UNIVERSITI PUTRA MALAYSIA

NUMERICAL AND EXPERIMENTAL ANALYSIS OF HEAT TRANSFER AND NANOFLUID FLOW THROUGH AN ANNULAR PIPE WITH ABRUPT CONTRACTION

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By

TUQA ABDULRAZZAQ

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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DEDICATION

To

My late Mother

Who has supported me all the way, may ALLAH rest her soul in heaven

My lovely father

For his love, care and support

My husband, sister and sons

For their great encouragement

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the Degree of Doctor of Philosophy

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March 2015

Chairman: Mohd Khairol Anuar Bin Mohd Ariffin, PhD

Faculty: Engineering

The energy crises in the worldwide have been encouraging the researchers to look for new methods which increase of thermal performance. One of common technique to improve efficiency of energy system equipment is by changing the design configuration of channel and conventional fluid such as nanofluids. Enhancements of heat transfer and nanofluid flows through an annular channel with abrupt contraction are numerically and experimentally investigate. The finite volume method in three dimensional domains with an SST K-ω model is use in simulation. Aluminum oxide and titanium oxide (Al_2O_3, TiO_2) nanoparticles with volume fractions varied from 0.5% to 2% have been use. Reynolds number range varying between 10000 and 40000 and contraction ratios from 1 to 2 at heat flux varied from 1000 W/m^2 to 6000 W/m^2 were apply. In order to validate numerical results Al_2O_3 water based nanofluid was use in experimental study. The outer cylinder of the entrance pipe had a constant diameter while the outer cylinder of the exit pipe had different diameters to generate the contraction. Both the entrance and exit pipe were heated under uniform heat flux and the overall length of the inner cylinder were unheated and has constant diameter. The results showed that the maximum heat transfer coefficient was about 194.7% in an annular pipe with contraction ratio of 2 compared with a straight pipe, due to the generated recirculation flow zone that begins after the separation point of the wall. It was observed that by increasing nanoparticle volume fraction for all type of nanofluids, enhances the heat transfer coefficient due to augmented heat transport by nanoparticles in base fluid which raises the convection heat transfer where were about 26.9 % (Al_2O_3) and 5.5% (TiO_2). Also the effect of Reynolds number on the increase of surface heat transfer coefficient noted. Recirculation regions appeared to increase with increasing step height and Reynolds number. Also pressure drop observed decreases and increases before and after the step due to recirculation flow. The maximum pressure drop were about 7.5% (Al_2O_3) and 5.9% (TiO_2) nanofluid compared with pure water at contraction ratio of 2 and Reynolds number of 40000. Additional investigations have been done in this research in order to clarify the effect of

separation flow on augmentation of heat transfer and pressure drop. Heat transfer and turbulent fluid flow over double forward-facing step or through annular pipe with sudden contraction were performed numerically. Same findings have been observed in those studies where increase of thermal performance and pressure drop with increases Reynolds number and step heights.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

ANALISIS BERANGKA DAN EKSPERIMEN BAGI PEMINDAHAN HABA DAN ALIRAN BENDALIR-NANO MELALUI PAIP ANULUS DENGAN PENGUNCUPAN MENDADAK

