

**NUMERICAL INVESTIGATION OF TURBULENT NANOFLUID FLOW
EFFECT ON ENHANCING HEAT TRANSFER IN STRAIGHT CHANNELS**

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To my beloved parents, wife and son.

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ABSTRACT

Turbulent friction and heat transfer behaviors of magnetic nanofluid (Fe_3O_4 dispersed in water) as a heat transfer fluid in three different cross sectional channels (circular, rectangular and square) was investigated numerically. The channels with hydraulic diameter of 0.014 m and 1.7 m length subjected a uniform heat flux (13500 W/m^2) on all their walls has been presented in order to determine the effects of geometry change, nanoparticle concentration and flow rate on the convective heat transfer and friction factor of nanofluid with neglecting the effect of magnetic flow field. Fe_3O_4 nanoparticles with diameters of 36 nm dispersed in water with volume concentrations of 0–0.6 vol. % were employed as the test fluid. The investigation was carried out at steady state, turbulent forced convection with the range of Reynolds number varied from 5000 to 20000, three dimensional flow, and single phase approach. Computational fluid dynamics (CFD) model by using FLUENT software depending on finite volume method was conducted. In this study, the result exhibited that the Nusselt number of nanofluid for all geometries is higher than that of the base liquid and increased with increasing the Reynolds number and particle concentrations. But the circular pipe had the highest value of Nusselt number followed by rectangular and square tube. On the other hand, for the friction factor, the results revealed that the friction factor of nanofluids was higher than the base fluid and increases with increasing the volume concentrations and decreases with increasing of Reynolds number. In addition the friction factor of square channel is higher than others followed by rectangular and circular channel, respectively.

ABSTRAK

Geseran gelora dan tingkah laku pemindahan haba bendalir nano bermagnet (Fe_3O_4 tersebar dalam air) sebagai bendalir pemindahan haba dalam tiga saluran keratan rentas yang berbeza (bulat, segi empat tepat dan segi empat sama) telah diuji secara berangka. Saluran-saluran berdiameter hidraulik sepanjang 0.014 m dan 1.7 m tersebut adalah tertakluk kepada fluks haba seragam (13500 w/m^2) pada kesemua dinding telah dibentangkan untuk menentukan kesan perubahan geometri, kepekatan zarah nano dan kadar aliran pada pemindahan haba perolakan, dan faktor geseran bendalir nano dengan mengabaikan kesan medan aliran bermagnet. Zarah nano Fe_3O_4 berdiameter 36 nm tersebar dalam air dengan jumlah kepekatan 0-0.6% isipadu diambil sebagai bendalir ujian. Penyelidikan telah dijalankan pada keadaan mantap, daya perolakan gelora dengan julat nombor Reynolds diubah daripada 5000 hingga 20000, aliran tiga dimensi, dan pendekatan fasa tunggal. Model Pengiraan dinamik bendalir (CFD) dengan menggunakan perisian FLUENT yang bergantung kepada kaedah isipadu terhingga telah dijalankan. Dalam kajian ini, keputusan menunjukkan bahawa nombor Nusselt bendalir nano untuk semua geometri adalah lebih tinggi berbanding bendalir asas dan meningkat dengan peningkatan nombor Reynolds dan kepekatan zarah. Tetapi paip bulat mempunyai nilai tertinggi nombor Nusselt diikuti dengan tiub segi empat tepat dan tiub segi empat sama. Sebaliknya, bagi faktor geseran, keputusan mendedahkan bahawa faktor geseran bendalir nano adalah lebih tinggi berbanding bendalir asas dan meningkat dengan peningkatan kepekatan isi padu dan berkurang dengan peningkatan nombor Reynolds. Selain itu, faktor geseran bagi saluran segi empat sama adalah lebih tinggi berbanding dengan yang lain diikuti oleh saluran segi empat tepat dan saluran bulat.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	x
	LIST OF FIGURES	xi
	LIST OF ABBREVIATIONS	xiv
	LIST OF SYMBOLS	xv
1	INTRODUCTION	1
	1.1 Background of Study	1
	1.2 Problem Statement	3
	1.3 Application of the Study	3
	1.4 Objectives of the Study	4
	1.5 Scope of the Study	4
	1.6 Dissertation Outline	5
2	LITERATURE REVIEW	7
	2.1 Introduction	7
	2.2 Fully Developed Turbulent Flow inside Straight Channels	8
	2.3 Fundamental of Nanofluid in Turbulent Flow	11

