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NUMERICAL INVESTIGATION ON HEAT TRANSFER ENHANCEMENT IN A DOUBLE PIPE HEAT EXCHANGER USING ROD INSERTS AND NANOFLUIDS

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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Chairman : Siti Ujila Binti Masuri, PhD
Faculty : Engineering

In recent years, research on the methods for heat transfer enhancement in heat exchangers have received great attention in order to cater for the growing needs of higher efficiencies in these devices. For this purpose, double pipe heat exchanger with inserts devices is one of the many suitable techniques to enhance the heat transfer in heat exchangers. When fluid flows in a pipe with rod inserts fitted on the inner wall of the pipe, the flow becomes disturbed due to growing re-circulation regions near the pipe wall, which enhances the mixing of fluid as well as heat transfer. On the coolant side, the use of nanofluids (a liquid in which nanoparticles are added to a base fluid) can also enhance the heat transfer due to the improved thermal conductivity of the fluid.

The objectives of the present investigation are to improve the thermal performance of double pipe heat exchanger by using compound of vortex generator and nanofluids simultaneously. Different angles of vortex generators were examined. Four types of nanoparticles were investigated. Several solid particle diameters and concentrations were covered. Constant nanofluid properties and single- phase models were numerically considered.

A wide range of Reynolds number has been studied to cover the turbulent flow regimes. The results were subjected to Performance Evaluation Criteria to show their superiority. Numerical simulations have been achieved on wide parameters of forced convection heat transfer and nanofluids flow characteristics in the circular pipe by using turbulators protrusions namely, rod inserts of vortex generator. The rod inserts were attached on the inner wall of the test pipe while the wall was directly heated by using constant wall temperature of constant heat flux boundary conditions. The effects of four different slant angles of rod inserts (α=20°, 25°, 35°, 45°) with different of Reynold numbers from 7,500 -20,000 on the flow and thermal fields are presented and analyzed. Four different types of nanoparticles, Al_2O_3, CuO, SiO_2, and ZnO with different volume fractions in the range of 0% to 4 % and different nanoparticle diameters in the range of 20nm to 60nm, dispersed in a base fluid (water) were used. Comparisons of the numerical results with those available in the literature have been presented and a good agreement between the results is observed. The value of performance evaluation criterion (PEC) lies in the range of 1.74-2.82, which demonstrates that the rods strip insert has a very good thermo-hydraulic performance. From the numerical results, it is clearly seen that the heat transfer with rod inserts was higher than smooth tube. Results show that the average Nusselt number, heat transfer enhancement, pressure drop, as well as the thermal hydraulic performance increase with higher values of slant angle. The circular pipe with (α=45°) rod insert provides the highest thermal- hydraulic performance at amplitudes of 7500 and 20000 of Reynolds numbers.

A dramatic enhancement in Nusselt number obtained by using rod inserts of vortex generator and base fluid compared to the plane tube. Maximum enhancement of Nusselt number is about 174% by using rod inserts compared to the plane tube with water. The maximum skin friction coefficient has been found by using rod inserts in the tube at (α=45°) and pitch distance (S = 30mm). The maximum value of the (PEC) was found in the case of the lowest slant angle of (α =20°) and the pitch distance of S=30mm. Results presented show that the average Nusselt number, heat transfer enhancement, pressure drop as well as the thermal-hydraulic performance increase with higher nanoparticle volume fraction and with smaller diameter of nanoparticles. Furthermore, the SiO_2 water nanofluid provides the best thermal hydraulic performance followed by Al_2O_3, ZnO and CuO water nanofluids. The average Nusselt number and pressure drop in the circular pipe with different shapes significantly increase, as the Reynolds number increases. About 7.5 % enhancement in the heat transfer rate were observed for SiO_2-water nanofluid with 4% volume fraction and 20 nm particles diameter compared to the CuO-water nanofluid at the same volume fraction and particles diameter.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah ijazah Master Sains

PENYIASATAN BERANGKA BERKENAAN PENINGKATAN PEMINDAHAN HABA DI DALAM PENUKAR HABA PAIP BERGANDA MENGGUNAKAN SISIPAN ROD DAN NANOBENDALIR