Oleh

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Krisis tenaga di seluruh dunia yang telah mendorong para penyelidik untuk mencari kaedah baru yang dapat meningkatkan prestasi terma. Salah satu teknik yang sering digunakan bagi meningkatkan kecekapan peralatan sistem tenaga adalah dengan menukar konfigurasi reka bentuk saluran dan cecair konvensional seperti nanofluids. Peningkatan pemindahan haba dan aliran bendalir-nano melalui saluran anulus dengan penguncupan mendadak disiasat secara berangka dan ujikaji. Kaedah isipadu terhingga dalam ruang tiga dimensi dengan model SST K-ω digunakan dalam simulasi. Aluminium oksida dan Titanium Oksida (Al_2O_3, TiO_2) nanopartikel dengan pecahan isipadu diubah daripada 0.5% kepada 2% telah digunakan. Julat nombor Reynolds yang berbeza antara 10000 dan 40000 dan nisbah penguncupan daripada 1-2 pada fluks haba yang diubah daripada 1000 W/m2 untuk 6000 W/m2 telah digunapakai. Dalam usaha untuk mengesahkan keputusan berangka, bendalir-nano Al_2O_3 berasaskan air telah digunakan dalam kajian eksperimen. Silinder luar bagi pintu masuk paip mempunyai diameter yang tetap manakala silinder luar bagi paip keluar mempunyai diameter yang berbeza untuk menghasilkan penguncupan. Kedua-dua pintu masuk dan keluar paip telah dipanaskan di bawah fluks haba seragam dan panjang keseluruhan silinder dalaman tidak mengalami pemanasan dan mempunyai diameter yang tetap. Hasil kajian menunjukkan bahawa pekali pemindahan haba maksimum adalah kira-kira 194.7% dalam paip anulus dengan nisbah pengecutan 2 berbanding dengan paip lurus disebabkan zon aliran edaran semula yang dihasilkan bermula selepas titik pemisahan pada permukaan dinding. Ianya telah diperhatikan bahawa dengan peningkatan isipadu pecahan nanopartikel untuk semua jenis bendalir–nano telah meningkatkan pekali pemindahan haba disebabkan pertambahan pengangkutan haba dengan partikel-nano di dalam bendalir asas yang meningkatkan pemindahan haba perolakan pada kira-kira 26.9% (Al_2O_3) dan 5.5% (TiO_2). Juga kesan nombor Reynolds pada peningkatan pekali pemindahan haba permukaan telah diperhatikan. Kawasan edaran semula dilihat

meningkat dengan peningkatan ketinggian tetangga dan nombor Reynolds. Juga kejatuhan tekanan diperhatikan menurun dan menaik sebelum dan selepas tetangga disebabkan oleh aliran edaran semula. Penurunan tekanan maksimum adalah kira-kira 7.5% bagi (Al_2O_3) dan 5.9% bagi (TiO_2) bendalir-nano berbanding dengan air tulen pada nisbah pengecutan 2 dan nombor Reynolds 40000. Siasatan tambahan telah dilakukan dalam kajian ini untuk menjelaskan kesan aliran pemisahan terhadap peningkatan pemindahan haba dan kejatuhan tekanan. Pemindahan haba dan aliran bendalir bergelora melalui tetangga berkembar menghadap kehadapan atau melalui paip anulus dengan penguncupan mendadak telah dijalankan secara berangka. Penemuan yang sama telah diperhatikan dalam kajian tersebut di mana peningkatan prestasi terma dan kejatuhan tekanan berlaku dengan peningkatan nombor Reynolds dan ketinggian tetangga.

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This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfillment for the degree of Doctor of Philosophy. The members of the Supervisory committee are as follows:

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¶ the research conducted and the writing of this thesis was under our supervision;

¶ supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF NOMENCLATURE

A	Length of entrance pipe (m)
b	Length of exit pipe (m)
CR	Contraction ratio (CR=De/Dt)
De	Diameter of entrance pipe (m)
d	Diameter of inner solid rod (m)
Dt	Diameter of exit pipe (m)
Q	Heat Flux (W/m2)
H	Heat Transfer Coefficient ($W/m^2.K$)
Nu	Nusselt number
Pr	Prandtl number
P	Pressure (Pa)
Re	Reynolds number
C_p	Specific Heat Capacity (J/kg.K)
S	Step Height (m)
T	Temperature (K)
E	Total Energy (J/Kg)
k	Turbulence Kinetic Energy (m^2/s^2)
X_i	Upstream Length (m)
U	Velocity Component (m/s)
X, Y, Z	Cartesian Coordinates (m)

CHAPTER 1

INTRODUCTION

1. 1Background of the Study

Energy is such a great innovation which makes the life more comfortable and suitable. It has become most needed necessity for modern life. In the industrially advanced world, the demand for energy is increasing day by day, but at the same time resources of energy decrease according to continues consumption. The growing of pollution as another reason which putting pressure on companies to be more energy efficient and at the same time reduce emissions and pollution. Thermal loads can be considered as one of the energy consumption way which increasing in the recent years. Also, it has different applications such as transportation, microelectronics, utilization of solar energy for power generation and many applications in different fields. Therefore, the researchers have many presented studies to produce high energy efficiency which significantly lowering cost and pollution.