2.3.1	Introduction	11
2.3.2	Nanofluid – Definition	12
2.4	Nanofluid Assessment	14
2.4.1	Fluid Assessment Considering Only Heat Transfer Behaviour	14
2.4.2	Nanoparticle and Host Liquid Type	15
2.5	Production of Nanoparticles and Nanofluids	16
2.5.1	One Step Method	16
2.5.2	Two Step Method	17
2.6	Thermophysical Properties of Nanofluids	18
2.6.1	Thermal Conductivity of Nanofluids	18
2.6.2	The Effects of Particle Volume Concentration	22
2.6.3	The Effects of Brownian motion	22
2.6.4	Viscosity of Nanofluids	23
2.6.5	Temperature Effect	24
2.6.6	Particle Size Effect	24
2.6.7	Heat Capacity	25
2.7	Application of Nanofluids in Channels	25
3	METHODOLOGY	35
3.1	Introduction	35
3.2	CFD Theories	36
3.3	Turbulence Models	36
3.4	The CFD Modelling Processes	37
3.5	Mathematical Modelling Assumptions	39
3.5.1	Physical Models	39
3.5.1.1	Circular Channel	39
3.5.1.2	Rectangular Channel	40
3.5.1.3	Square Channel	40
3.5.2	Assumptions	41
3.5.3	Governing Equations	42
3.5.4	Boundary Conditions	47

3.5.5	Numerical Method	47
3.6	The Key Parameters of Flow and Heat Transfer	48
3.6.1	Dimensionless Parameter	48
3.6.2	Turbulent Channel Flow Correlations	50
3.7	Thermophysical Properties of Nanofluid	51
3.8	Summary	54
4	RESULTS AND DISCUSSION	55
4.1	Introduction	55
4.2	Code validation	56
4.2.1	Forced Convection through Different Straight Channels	56
4.3	Grid Independent Test	59
4.4	The Effect of Nanofluid Parameters	62
4.4.1	Effect of Nanoparticle Volume Concentration on the Average Nusselt Number and Heat Transfer Coefficient	62
4.4.2	Effect of Nanoparticle Volume Concentration on the Friction Factor	65
4.5	The Influence of Employing Different Cross Sectional Geometries	67
4.6	Summary	77
5	CONCLUSIONS AND RECOMMENDATION	78
5.1	Introduction	78
5.2	Conclusion	78
5.3	Recommendation for Future Work	79
	REFERENCES	80

LIST OF TABLES

TABLE NO	TITLE	PAGE
3.1	Dimensions of circular channel	39
3.2	Characteristics of rectangular channel	40
3.3	Characteristics of square channel	41
3.4	Thermophysical properties of base fluid (pure water) at T=293k°	53
3.5	Thermophysical properties of, with range of 0.1% - 0.6% and 36 nm particle diameter at T=293k°	53

LIST OF FIGURES

FIGURE NO	TITLE	PAGE
3.1	The general modeling step	38
3.2	Schematic diagram of circular straight channel	39
3.3	Schematic diagram of rectangular straight channel	40
3.4	Schematic diagram of square straight channel	41
4.1	Grid generation for three different cross sectional channels (a-circular, b-rectangular and c-square)	57
4.2	Comparison of the computed values of Nusselt number with results of Notter-Rouse and Sundar for pure water in three different geometries	58
4.3	Comparison of the computed results of friction factor for three different geometries with data of Blasius and Sundar for water in turbulent regime	59
4.4	Grid independent test of circular geometry for pure water	60
4.5	Grid independent test of rectangular channel for pure water	61
4.6	Grid independent test of square geometry for pure water	62
4.7 a	Average Nusselt number for Fe_3O_4 at different volume fractions and Reynolds numbers for circular channel	63
4.7 b	Average Nuesselt number for Fe_3O_4 at different volume fractions and Reynolds numbers for rectangular channel	63
4.7 c	Average Nuesselt number for Fe_3O_4 at different volume fractions and Reynolds numbers for square channel	64
4.7 d	Effect of volume fraction on heat transfer coefficient	65