Oleh

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Dalam tahun-tahun kebelakangan ini, penyelidikan mengenai kaedah untuk meningkatkan pemindahan haba di dalam penukar haba telah mendapat perhatian yang besar untuk menampung keperluan yang semakin meningkat terhadap kecekapan yang lebih tinggi di dalam peranti ini. Bagi tujuan ini, penukar haba paip berganda dengan peranti sisipan adalah salah satu daripada teknik-teknik yang sesuai untuk meningkatkan pemindahan haba di dalam penukar haba. Apabila bendalir mengalir di dalam paip yang mempunyai sisipan rod dipasang pada dinding sebelah dalam paip tersebut, aliran menjadi terganggu kerana kawasan peredaran semula membesar berhampiran dinding paip itu, yang meningkatkan pencampuran cecair serta pemindahan haba. Dari segi penyejuk, penggunaan nanobendalir (cecair di mana nanopartikel ditambah kepada cecair asas) juga boleh meningkatkan pemindahan haba kerana kekonduksian haba bendalir itu yang lebih baik. Objektif penyiasatan ini adalah untuk meningkatkan prestasi haba penukar haba paip berganda dengan menggunakan gabungan penjana vorteks dan nanobendalir serentak. Sudut penjana vorteks yang berbeza telah diperiksa. Empat jenis nanopartikel telah disiasat. Beberapa diameter zarah pepejal dan kepekatan diliputi. Ciri-ciri nanobendalir malar dan model fasa-tunggal telah dipertimbangkan secara berangka. Julat angka Reynolds yang luas telah dikaji untuk merangkum rejim aliran gelora. Hasil telah tertakluk kepada Kriteria Penilaian Prestasi untuk menunjukkan kelebihannya. Simulasi berangka telah dicapai pada parameter yang luas bagi pemindahan haba periplakin terpaksa dan ciri-ciri aliran nanobendalir di dalam paip bulat itu dengan menggunakan tonjolan gelora iaitu, sisipan rod penjana vorteks tersebut. Sisipan rod ditempatkan di dinding dalaman paip ujian manakala dinding tersebut dipanaskan secara langsung dengan menggunakan suhu dinding malar dengan keadaan sempadan fluks haba malar. Kesan daripada empat sudut condong sisipan rod yang berbeza (α=20º, 25°, 35°, 45°) dengan angka Reynolds dari 7500-20,000 terhadap aliran dan bidang-bidang haba dibentangkan dan dianalisis. Empat jenis nanopartikel, Al_2O_3, CuO, SiO_2, dan ZnO dengan pecahan isi padu yang

berbeza dengan julat 0% hingga 4% dan diameter nanopartikel yang berbeza dengan julat 20nm hingga 60nm, tersebar di dalam cecair asas (air) telah digunakan. Perbandingan keputusan berangka dengan yang terdapat di dalam kepustakaan telah dibentangkan dan kesesuaian yang baik antara keputusan diperhatikan. Nilai kriteria penilaian prestasi (PEC) terletak di dalam julat 1.74-2.82, yang menunjukkan bahawa jalur sisipan rod mempunyai prestasi termo-hidraulik yang sangat baik. Daripada keputusan berangka, jelas kelihatan bahawa pemindahan haba dengan sisipan rod adalah lebih tinggi berbanding tiub licin. Hasil menunjukkan bahawa purata angka Nusselt, peningkatan pemindahan haba, penurunan tekanan, serta prestasi hidraulik terma meningkat dengan nilai-nilai sudut condong yang lebih tinggi. Paip bulat dengan sisipan rod (α=45°) memberi prestasi terma-hidraulik tertinggi pada amplitud 7500 dan 20000 angka Reynolds. Suatu peningkatan dramatik dalam angka Nusselt telah diperolehi dengan menggunakan sisipan rod penjana vorteks dan cecair asas berbanding tiub satah. Peningkatan maksimum angka Nusselt adalah kira-kira 174% dengan menggunakan sisipan rod berbanding tiub satah dengan air. Pekali geseran kulit maksimum telah didapati dengan menggunakan sisipan rod dalam tiub di (α=45°) dan jarak pic (S=30mm). Nilai maksimum (PEC) didapati dalam kes sudut menyenget terendah ($\alpha = 20^{o}$) dan jarak pic S=30mm. Keputusan yang dikemukakan menunjukkan bahawa purata angka Nusselt, peningkatan pemindahan haba, kejatuhan tekanan serta prestasi terma-hidraulik meningkat dengan pecahan isipadu nanopartikel yang lebih tinggi dan dengan diameter nanopartikel yang lebih kecil. Tambahan pula, nanobendalir air SiO_2 memberikan prestasi hidraulik terma yang terbaik diikuti oleh nanobendalir air Al_2O_3, ZnO dan CuO. Purata angka Nusselt dan kejatuhan tekanan di dalam paip bulat dengan bentuk yang berbeza meningkat dengan ketara, apabila angka Reynolds meningkat. Kira-kira 7.5% peningkatan kadar pemindahan haba diperhatikan untuk nanobendalir air SiO_2 dengan 4% pecahan isipadu dan 20 nm diameter partikel berbanding dengan nanobendalir air-CuO pada pecahan isipadu dan diameter partikel yang sama.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Date:

Declaration by Members of Supervisory Committee

This is to confirm that:

- 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.

Signature: ____________________
Name of Chairman of Supervisory Committee: Dr. Siti Ujila Binti Masuri

Signature: ____________________
Name of Member of Supervisory Committee: Associate Professor Ir. Dr Nor Mariah bt. Adam

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

A	Area, m^2
Cp	Specific heat, kJ/kg. K
D	Hydraulic diameter, m
dp	Nanoparticles diameter, nm
C_f	Skin friction coefficient, $C_f = \frac{\Delta PD}{2L\rho u^2}$
h	Average heat transfer coefficient, $W/m^2 \cdot K$
k	Thermal conductivity, W/m·K
k_{eff}	Effective thermal conductivity, W/m. K
L	Length of tube, m
M	molecular weight (kg/mol)
m.b	The component of vector *b*
Nu	Nusselt number, Nu = h D/K
N	Avogadro number ($N=6.02214179\times1023\ mol^{-1}$)
P	Pressure, N/m^2
Pr	Prandtl number, Pr = μ Cp /k
PEC	Performance evaluation criteria, $PEC = Nu/Nu_{\circ}/(f/f_{\circ})^{1/3}$
q''	Heat flux rate per unit tube length, W/m
Re	Reynolds number, Re = ρ u D/μ
S	Pitch distance of louvered strip, m
T	Temperature, K

Greek symbols

α	Slant angle (°)
ρ	Density of fluid, kg/m^3
μ	Dynamic viscosity, Ns/m^2
ε	Turbulent dissipation rate, m^2/s^3
ϕ	Nanoparticles volume fraction

Subscript

o	smooth tube
av	Average value
b*f*	base fluid
eff	Effective
f	Fluid
nf	nanofluid
np	Nanoparticles
p	particle
w	wall

CHAPTER 1

INTRODUCTION

1.1 Research background

Forced convection heat transfer in a circular tube with inserts (Figure 1.1), has been a subject of attention in many research studies recently. In order to reduce the cost and the size of the heat exchangers devices and save up the energy, many engineering techniques played vital role to enhance the heat transfer rate among fluids in heat exchangers. One of best techniques has been used to improve the heat transfer rate is the passive method.

