NUMERICAL INVESTIGATION OF HEAT TRANSFER ENHANCEMENT FOR METAL OXIDE NANOFLUID IN ELLIPTICAL TUBE HEAT EXCHANGER

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ABSTRACT

Heat exchangers are an important system used for heat transference. These systems are present in many devices and utilities. These devices can be big such as in oil refineries, or small, such as in fridges and air-conditioners. However, there are several types of heat exchangers, each with their own benefit and advantage. In this study, two types of passive heat transfer solutions are used to numerically investigate the relationship between nanofluid particle diameter and fluid volume fraction concentration. The first is a double pipe with an elliptical cross-section that has a counter-fluid flow mechanic. This is then combined with another passive technique, which is the use of nanoparticles in combination with water, which creates nanofluids. ANSYS was used as a tool to numerically simulate the various scenarios using different nanoparticles. The boundary conditions and geometry, as well as the governing equations and the mesh of the heat exchanger are numerically simulated. The experiment was conducted under a laminar flow regime in an elliptical tube double pipe heat exchanger. The results of the simulation indicated that nanofluids such as silicon oxide, enhance heat transfer when compared to water. However, for the nanofluid characteristics itself, it was observed that as the diameter decreased and the concentration increased, the heat transfer values also improved. The ideal values identified in this research indicated that at 7 % volume fraction, and 15 nm particle size the results are most optimal. There is also an indication that as the Reynolds Number increased, the heat transfer enhancement values such as Nusselt Number and heat transfer coefficient also improve.

ABSTRAK

Penukar haba merupakan sistem penting yang digunakan untuk pemindahan haba. Sistem ini terlibat dalam banyak aplikasi dan utiliti. Sistem ini boleh terlibat aplikasi besar sperti kilang penapis minyak, atau aplikasi kecil seperti dalam peti sejuk dan penghawa dingin. Walau bagaimanapun, terdapat beberapa jenis penukar haba memberikan manfaat dan kelebihan mereka sendiri. Dalam kajian ini, dua jenis penyelesaian pemindahan haba pasif akan digunakan untuk menyiasat secara numerik hubungan antara diameter zarah nanofluid dan kepekatan pecahan isipadu cecair. Terutama ialah paip berganda dengan salib berbentuk eliptikal yang mempunyai mekanikal aliran kontra-bendalir. Kemudian digabungkan dengan teknik pasif yang lain, iaitu penggunaan nanopartikel dalam gabungan dengan air, yang menghasilkan nanofluid. ANSYS akan digunakan sebagai alat untuk menstimulasikan pelbagai senario yang menggunakan nanopartikel dengan berbeza. Kondisi dan geometri sempadan, serta persamaan pentadbiran dan jejaring penukar haba bersifat simulasi. Eksperimen ini dijalankan di bawah rejim aliran lamina di dalam tiub eliptikal tiub dua penukar haba. Kehasilan stimulasi yang menunjukkan bahawa nanofluid seperti silikon oksida akan meningkatkan pemindahan haba apabila dibandingkan dengan air. Walau bagaimanapun, bagi ciri-ciri nanofluid itu akan diperhatikan bahawa apabila diameter yang menurun dan penumpuan yang meningkat, nilai pemindahan haba juga akan bertambah. Nilai-nilai ideal yang dikenalpasti dalam kajian ini akan menunjukkan bahawa pada 7% pecahan yang jumlah, dan saiz zarah 15 nm hasilnya paling optimum. Terdapat juga petunjuk bahawa ketika Reynolds Numberyang yang meningkat, nilai peningkatan pemindahan haba seperti Nusselt Number dan pekali pemindahan haba juga bertambah baik.

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LIST OF ABBREVIATIONS

HTE	Heat Transfer Enhancement
ANSYS	Analysis System

LIST OF SYMBOLS

Avg	-	Average
N	-	Avogadro number
Bf	-	Base fluid
K_B	-	Boltzmann constant (J/K)
B	-	Brownian
B	-	Bulk
Tb	-	Bulk temperature, K
Dc	-	Coil diameter
Pc	-	Coil pitch
i, j	-	Component
Conv	-	Convective
D	-	Darcy
P	-	Density (kg/m^3)
M	-	Dynamic viscosity (kg/m^3)
Eff	-	Effective
Ƒ	-	Fluid
D*f*	-	Fluid molecule diameter, (m)
f	-	Friction factor
C_f	-	Skin friction coefficient
q''	-	Heat flux (W/m^2)
H	-	Heat transfer coefficient, (W/m^2. K)
Q	-	Heat transfer rate, (W)