Heat transfer enhancement is one of the most important priorities for the efficiency of heat transfer equipment. So, in last two decades the main objective of investigations were to reduce the size of the heat exchanger, hence decreasing the costs related with material and manufacturing as well as the cost of fuel that used to produce power.

1.2 An overview of flow separation

Sudden changes in section area in flow passage such as contraction or expansion will lead to an important phenomenon of internal flows namely separation flow. Generally, it‘s happened when the boundary layer move adverse the pressure gradient where the speed of the boundary layer on the wall be zero. However it can be considered as one of viscous flow problems. Nevertheless, it has importance for science and practical applications as well.

The fact that stream lines diverge in a flow net means that there is a tendency for separation to occur. Whether separation occurs or not depends on the velocity, density and viscosity of the fluid. For a given fluid, separations will not accurse until a certain velocity is reached. Generally there are two types of flow separation, separation at external and internal flow. The turbulent flow separation has been considered to a larger extent compared to laminar range Chang (1970) and Kiya et al. (1975) due to:

a) Turbulent flows are more commonly encountered than laminar flows.

b) Separation is more expected to happen when the flow is turbulent.

c) The separation flow has a much larger effect in turbulent flows due to inertial effects where a big change of the local heat transfer rate in the separated flow regions and significant heat transfer enhancement may result up to the reattachment region.

1.3 Nanotechnology

One of the vital techniques which used in the recent years is nanotechnology. It can be considered as a revolution in heat transfer enhancement field. Nanofluids have been interesting significant attention in the heat transfer investigation community. It has unique feature as compared with micron-sized particles. The concept of a Nano fluid has been discovered by Choi and Eastman (1995) and utilized the nanotechnology in the heat transfer field and proposed the term of ‗nanofluids‘‘

Nanofluid is defined as suspension of nanoparticles in basic fluid (gas or liquid) which acts as base fluid. Stated the superior characteristic of nanofluids, which could increase the cooling or heating rate of heat exchangers it has small diameters measured in nanometers ,generally their sizes between 1 and 100 nm the main idea behind suspending such small particles in regular fluids is to increase as much as likely the thermal conductivity specially after several researches founded that adding of solid nanoparticles to fluids such as water are an effective approach to increase the critical heat flux and the thermal conductivity of these fluids as compared to the same fluids without nanoparticles in regular fluids. Nanofluids are not only liquid-solid mixtures, some special requirements are needed, e.g., even by dispersed and stable suspension, negligible accumulation of particles, no chemical change of the fluid but the suspending mechanism of these particles in their base fluids is depending on Brownian motions. When they are distributed in a balance between buoyant weight and thermal agitation and that is referred it as equilibrium with no flow. Nanophase powders have much greater relative surface areas and a great potential for heat transfer enhancement. Therefore it has great remarkable with a prediction that the successful employment of nanofluids will support the recent trend to component reduction by enabling the design of smaller and lighter heat exchanger.

Many studies in the past few decades as solids materials in particular metals can have high thermal conductivities where conducted on the thermal behavior of suspensions of particulate solids in liquids; for example (Ahuja (1975); Sohn (1981) ; Hetsroni & Rozenblit (1994)).

The base fluid can be either liquid such as water, ethylene glycol (EG), oils, or gas such as air and the materials used for nanoparticles contain noble metals (e.g., gold, silver, platinum) and metal oxides (e.g., alumina, zirconia, silica, titania)

Preparation of nanofluids included the two techniques to produce nanofluids as represented by the single-step and the two-step method. The single step directs the synthesis of nanofluids in one-step while the two-step method is widely used in the synthesis of nanofluids as the available commercial nanopowders delivered by several companies. In this method, nanoparticles are first created and then dispersed in the base fluids.