4.8 a	Friction factor of Fe_3O_4 with different volume fraction and Reynolds number for circular channel	66
4.8 b	Friction factor of Fe_3O_4 with different volume fraction and Reynolds number for rectangular channel	66
4.8 c	Friction factor of Fe_3O_4 with different volume fraction and Reynolds number for square channel	67
4.9 a	Comparison of three different geometries in terms of Nusselt number at 0.1% volume fraction of Fe_3O_4	68
4.9 b	Comparison of three different geometries in terms of Nusselt number at 0.3% volume fraction of Fe_3O_4	68
4.9 c	Comparison of three different geometries in terms of Nusselt number at 0.6% volume fraction of Fe_3O_4	69
4.10 a	Comparison of three different geometries in terms of friction factor at 0.1% volume fraction of Fe_3O_4	70
4.10 b	Comparison of three different geometries in terms of friction factor at 0.3% volume fraction	70
4.10 c	Comparison of three different geometries in terms of friction factor at 0.6% volume fraction of Fe_3O_4	71
4.11 a	Contour of temperature distribution of circular channel for pure water at $\text{Re}=10000$	71
4.11 b	Contour of temperature distribution of circular channel for 0.1% of Fe_3O_4 at $\text{Re}=10000$	72
4.11 c	Contour of temperature distribution of circular channel for 0.3% of Fe_3O_4 at $\text{Re}=10000$	72
4.11 d	Contour of temperature distribution of circular channel for 0.6% of Fe_3O_4 at $\text{Re}=10000$	73
4.11 e	Contour of temperature distribution of rectangular channel for pure water at $\text{Re}=10000$	73
4.11 f	Contour of temperature distribution of rectangular channel for 0.1% of Fe_3O_4 at $\text{Re}=10000$	74
4.11 g	Contour of temperature distribution of rectangular channel for 0.3% of Fe_3O_4 at $\text{Re}=10000$	74
4.11 h	Contour of temperature distribution of rectangular	

	channel for 0.6% of Fe_3O_4 at $\text{Re}=10000$	75
4.11 i	Contour of temperature distribution of square channel for pure water at $\text{Re}=10000$	75
4.11 j	Contour of temperature distribution of square channel for 0.1% of Fe_3O_4 at $\text{Re}=10000$	76
4.11 k	Contour of temperature distribution of square channel for 0.3% of Fe_3O_4 at $\text{Re}=10000$	76
4.11 l	Contour of temperature distribution of square channel for 0.6% of Fe_3O_4 at $\text{Re}=10000$	77

LIST OF ABBREVIATIONS

Cp	-	Specific heat capacity (J/kg.K)
D	-	Diameter of channel (m)
H	-	Height of channel (m)
L	-	Length of channel (m)
K	-	Thermal conductivity (W/m.K)
Nu	-	Nusselt number
Nu _{ave}	-	Average Nusselt number
T	-	Temperature (K)
u	-	Velocity in x direction
v	-	Velocity in y direction
w	-	Velocity in z direction
Fr	-	Friction factor
Re	-	Reynolds number

LIST OF SYMBOLS

ϕ	-	Particle volume fraction
μ	-	Dynamic viscosity (kg/m.s)
ρ	-	Density (kg/m ³)
ν	-	Kinematic viscosity (m ² /s)
α	-	Thermal diffusivity (m ² /s)
ε	-	Internal energy (J/kg)

CHAPTER 1

INTRODUCTION

1.1 Background of Study

The usual design requirements for modern heat transfer equipment are reduced size and high thermal performance. In this connection, in the past decades a considerable research effort has been dedicated to the development of advanced methods for heat transfer enhancement, such as those relying on new geometries and configurations, and those based on the use of extended surfaces and/or turbulators. On the other hand, according to a number of studies achieved in recent times, a further significant contribution may derive by the replacement of traditional heat transfer fluids, such as water, ethylene glycol and mineral oils with nanofluids, i.e., colloidal suspensions of nano-sized solid particles, whose effective thermal conductivity has been demonstrated to be higher than that of the corresponding pure base liquid.

Straight channels are accounted as prime chambers which used for enhancement of heat transfer. They are widely used in electronic devices, heat exchangers, cooling of gas turbine blade, gas-cooled nuclear reactors and solar air heater ducts, etc. The augmentation of heat transfer in channels and pipes is based on various factors such as material of walls, types of fluid flow inside them, thermal properties of fluids and etc. Generally, the improvement of heat transfer implies the increase of heat transfer rate. According to Newton's law of cooling, and the equations related to heat transfer can be noticed that increasing in (convection heat

transfer coefficient, thermal conductivity, surface area and temperature difference between the surface and fluid) leads to increase in the rate of heat transfer. In recent years, many researchers have attempted to develop special classes of heat transfer fluids for augmentation of their heat transfer properties. An innovative method is to suspend small solid particles in the common fluid to form fluid slurries. Different types of solid particles, such as metallic, non-metallic and polymeric can be added into fluids. In the early studies, however, use of suspended particles of millimetre or even micrometre-size demonstrated unusually high thermal enhancement, but some extreme problems are also experienced, such as poor stability of the suspension, clogging of flow channels, eroding of pipelines and increase in pressure drop in practical applications. Although the solutions show better thermal performance compared to common heat transfer fluids, they are still not suitable for use as heat transfer fluids in practical applications, especially for the mini and/or micro-channel or even electronic cooling equipment. With the rapid development of modern nanotechnology, particles of nanometre-size (normally less than 100 nm) are used instead of micrometre-size for dispersing in base liquids, and they are called nanofluids. This term was first suggested by Choi [1] in 1995, and it has since gained in popularity. Compared with millimetre or micrometre sized particle suspensions, a number of researchers have reported that nanofluids have shown a number of potential advantages, such as better long-term stability, little penalty in pressure drop, and can have significantly greater thermal conductivity.

