductivities, which is not very practical to be used in industrial sector now.

In order to reduce our rely on today’s conventional coolant fluids which is not very cost effective, research must be carry out numerically and experimentally to find the alternative way to solve this problem which is more valuable to people, society, country and world.

1.3 SIGNIFICANT OF STUDY

There are few significances of this study when objectives have been achieved as follows:

(i) Commercialize these nanofluids as a new era of liquid coolants which are very practical to be used in industrial sector.
(ii) People can enjoy new liquid coolants which are more reliable compared to conventional liquid coolants which are poor in thermal properties.
(iii) Apply the advantages of nanofluids as new coolant fluids in our country to overcome the overheating and to increase the rate of heat transfer in electrical devices, transportation engine and HVAC.

1.4 PROJECT OBJECTIVES

In order to complete a project successfully, the objectives for the project must be determined and the objectives of this project includes:

(i) To investigate numerically the behaviors of nanofluid (Aluminum Oxide, Al_2O_3/Water nanofluid) for different Reynolds number and volume concentration during the forced convection heat transfer using FLUENT.
(ii) To compare the results obtained from the numerical simulation software with the experimental and previous study.

1.5 SCOPES OF THE PROJECT

The scopes of this project are limited to:

(i) Simulate the nanofluid forced convection heat transfer under turbulent flow condition using numerical method.
(ii) Simulate forced convective heat transfer of Al_2O_3-water based nanofluid for different Reynolds number and volume concentrations.

(iii) Study the optimum working condition of nanofluid by considering some special requirements such as even suspension, stable suspension, durable suspension, low agglomeration of particles, and no chemical change of the nanofluid.

(iv) Analyze nanofluid numerically using three different approaches which are:

- The first approach assumes that the continuum assumption is still valid for fluids with suspended nanosize particles.
- The second approach is to consider one-phase model for description of both the fluid and the solid phases.
- The third approach is to adopt the Boltzmann theory.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Heat is the form of energy that can be transferred from one system to another as a result of temperature difference. The science that deals with the determination of the rates of such energy transfer is called heat transfer.

In other word, heat transfer is the transition of thermal energy from a hotter mass to a cooler mass. When an object is at a different temperature than its surroundings or another object, transfer of thermal energy, also known as heat transfer, or heat exchange, occurs in such a way that the body and the surroundings reach thermal equilibrium; this means that they are at the same temperature. Heat transfer always occurs from a higher-temperature object to a cooler-temperature one as described by the second law of thermodynamics or the Clausius statement. Where there is a temperature difference between objects in proximity, heat transfer between them can never be stopped; it can only be slowed.

In the simplest of terms, the discipline of heat transfer is concerned with only two things: temperature, and the flow of heat. Temperature represents the amount of thermal energy available, whereas heat flow represents the movement of thermal energy from place to place.

On a microscopic scale, thermal energy is related to the kinetic energy of molecules. The greater a material's temperature, then the greater the thermal agitation of its constituent molecules (manifested both in linear motion and vibration modes). It is natural for regions containing greater molecular kinetic energy to pass this energy to regions with less kinetic energy.

Several material properties serve to modulate the heat transferred between two regions at differing temperatures. Examples include thermal conductivities, specific heats, material densities, fluid velocities, fluid viscosities, surface emissivity, and more. Taken together, these properties serve to make the solution of many heat transfer problems an involved process.

For this chapter, a little bit of historical background and a brief explanation of the basic theory of heat transfer will be discussed. Then some discussion on concepts of nanofluids, technology for production of nanofluids and the benefits of nanofluids in industry will be explained. Besides, some discussion on the materials used for making the nanofluids and together with the previous study in both experimental and numerical about nanofluids will be discussed. Then it is followed by some of the result from previous study by researchers have been included as a references to this study. Finally, this chapter is ends by a little bit conclusions from overall of this study.

2.2 HISTORY OF HEAT TRANSFER

First modern chemist to study heat was Joseph Black (1728 - 1799). Black tried to explain heat in terms of a fluid. He explained how a kettle of water placed over a fire increased in temperature but a kettle filled with water and ice placed over a fire did not change in temperature till all the ice was melted. He said that until the ice was saturated with the heat-fluid and thus became melted could its temperature rise. French chemist Antoine Lavoisier (1743-1794) accepted this theory and proposed a theory based from this phenomenon called as “caloric theory”. The caloric theory states that heat is a fluid-like substance called “caloric” (Latin word for heat) that is a mass less, colorless, odorless, and tasteless substance that can be poured from one body into another. When caloric was added to a body, its temperature increased; and when caloric was removed from body, its temperature decreased.

Another idea competed with the caloric theory. Scientist knew that kinetic energy of motion plus the stored energy called potential energy was given the name mechanical energy and that friction was a part of the conservation of these energies. They knew friction could warm up an object so maybe the invisible motion of invisible particles was what we call heat. Summed up; friction was converting mechanical energy into heat. The problem was this idea of really small particles of matter (i.e., atoms and molecules).

An English physicist, James Prescott Joule (1818-1889) was attempting to find the mechanical equivalent of heat. In the end he found that a given amount of energy of whatever form always yielded that same amount of heat (at 4.18 joules per calorie). The relationship of the motion of atoms to temperature and heat was placed on firm theoretical basis about 1860 by the Scottish physicist James Clerk Maxwell and thus put the caloric theory to the rest.

2.3 THEORY OF HEAT TRANSFER

From the introduction, heat is defined as the form of energy that can be transferred from one system to another as a result of temperature difference. The transfer of energy as heat is always from the higher temperature medium to the lower one. This transfer process stops when both medium reach the same temperature.

Heat can be transferred in the three different mechanisms which are conduction, convection, and radiation. These three mechanisms of heat transfer require the existence of a temperature difference, and begin from the high temperature medium to a lower temperature medium. Below is the brief description of each mechanism of heat transfer:

(i) Conduction:

Regions with greater molecular kinetic energy will pass their thermal energy to regions with less molecular energy through direct molecular collisions, a process known as conduction. In metals, a significant portion of the transported thermal energy is also carried by conduction-band electrons.