The nanofluid has many advantages one of these advantage is suspended nanoparticles have high specific surface area and therefore more heat transfer surface of nanoparticals which lead to increase heat capacity of the fluid. Also high dispersion stability with predominant Brownian motion of particles decreases pumping power when compared to the pure liquid to reach equivalent heat transfer increase. The properties of nanofluids are adjustable containing thermal conductivity and surface wettability by changing particle concentrations to suit different applications. In addition to many other advantages increasing the thermal conductivity of the base fluids and flattens the transverse temperature gradient of the fluid.

Generally, the nanofluids are considered to give significant advantages over conventional heat transfer fluids. The main factors which effect on thermal conductivity of nanofluids are volume fraction, shape and size of particles, and the thickness and the thermal conductivity of nanolayer Jang and Choi (2007), Chon et al. (2005), Eapen et al. (2007), Teja et al. (2010), and Yu et al. (2010).

1.4 Problem statement

The energy crises in the worldwide have been encouraging the researchers to look for new methods which increase of thermal performance. Generally there are two techniques have been used to enhance heat transfer (Anirudh and Mayank (2012).

Active technique (using external power. In this method using mechanical aids, surface vibration, and electrostatic).

Passive technique (use surface or geometrical modifications or adding Nanoparticles.

One of common technique to improve efficiency of energy system equipment is by changing the design configuration of channel with using nanofluids.
According to latest studies which presented by (Abu-Nada, 2008; Mohammed et al., 2012; Kherbeet et al., 2014; Togun et al., 2014; and Safaei et al., 2014) all of those investigations concerned heat transfer and nanofluids flow over backward or forward facing step with laminar range and microscale and most of them studied numerically. At present, there is a lack of studies for nanofluids flow and heat transfer through sudden contraction with lab scale, turbulent range, and use both simulation and experimental in same study.

1.5 Objective of the Research

The main objective of present research is to simulate and investigate nanofluid flow and heat transfer analysis through an annular pipe with abrupt contraction.
The sub-objectives of the present study are:

1. To study the effect of recirculation flow in nanofluids due to a abrupt contraction of an annular passage on thermal and flow fields.
2. To examine the effects of Reynolds numbers and heat flux on the heat transfer improvement for nanofluids.
3. To investigate the effect of contraction ratio of an annular passage subjected to turbulent nanofluids flow on heat transfer augmentation.
4. To obtain the effects of nanofluids types and concentration nanoparticales on thermal performance.

1.6 The novelty of research

The performed literature survey showed that the heat transfer and nanofluid flow for turbulent range through annular channel with contraction passage has not been investigated as yet experimentally and numerically. Therefore the novelty of this research represented by:

1. Heat transfer characteristics of nanofluids flow in sudden contraction studied by simulation and experimental.
2. Coupling effects of using nanofluids and recirculation flow on thermal performance.
3. Different types and volume fractions of nanofluids has been used.
4. Using lab scale set up for nanofluids flow.

1.7 Scopes of study

The scopes of this research are to study recirculation flow due to an abrupt contraction of an annular passage by simulation and experiments. Software used: ANSYS FLUENT14 - ANSYS ICEM and then export to FLUENT. The Simulation is based on:

1. Suitable governing steady-state Navier-Stokes, continuity, momentum and energy equations with incompressible flow are employed in these simulations with the SST K-ω Model.
2. Grid independent and code validations are conducted for validation purposes.

Assumptions

1. All flow involve is Turbulence
2. Simulation and Experimental work is carried out for prototype model, not the actual industrial size.

1.8 Limitation of research

1. Due to the settling of nanoparticles when increase of volume concentration of nanoparticle beyond a particular limit then no significant increase in convective heat transfer coefficient.
2. Increases of volume concentration of nanoparticle leads to increase viscosity which need higher pumping power then increase energy consumption.

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