A	-	Heat transfer surface area, (m^2)
N	-	Kinematic viscosity (m^2/s)
M	-	Mass flow rate, (kg/s)
Nf	-	Nanofluid
Np	-	Nanoparticle
Dp	-	Nanoparticle diameter, (m)
Nu	-	Nusselt Number (dimensionless)
Pr	-	Prandtl number (dimensionless)
P	-	Pressure (Pa)
T_0	-	Reference temperature
Re	-	Reynolds Number (dimensionless)
Cp	-	Specific heat capacity, (J/kg K)
T	-	Temperature (Celsius, Kelvin)
K	-	Thermal conductivity, (W/m. K)
A	-	Thermal diffusivity (mm^2/s)
H	-	Thermal performance factor (dimensionless)
Dh	-	Tube hydraulic diameter, (m)
Di	-	Tube inner diameter, (m)
L	-	Tube length, (m)
Do	-	Tube outer diameter, (m)
U	-	Velocity (m/s)
Φ	-	Volumetric concentration (%)

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Heat transfer has always been an important topic in many industries due to its energy-saving abilities. Heat exchangers are used as systems and devices to enhance heat transfer in a variety of applications (Sheikholeslami, Gorji-Bandpy and Ganji, 2015). There are several methods in which heat transfer is enhanced, one such method is through the fluids used in the heat exchangers. One of the most widely used fluids for heat transfer is water, oil or ethylene glycol. These fluids are relatively easy to obtain and use, however they are not as effective as they need to be due to the fact that their thermal conductivity is considered to be low. Thus, in order to enhance the conductivity of the fluids, suspended particles were added to these base fluids that would enhance their conductivity by a great margin. These particles are mostly nano sized, and are often based on metal oxides, as the metal aspect of the formation would improve the thermal conduciveness of the fluid overall.

Thus, with the advances in the field of nanotechnology, the use of nanoparticles have become a popular additive in chemical engineering that would aid in a variety of applications, such as improving thermal conductivity (Choi and Eastman, 1995). After the initial spread of nanoparticles, researchers used them in 1999 in order to improve thermal conduciveness, and the results indicated a 20 % increase in conductivity when combining the copper oxide (CuO) nanoparticles in tandem with ethylene glycol (Lee et al., 1999)

There are several studies that focus on the thermal conduciveness of the nanofluids using different types of nanoparticles. Copper oxide (CuO) has shown to improve thermal conduciveness by 60 % in research performed by Sivakumar, Alagumurthi and Senthilvelan (2014), in which the nanoparticle was mixed in with water in order to produce the copper oxide nanofluid.

There are experimental researches that use different flow regimes (turbulent/laminar) to enhance the heat transfer of nanofluids (Karimzadehkhouei et al., 2019; Gheynani et al., 2019; Rasheed et al., 2018; Sajadifar et al., 2017). There seems to be a relationship between varieties of factors related to the enhancement performance of the nanofluids. Significant heat transfer performance was reported by Wen and Ding (2005), with the use of aluminium oxide as the nanofluid, used in a copper tube, under the laminar flow conditions.

Research indicates that the change in nanofluids' volume fraction, has a positive impact on heat transfer performance under constant temperature settings (Madhesh and Kalaiselvam, 2014). Another experiment which was conducted both numerically and practically used aluminium oxide in a spiral coil tube ((Doshmanziari et al., 2016. The results indicated that under a constant temperature the aluminium oxide would improve heat as the particle size is reduced and the volume fraction is increased. The use of a constant temperature in the experiment, allows for the removal of temperature as the main element of heat transfer, thus making the experiment itself relatively self-contained. Thus, other affecting elements such as the diameter of the particles as well as the volume fraction degree of effectiveness are more visible and measurable. Other than copper oxide and aluminium oxide, other nanoparticles are also used, such as zinc oxide, silicon oxide, and other types of metal oxide, each with varying degrees of effectiveness (Akbari et al., 2017; Karimzadehkhouei et al., 2017; S. Lee et al., 1999).

Laminar flow has several key applications that make it just as important as turbulent. Some examples include air-fuel usage in planes, thermal-based mass flow controller, unidirectional flow in pharmaceutical industries, in oil refinery stations for separating the gas from oil and water, and the water pump engines.

1.2 Problem Statement

Although there are several studies that use nanofluids to improve heat transfer, there is certainly a lack of deep numerical studies on the effects of silicon oxide and zinc oxide as nanoparticles with various diameters. The novelty of this study is suggesting an analytical method to study the heat transfer enhancement in a double pipe heat exchanger with an inner tube that has an elliptical cross-section. The various characteristics under test that relate both to the new geometry of the tube, as well as the related factors affecting the heat transfer via the nanofluid lead to an understanding of obtaining an optimal value using some of the underutilized nanoparticles as a form of enhancing the heat transfer rate. Although the main shape is a double pipe heat exchanger, the inside pipe geometry poses a different kind of problem which can be seen in Figure 1.1. Here, the exact solution of the Nusselt Number in terms of aspect ratio is presented.

