HEAT TRANSFER ENHANCEMENT USING NANOFLUIDS IN A PARALLEL FLOW DOUBLE PIPE HEAT EXCHANGER

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ABSTRACT

Heat Exchanger are among those engineered designs in which is widely used among many industries. Thus, in this research a double pipe heat exchanger is numerically and mathematically investigated, in which the various characteristics of heat transfer are evaluated. The experiment is mainly conducted using nanofluids, hence why the characteristics of the nanofluid itself is also considered a variable. Copper oxide, and aluminum oxide are the two nanoparticles used to conduct the simulation. Each of these are tested using different diameter sizes, as well as different concentrations dissolved in water. The Reynolds Number is also floating between 5000 and 20,000. The aim is to determine the effect of volume friction and diameter of nanoparticle on heat transfer and fluid flow, via the use of a double pipe heat exchanger. This is done by numerically investigating the heat exchanger by using ANSYS software system, which is able to simulate the results as well as the various characteristics involved. The results indicated that aluminum oxide is superior to copper oxide in terms of heat transfer enhancement. They also indicated that as the diameter of the nanoparticles increased, the heat transfer effectiveness decreased. The most optimal solution presented itself as the lowest diameter, and highest concentration in relation to the base fluid. When compared to the conventional fluid (water) the heat transfer coefficient was improved by 94.7% on average, and the Nusselt Number was also improved by 44.5%. Furthermore, there was a 45.37% improvement observed when comparing the best obtained results to an existing literature that uses a double pipe heat exchanger, and a 61.3% improvement for when the results are compared to an existing baseline straight tube heat exchanger. The results also indicated that there are minor differences between parallel and counter-flow regimes in the double pipe heat exchanger, with the counter-flow performing better at higher Reynolds numbers, while the parallel performs better when under 10,000 Reynolds number. This indicates that the proposed solution is practical and better to use versus water.

ABSTRAK

Pembalik haba adalah antara reka bentuk rekayasa yang banyak digunakan di kalangan industri-industri. Oleh itu, dalam penyelidikan ini penukar haba paip berganda diselidiki secara numerik dan matematik, di mana pelbagai ciri pemindahan haba dinilai. Eksperimen ini dijalankan terutamanya menggunakan nanofluid, oleh itu mengapa ciri-ciri nanofluid itu sendiri juga dianggap pemboleh ubah. Tembaga oksida, dan aluminium oksida adalah dua nanopartikel yang digunakan untuk melakukan simulasi. Masing-masing diuji dengan menggunakan ukuran diameter yang berbeza, serta kepekatan yang berlarutan di dalam air. Nombor Reynolds juga terapung antara 5000 dan 20,000. Tujuannya adalah untuk menentukan kesan geseran isipadu dan diameter nanopartikel pada pemindahan haba dan aliran bendalir, melalui penggunaan penukar haba paip berganda. Ini dilakukan dengan memeriksa penukar haba secara berangka dengan menggunakan sistem perisian ANSYS, yang dapat mensimulasikan hasilnya serta pelbagai ciri yang terlibat. Hasil kajian menunjukkan bahawa aluminium oksida lebih unggul daripada oksida tembaga dari segi peningkatan pemindahan haba. Ini juga menunjukkan bahawa ketika diameter nanopartikel meningkat, keberkesanan pemindahan haba menurun. Penyelesaian yang paling optimum menunjukkan ianya sebagai diameter terendah, dan kepekatan tertinggi berkaitan dengan bendalir asas. Jika dibandingkan dengan cecair konvensional (air), pekali pemindahan haba meningkat rata-rata 94.7%, dan Nusselt Number juga bertambah 44.5%. Selain itu, terdapat peningkatan 45.37% yang diperhatikan ketika membandingkan hasil terbaik yang diperoleh dengan literatur yang ada yang menggunakan penukar haba paip berganda, dan peningkatan 61.3% untuk ketika hasilnya dibandingkan dengan penukar panas tiub lurus garis dasar yang ada. Hasilnya juga menunjukkan bahawa terdapat perbezaan kecil antara rejim selari dan aliran balik dalam penukar haba paip berganda, dengan aliran balas yang lebih baik dalam jumlah Reynolds yang lebih tinggi, sementara selari menunjukkan prestasi yang lebih baik ketika di bawah 10.000 jumlah Reynolds. Ini menunjukkan bahawa penyelesaian yang dicadangkan adalah praktikal dan lebih baik digunakan berbanding air.

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LIST OF ABBREVIATIONS

HTE	Heat Transfer Enhancement
DPHE	Double Pipe Heat Exchanger

ν	-	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)
α	-	Thermal diffusivity (mm^2/s)
η	-	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 (%)

[redacted]

INTRODUCTION

1.1 Background of the Study

Heat exchangers play a great role in energy efficiency, as the world is moving towards a more fuel efficient environment, and the industries aim to save capital and resources in any way possible, leads to the popularity and importance of the heat exchangers as an important energy management system. Heat exchangers are also used in many everyday appliances and utilities, from refrigerators, to air conditioners, they usage is rather universal. Thus, the popularity and usage of double pipe heat exchangers has only grown with the rising demand in the industry (Goodarzi et al., 2016; Hashemian et al., 2016; Sheikholeslami et al., 2016a; Bahmani et al., 2018).

