HEAT TRANSFER AND NANOFLUID FLOW CHARACTERISTICS THROUGH A CIRCULAR TUBE FITTED WITH HELICAL TAPE INSERTS

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To my beloved wife and my supportive parents

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ABSTRACT

Numerical investigations are conducted using finite volume method of study the laminar convective heat transfer and nanofluids flows through a circular tube fitted with helical tape insert. The continuity, momentum and energy equations are discretized and the SIMPLE algorithm scheme is applied to link the pressure and velocity fields inside the domain for plain tube and four different twist ratios of 1.95-4.89, two different types of nanoparticles, Al_2O_3 and SiO_2 with different nanoparticle shapes of spherical, cylindrical and platelets, 0.5-2.0 % volume fraction in base fluid (water) and nanoparticle diameter of 20-50 nm. The wall of tube was maintained at uniform heat flux. In this project, several parameters such as boundary condition (different Reynolds number), types of fluids (base fluid with different type of nanoparticles), different nanoparticle shapes, different volume fraction and different particle diameter are investigated to identify their effect on the heat transfer and fluid flow through a circular tube fitted with helical tape insert geometries. The numerical results indicate that the four types of Nanofluid achieved higher Nusselt number than pure water. Nanofluid with Al_2O_3 particle achieved the highest Nusselt number. For all the cases Nusselt number increased with the increase of Reynolds number and Nusselt number will increase through a circular tube fitted with helical tape insert with decrease of twist ratio.

ABSTRAK

Siasatan berangka dijalankan menggunakan kaedah isipadu terhingga kajian lamina pemindahan haba perolakan dan nanofluids mengalir melalui tiub bulat dipasang dengan memasukkan pita heliks. Kesinambungan, momentum dan tenaga persamaan adalah discretized dan skim algoritma MUDAH digunakan untuk menghubungkan tekanan dan halaju bidang dalam domain untuk tiub kosong dan empat nisbah twist yang berbeza 1,95-4,89, dua jenis nanopartikel, Al_2O_3 dan SiO_2 dengan berbeza bentuk nanopartikel daripada sfera, silinder dan platelet, 0.5-2.0% pecahan isipadu cecair dalam asas (air) dan diameter nanopartikel daripada 20-50 nm. Dinding tiub dikekalkan pada fluks haba seragam. Dalam projek ini, beberapa parameter seperti keadaan sempadan (nombor Reynolds yang berbeza), jenis cecair (cecair asas dengan pelbagai jenis partikel nano), bentuk nanopartikel yang berbeza, pecahan isipadu yang berbeza dan diameter zarah berbeza disiasat untuk mengenalpasti kesannya terhadap pemindahan haba dan aliran cecair melalui tiub bulat dipasang dengan heliks geometri memasukkan pita. Keputusan berangka menunjukkan bahawa empat jenis Nanofluid mencapai nombor Nusselt lebih tinggi daripada air tulen. Nanofluid dengan Al_2O_3 zarah mencapai nombor Nusselt tertinggi. Bagi semua kes Nusselt jumlah meningkat dengan pertambahan nombor Reynolds dan nombor Nusselt akan meningkat melalui tiub bulat dipasang dengan memasukkan pita heliks dengan penurunan nisbah twist.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

A	-	Cross-Section Area, m^2
a	-	Component of Vector
C_P	-	Specific Heat, kJ/kg.K
D_h	-	Hydraulic Diameter
d_p	-	Nanoparticles Diameter, m
d_f	-	Equivalent Diameter of a Base Fluid Molecule
f	-	Darcy Friction Factor
h	-	Average Heat Transfer Coefficient, $W/m^2.K$
k	-	Thermal Conductivity, W/m.K
M	-	Molecular Weight of Base Fluid
N	-	Avogadro Number, mol^{-1}
n	-	Direction Normal to the Surface Element
Nu	-	Nusselt Number
P	-	Pressure, N/m^2
P^*	-	Initial Guessed Pressure, N/m^2
$\bar{P}$	-	Pressure Correction, N/m^2
ΔP	-	Pressure Drop
PEC	-	Performance Evaluation Criteria Index
q''	-	Heat Flux Rate Per Unit Channel Length, W/m^2
Re	-	Reynolds number
T	-	Temperature, K
T_0	-	Reference Temperature, 293K
T_{in}	-	Inlet Temperature, K
u	-	Flow Velocity Component, m/s
$\bar{u}$	-	Velocity Correction, m/s
u^*	-	Initial Guessed Velocity, m/s