In general, nanofluids are colloidal mixtures of nanometric metallic, magnetic or ceramic particles in a base fluid, such as water, ethylene glycol or oil. Nanofluids possess immense potential to enhance the heat transfer characteristics of the original fluid due to improved thermal transport properties and according to passive studies that the non-metallic materials, such as alumina (Al_2O_3), CuO, TiO_2 , carbon and iron oxide Fe_3O_4 that possess higher thermal conductivities than the conventional heat transfer fluids.

1.2 Problem Statement

At the first part of problem statement, numerical investigation of thermal and flow fields of three dimensional fully developed turbulent flow with nanofluids in circular, rectangular, and square straight channels with constant heat flux.

Behaviour of nanofluids and modelling during heat transfer is still in the early stages of development and therefore it has not been fully investigated. Research is needed to advance nanotechnology and to determine heat transfer applications for nanoparticles/nanofluids. Research will help to understand the relationship of nanofluids and heat transfer rates at various operational conditions. Experiments will also help to understand the relationship of deposition of nanoparticles and its effect on heat transfer rates.

The research being conducted in this study uses nanoparticle of Fe_3O_4 , then studies the effects of three different shapes (circular, rectangular, and square straight channels) with different volume fraction on heat transfer enhancement and fluid flow without the effect of magnetic field.

1.3 Application of the Study

The amount of heat transfer rate through various shapes of straight channels considerably relies on the velocity of flow to carry out an impressive heat transfer that will be discussed in this study. This increment should be used in applications to keep high efficient system. Straight channels are largely performed in a wide range of applications for instance condensers, evaporators, oil radiators, heat exchangers, food industry, nuclear reactors renewable energy, thermal storage tanks in air conditioning and paint production to reduce the cost, weight and size. Therefore, the investigation of heat transfer in straight channel using fluids such as nanofluids in the present study will provide many details related to the fluid flow and thermal processes enhancement in channels. It could be employed to increase the heat

recovery quantity in plants (boilers and furnaces) for different sources of waste heat for example high temperature, medium temperature and low temperature range, for instance utility and industrial boilers, steel blast furnace, annealing furnaces, cement kiln and gas turbine exhaust by using gas to gas, gas to liquid and liquid to liquid heat recovery system according to the nature of the streams exchanging energy [2].

Usage of nanofluid is not only ideal for thermal applications but also will be used fully turbulent flow with high Reynolds number to enhance the heat transfer in this study. It would be obvious from foregoing notions that nanofluid has the potential to be proper alternative working fluid with higher thermal properties compared to a conventional fluid.

1.4 Objectives of the Study

The objectives of the present study can be outlined as follows

- 1- To investigate the effects of different Reynolds numbers on the thermal and flow fields.
- 2- To study the effect of nanofluid with different particles volume concentrations on the thermal and flow field Fe_3O_4 - water nanofluid on the heat transfer efficiency.
- 3- To examine the influence of geometry shape on thermal and flow field.

1.5 Scope of the Study

The scope of the present study can be limited to

- Reynolds number is ranging from 5000 to 20000.

- Assuming the type of flow is fully turbulent and forced heat transfer convection in the straight channel with circular, rectangular and square cross sections, respectively.
- Incompressible flow.
- Three dimensional flow.
- Steady state flow.
- Flow assumed to be single phase flow
- Nanofluid consists of Fe_3O_4 with volume fraction (0, 0.1, 0.3 and 0.6%) suspended in water as a base fluid.
- Using CFD code FLUENT 15 software to model the internal NF flow in the straight channel.

1.6 Dissertation Outline

This thesis is divided into five chapters as follows:

Chapter 1 contains introductory information as well as the problem statement and scope of this study. Applications of the study and the objectives of the project are also reported.

Chapter 2 presents the literature review which is related to the fluid flow and heat transfer problem in straight channels with various geometries involving experimental and numerical studies with different types of working fluids. The first section presents the fluid flow and heat transfer through straight channels, while the last section is related to nanoparticles and nanofluids parameters, application, production and thermo physical properties.

Chapter 3 focuses on the mathematical and theoretical aspects governing the forced turbulent convection heat transfer for three-dimensions in a straight channel. This chapter shows the numerical procedures for solving the present problem in details as well as the assumptions and limitations of boundary conditions for the

computational domain are also mentioned. Furthermore, the analysis and equations of nanofluids thermophysical properties are presented according to their diameter and volume fraction.

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