Generally, heat transfer methods are divided into two types of active and passive (Sidik et al., 2017). Each of these types depends on the source in which they originate from. While the active techniques rely on an external source in order to regulate the heat transfer process, the passive techniques would focus on internal solutions, such as changing the chemistry of the fluid involved as well as changing the shape of the pipes or tubes. In this scenario, a double pipe heat exchanger has been proved to be an effective form of heat transfer enhancement. On the other hand, other techniques such as the usage of nanofluids, which are basically a mixture of a base fluid such as water, with nanoparticles, have shown to improve the heat transfer rate as well.

Previously, there has been studies that use a double pipe heat exchanger in order to improve heat transfer rate (Goodarzi et al., 2016; Hashemian et al., 2016; Shakiba et al., 2016; Sheikholeslami et al., 2016a; Sheikholeslami et al., 2016c; Templeton et al., 2016; Bahmani et al., 2018). For instance, in a research that was carried out with the aim of investigating the effectiveness of the double pipe heat exchanger, it was found that by combining both heat transfer and a variety of different working fluids, that the heat transfer rate is enhanced considerably when compared to a base fluid with no nanoparticles (Goodarzi et al., 2016). Another researcher investigated the effect of discontinuous helical tabulators on heat transfer rate and characteristics in a double pipe heat exchanger (Sheikholeslami et al., 2016a). The results of the experiment indicated that the Nusselt Number and the Friction factors are affected by the open area and pitch ratios. However, this relationship has been ordained to be a negative relationship, meaning that as one is increased, the other is decreased or reduced. A numerical investigation on heat transfer properties of a double pipe heat exchanger was performed, which involves in digitally simulating the heat exchanger with various characteristics such as those that relate to the thermodynamics, as well as the geometrical and hydraulic attributes (Hashemian et al., 2016). Their simulation resulted in a solid enhancement in effectiveness of 55%, and a 40% improvement in the heat transfer number.

However, there are other studies that focus on nanofluids as the source of heat transfer improvement technique. Some of these techniques use a variety of nanoparticles mixed with a base fluid, which can either be water or any other type of base fluid, which ultimately contribute into creating the nanofluid. For instance, a study that conducted both a numerical, and practical experiment in order to analyze the heat transfer effectiveness of α-Al_2O_3 mixed with water as the base fluid (Akhtari et al., 2013). The experiment was conducted using the laminar flow conduction, with the results indicating that when compared to pure water, the double pipe performs better with a nanofluid than with no nanofluid.

1.2 Problem Statement

Conventional fluids such as water, oil, and ethylene glycol have relatively low thermal conductivity (Sajid et al., 2019). Thus, in order to enhance the thermophysical conduciveness of the liquids, nanoparticles are used that have innately higher thermal conduciveness. However, in many industries, the goal is to achieve the highest level of heat transfer enhancement. Thus, in most cases a combination of techniques are used in order to increase the performance of the heat transfer rate. Nanofluids is considered to be one of the additives that is typically combined with other techniques, such as shaped tubes for heat exchangers.

However, in spite of their great potential, these nanofluids are still in the early stages of development. There are several studies that indicate a relationship between nanoparticle sizes versus heat transfer coefficient. Some have also reported that an increase in concentration (volume fraction) of the nanofluid has led to an improved heat transfer (Chamkha et al., 2018). These parameters and factors all have a relationship with one another, and understanding this relationship is essential in identifying the most optimal combination of the aforementioned factors in order to enhance heat transfer. A big unresolved issue for most environmental and industrial applications is to find the flow and heat transfer behaviors of nanofluids towards different nanoparticle size and concentration on turbulent flow regime (which is widely used in all industries) (Sajid et al., 2019). The volume fraction and particle size have shown to have great effect on the heat transfer properties, however the extent of their usefulness in a parallel flow double pipe heat exchanger needs to be explored further.

Double Pipe Heat Exchangers also have several innate disadvantages, and almost none of the existing techniques uses parallel flow, as mostly focus on counter flow (Bahmani et al., 2018). Thus, there is a need to enhance the parallel flow heat transfer enhancement so that there are less application restrictions.

In this study, heat transfer and turbulent fluid flow of water/Al_2O_3-CuO nanofluids in a double pipe heat exchanger are numerically investigated. In this research, effects of nanoparticles volume fraction and Reynolds Number on temperature variations of base fluid, nanofluid and wall, thermal efficiency, Nusselt Number and convective heat transfer coefficient has been investigated. According to the abundant application of heat exchangers in heat transfer of power plant equipment, the results of this research can be used in many industries, especially oil, gas and petrochemical industries.

1.3 Research Objectives

The objectives of this research are:

i. to determine the heat transfer coefficient in parallel flow double pipe heat exchanger.

ii. to measure the effects of flow rate on nanofluids and water for heat transfer enhancement.

iii. to analyze the effects of nanoparticle diameter and volume fraction (starting from 1% to 4%) on the heat transfer enhancement.