Greek Symbols

ρ	-	Density of Fluid, kg/m^3
μ	-	Dynamic Viscosity, $N.s/m^2$
β	-	Fraction of the Liquid Volume which Travels with a Particle
$\emptyset$	-	Nanoparticles Volume Fractions

τ	-	Shear Stress, kg/m^2

Subscripts

0	-	Plain tube
eff	-	Effective
f	-	Base Fluid
nf	-	Nanofluid
p	-	Particle
w	-	Wall
in	-	Inlet
M	-	Mean
i, j	-	Components
b	-	Bulk

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Heat exchangers application in industrial and engineering purposes are quiet popular. The need of analysis on heat transfer rate, efficiency and pressure drop with respect to long-term performance and economic aspects of the equipment, caused to a complicated design procedure. Higher pumping cost which is caused by the rise of pressure drop is the price that should be paid along with the improvement in the heat transfer rate by insert technologies and this is the reason to implement optimization on any methods or augmentation device which is about to be utilized in the heat exchanger between the benefits of higher heat transfer rate and higher frictional losses [1].

In general, methods of heat transfer enhancement are classified into three broad categories which will be explained.

1.1.1 Active method

In this method, the enhancement of heat transfer is caused by some external power input. Reciprocating plungers, use of magnetic field, surface vibration, fluid vibration, electrostatic fields, suction or injection and jet impingement are some examples which bring enhancement with some external power [2].

1.1.2 Passive method

In passive methods, surface and geometrical modifications which are applied to the flow passage and implementation of inserts or additional devices are used to augment the heat transfer rate. Inserts, swirl flow devices, treated surface, rough surface, extended surfaces, displaced enhancement devices, coiled tubes, surface tension devices and additives for fluids are some of the examples for passive method [3].

1.1.3 Compound method

Compound method is the combination of any two methods of augmentation which is implemented at the same time like a rough surface with twisted tape swirl flow device or fluid vibration [4]. This literature review is focused on the passive methods pipe heat exchanger. One of the applicable ways to enhance heat transfer rate in the convective heat transfer is to increase the effective surface area and residence time of the heat transfer fluids and it's the main principle of passive methods to generate the swirl and disturb the boundary layer to increase the effective surface area, residence time and the heat transfer coefficient. There are several passive methods to enhance the heat transfer performance but in this article the most popular and related ones are mentioned:

- Displaced enhancement devices: This insert method is applied to perform force convection. It made the fluid displaced from heated area to cool area or from the bulk fluid in the middle of the duct with the fluid at the surface and indirectly improves the energy transfer.
- Swirl Flow devices: The axial flow's secondary recirculation and production of the superimposed swirl flow inside a channel is the main purpose of swirl flow devices and they include helical strip, cored screw and twisted tape inserts and they are both applicable in single and two phase flow heat exchangers.
- Coiled tubes: Coiled tubes are more conventional in smaller heat exchangers. Secondary flows are produced to augment the heat transfer coefficient.

- Additives for liquids: Addition of solid particles, solvable additives and bubbles in single phase fluids reduces the surface tension and increase the heat transfer

Besides the theoretical experimental approaches, numerical simulation has established itself as the most practical and viable alternative to study and to understand different engineering problems. However, numerical simulations would not be possible without the recent developments and improvements in computers in terms of memory size and computing speed[5].

As the power of supercomputers have increased in terms of computing speed and memory capacity, the accuracy of numerical simulations for physical problems has also increased by adding more complexity to the laws governing the phenomenon or by adding more any scientific and engineering problem can be achieved by using numerical simulation techniques and supercomputers.

The execution of numerical simulation avoids not only the annoying measurement in full-scale experimental setups, but also the prohibitively expensive and at times construction of such devices. On the other hand, the use of theoretical tools to solve such problems is limited and cumbersome thus precludes reaching the final solution. In contrast, numerical simulations are possible only after the complete mathematical description of the physical phenomenon is done and often experimental measurements are needed in order to verify the accuracy of the numerical results. In this sense, some followers define the numerical simulation as the modern approach, which joins the theoretical and experimental approaches for studying a physical phenomenon [6].