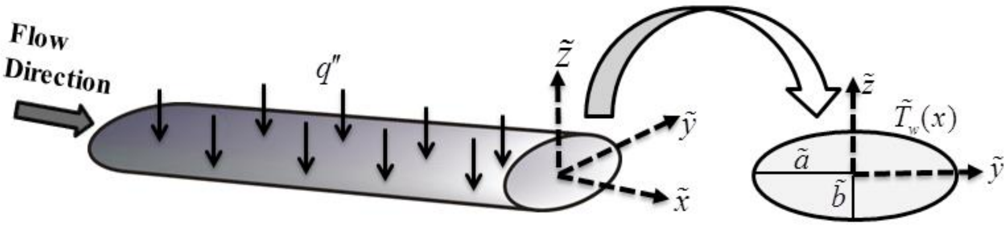

Figure 1.1 Shape of the inner tube

In this research, the laminar water based metal oxide nanofluid flow inside a double pipe elliptical tube is simulated using a finite volume method. Turbulent flows often have a higher rate of heat transfer as compared to laminar flow, which is why they require further assistance when it comes to heat transfer enhancement. Laminar flow is also not used as often as the Turbulent flow, and it has a lower research rate. This is mainly due to the fact that the turbulent flow regime is much more commonly used among heat exchangers, and the laminar fluid flow is only used in very certain industries. However, this does not make it any less critical. Thus, the heat transfer properties of nanofluids in laminar flow regime needs to be researched further, in order to gain a better understanding of its improvement mechanics. Laminar flow has a lower heat transfer rate than turbulent flow, hence why in this research, the aim is to identify the optimum setup that can enhance heat transfer under laminar flow conditions using nanofluids.

1.3 Research Objectives

This research has the following objectives:

i. to numerically determine the heat transfer coefficient of zinc oxide and silicon oxide nanofluids when compared to water.

ii. to analyze the effect of nanofluid particle diameter, and volume fraction on heat transfer effectiveness.

iii. to examine the effects of Reynolds Number in an elliptical tube double pipe heat exchanger.

1.4 Scope of the Research

The scope of this research is limited to two nanofluids: Zinc Oxide (ZnO) and Silicon Oxide (SiO_2). These nanofluids will be tested with different diameters (15 nm, 35 nm and 55 nm) and different concentration in terms of volume fraction (4 %, 5 %, 6 % and 7 %). The simulation is conducted in an elliptical tube heat exchanger, with the fluid flowing in counter type, meaning the inner tube flow direction is the opposite of the outer tube. The flow regime in which the experiment is conducted is Laminar flow, with Reynolds Numbers from 1000 to 2500.

1.5 Significance of the Study

This study will conduct a deep numerical experiment on the various aspects of heat transfer in a double pipe elliptical inner tube. By performing this simulated experiment, a deeper understanding of the benefits of nanofluid are examined, and ultimately the optimal values needed to make sure the heat exchanger performs at its best. Values such as the type of nanofluid, as well as the specific diameter, and Reynolds Number with the degree of nanoparticle concentration.

1.6 Research Outline

This research is structured into the different chapter, each cover an important module of the study.

Chapter 1 focuses on providing a general overview of the research, by first providing an explanation for the background of the problem, which identifies the gaps in the research. This is followed by the problem statement, which highlights the main gaps that this dissertation will focus on. The research objectives are defined based on the elaborated and identified problem statement, and the scope of research, as well as the significance of the study, are there to reinforce the boundaries of the research as well as highlighting the main contributions that are provided by the study.

Chapter 2 focuses on reviewing the related literature that pertains to the study. There are several concepts that need to be covered before they are elaborated further. First and the foremost concept is the nanofluid and its effect on various heat transfer attributes. Then, there needs to be a deeper understanding of the transfer convection types in order to better differentiate laminar and turbulent flow regimes. Then, the shape of the tube and its effect on heat transfer is studies, which is then followed up by a review on the elliptical tube heat exchangers and how they affected heat transfer using the shape of the tube. Finally, the effect of specific nanofluids is studied and reviewed with those that use predominantly the nanofluids used in the review.

Chapter 3 focuses on the research methodology, which highlights the important components used for performing the numerical simulation (such as the tools and related formulation and equations that allow for the simulation to proceed).

Chapter 4 focuses on the results obtained by performing the simulation process presented in Chapter 3. The results are presented and analyzed on each level and compared with one another, as well as existing researches that share a similar aspect to the proposed heat transfer enhancement process.

Finally, Chapter 5 concludes the research by elaborating on the objectives of the research and how each was achieved. Also, several avenues as to how the study can be further enhanced or pushed forward are mentioned in this chapter.

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