1.4 Scope of Research

The goal of this numerical experiment is to be as thorough as possible when it comes to the simulation. However, there are limits set that ensure the simulation process remains focused and not devolve into too many variations. For this reason, the focus of the simulation is on a parallel flow only, with a turbulent fluid flow characteristics using Reynolds Numbers 5,000 to 20,000.

The nanoparticles used are Copper Oxide (CuO) and Aluminum Oxide (Al_2O_3). These two metal oxide nanoparticles are among the most popular of the nanofluids, and are also very cost effective compared to the other metal oxides (Sajid et al., 2019). The pattern of these nanofluids is predictable, and thus they are used in order to better understand the parameters and characteristics of their effects on heat transfer. These particles are combined with water as a base fluid in order to create the nanofluid. This combination occurs at different concentrations which is measured in terms of volume fraction 1% to 4%. This volume fraction is chosen mainly due to previous research only focusing on less than 1% concentration (volume fraction). The goal is to see if higher volume fraction can enhance the heat transfer properties further, or that it would have an adverse effect. These values are also at around 4% maximum, since more than that is it not cost effective to use nanofluids (Chamkha et al., 2018).

The particles are also combined at different diameters, 25 nm, 50 nm and 100 nm. Usually, most studies take a single diameter, and test only using that value, however, in this study the goal is to see the effect of various different diameters, versus the other parameters that affect heat transfer enhancement.

There are many unknown factors that can affect the heat transfer effectiveness in a heat exchanger. A double pipe heat exchanger is used in order to better isolate the heat enhancement criteria, by controlling the temperature of the fluids inside and outside of the pipe (Bahmani et al., 2018). Thus, with the use of a double pipe heat exchanger, a nanofluid enhancement can be better examined and understood, with their underlying parameters that affect it.

1.5 Significance of Study

The role of conservation both in energy and material has become a critical point of interest as the price of fuel and material increases every day. However, with the rapid development and advancements in technology, the demand has only increased and become more conscious as with products that are smaller in size and shape, having new requirement for heat exchangers in which previously was not an issue. Thus, with the increase in demand, more effort has been put into improving the heat transfer rate of equipment, via heat transfer enhancement techniques. Based on the existing literature, some of the key elements and parameters affecting heat transfer when using a double pipe heat exchanger with various types of nanofluids. Furthermore, a sensitivity analysis is needed to evaluate the effects of Reynolds Number, nanoparticles volume fraction and entrance status of nanofluid on heat transfer rate and heat exchanger effectiveness inside a double pipe heat exchanger filled with nanofluid. By conducting a numerical study, an understanding of the effects of nanoparticles and their benefits are explored in a double pipe environment. This allows a deeper understanding of the nanoparticles such as copper oxide and aluminum oxide and their main difference due to their molecular composition. The experiment is also conducted on turbulent flow, which changes the way most particles behaves, thus it provides different challenges to overcome when it comes to heat transfer optimal level.

1.6 Research Outline

This research is structured into five chapters. Each of these chapters cover a specific aspect of the research. The structure is as following:

In Chapter 1, the main goals of the research are elaborated by first providing a basic background into heat transfer and heat exchangers, as well as nanofluids as a form of heat transfer improvement method. Once the background is elaborated, it is used as a precursor to the problem statement, which is then followed by the objectives of the research. The scope of research elaborates on the details that are used in the research. Finally, this chapter closes with significance of study and the research outline.

In Chapter 2, the literature review is elaborated. The aim of this chapter is to provide a complete background of the elements involved in heat transfer enhancement. The first main section focuses on the nanofluids as a heat transfer enhancement technique and the various sub-attributes that affect the performance of heat transference. The second section focuses on the double pipe heat exchanger and its effect on heat transfer enhancement. The third section performs a literature review and comparative analysis on different techniques that use both nanofluids and double pipe heat exchangers. The chapter closes with a critical analysis of existing research that is most recent and focuses on the usage of nanofluids and double pipe heat exchangers.

In Chapter 3, the research methodology is elaborated. This chapter starts with an overview of the research, and its various modules. It also elaborates the thermophysical properties of nanofluids as well the boundary conditions that are used for simulating the heat exchanger. The sections that follow focus on the simulation process with detailed steps on how the simulation is conducted using the appropriate tool.

In Chapter 4, the results of the simulation are discussed and analyzed. This chapter mainly follows the simulation process by numerically simulating the base fluid, the nanofluids and then comparing the results with one another and with researches that follow a similar research pattern. The chapter concludes by comparing the various heat transfer attributes such as Nusselt Number, heat transfer coefficient, and friction factor with nanofluid properties such as diameter and volume fraction (concentration).

In Chapter 5, the research is concluded. A reflection of the current objectives and how they were achieved is elaborated in the first section. The final section of this chapter proposes how future studies can be conducted in order to further the research field in both heat exchangers and nanofluids.

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