Currently, numerical simulation is employed in several scientific, engineering and industrial areas, e.g. analysis of stability in mechanical structures, optimization of chemical reactions and combustion process, bonding energy and atomic collision. Representations of DNA three-dimensional structures and microbiological reactions, meteorological and weather prediction, fluid flow in turbo machinery and aerodynamics in vehicles, design of engineering devices involving fluid flow and heat transfer phenomena, etc. [5].

Conventional fluids, such as water, engine oil and ethylene glycol are normally used as heat transfer fluids. Although various techniques are applied to enhance the heat transfer, the low heat transfer performance of these conventional fluids obstructs the performance enhancement and the compactness of heat exchangers. The use of solid particles as an additive suspended into the base fluid is technique for the heat transfer enhancement. Improving of the thermal conductivity is the key idea to improve the heat transfer characteristics of conventional fluids. Since a solid metal has a larger thermal conductivity than a base fluid, suspending metallic solid fine particles into the base fluid is expected to improve the thermal conductivity of that fluid. The enhancement of thermal conductivity of conventional fluids by the suspension of solid particles, such as millimeter- or micrometer-sized particles, has been well known for more than 100 years [7].

1.2 Project objectives

The objectives of three-dimensional, steady state numerical simulation of laminar flow in the circular tube fitted with helical tape inserts are listed as:

- To study the effect of the geometrical parameters of helical tape inserts, using nanofluids on thermal and flow field.
- To investigate the effects of using different nanoparticles, different nanoparticles shape, different nanoparticle volume fraction and different nanoparticle diameter on the thermal and flow field.
- To examine the effect of Reynolds numbers on the thermal and flow fields.

1.3 Scope of this study

Numerical three dimensional and steady state investigation of thermal and laminar flow of working fluid (water and nanofluid) inside the circular tube fitted with helical tape insert will be studied. The scope of this study is as follows:

- Literature review on heat transfer characteristics in various types of helical tape inserts with different geometries.
- Literature review on properties of nanofluid.
- Using the ANSYS Design Modeler for modeling and ANSYS Meshing for meshing the tube with helical tape inserts.
- Using CFD code ANSYS FLUENT 15 software to model the internal nanofluid flow in the tube with helical tape insert.
- Using different Twist ratios of 1.95, 2.93, 3.91 and 4.89.
- Using different nanofluid type including Al_2O_3 and SiO_2.
- Using different nanoparticle shapes including spherical, cylindrical and platelets.
- Using different nanoparticle volume fraction φ of 0.5, 1.0, 1.5 and 2.0 %.
- Using different nanoparticle diameter d_{np} of 20, 30, 40 and 50nm.
- Calculating Nusselt number (Nu), Friction factor (f) and performance evaluation criteria index (PEC).

1.4 Dissertation Outline

This thesis is divided into five chapters as follows:

Chapter 1 contains introduction including background, objectives and scope of study.

Chapter 2 contains literature review which related to experimental and numerical, investigation of helical tape inserts using both conventional fluids and nanofluids and literature review on properties of nanofluid.

Chapter 3 is methodology of the research. It is comprised of mathematical and theoretical aspects governing equations of the fluid flow and heat transfer in helical tape inserts. Governing equations for thermophysical properties of nanofluids based on their nanoparticles shape, diameter and volume fractions are also presented. The geometry of numerical simulation as well as the assumptions and boundary conditions are explained in details. Furthermore, the computational and numerical method for solving the problem is elaborated.

Chapter 4 consists of three sections; the first section shows the grid independence test for the study. The second section presents the code validation results for laminar flow in the circular tube fitted with helical tape insert. The third section demonstrates the results of the present numerical work to investigate the effects of different twist ratios, nanofluids with different nanoparticle shapes, different nanoparticle volume fractions, different nanoparticle diameter on the thermal and flow fields.

Chapter 5 summarizes the conclusions obtained from the numerical simulation with related recommendations for future work.

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