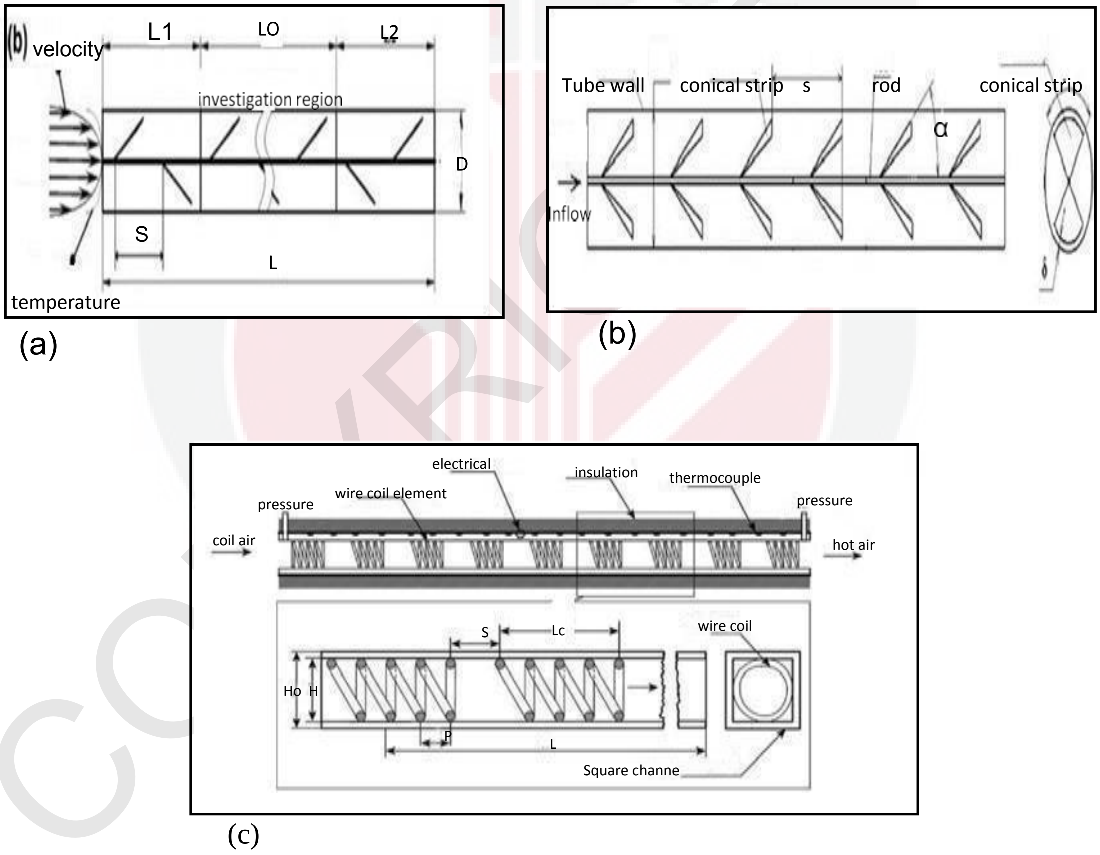

Figure 1.1*:* Tube inserts heat exchanger. (a) Fan et al. (2012), (b)You et al. (2012) (c) Eiamsa-ard et al. (2012)

The heat transfer enhancement techniques are employed to enhance the heat transfer rate between the fluids and the walls in the heat exchanger to save energy, reduce the cost and size of the heat exchanger. Passive method is one of the most important technique, which was used to enhance heat transfer. The passive technique involves the different elements inserts in order to increase the heat transfer coefficient from the flow surface through an increase in turbulent motion. The effect of various types of insertion elements in tube and channel on heat transfer enhancement were examined numerically and experimentally such as conical-strip inserts, vortex-generator VG inserts, V-finned tape inserts, twisted tapes inserts, wire coil inserts, butterfly inserts, helical tape inserts, Helical screw tape inserts, perforated circular disk inserts, louvered strip inserts, twisted tape and wire coil inserts, small rod insert, hollow twist tapes, and perforated plate inserts. The heat transfer enhancement technique in heat exchangers was improved and exceedingly employed in considerable engineering applications and industrial equipment such as; power plant, car radiator, process industry, solar thermal systems, petrochemical industry, air-conditioning, refrigeration, chemical reactors and nuclear reactor shell-and-tubes heat exchangers. The different insert in tube for previous studied was located in the core and the walls of the tube. Whilst the active techniques require a direct application of external power for enhancement, such as surface vibration, mechanical aids electrostatic fields and fluid vibration. Generally, the active techniques have received relatively little attention in research and practice because of the cost, noise, safety, or reliability concerns associated with the enhancement device and therefore the passive techniques are preferred. It is possible to combine two or more of the above techniques. These called compound technique, which can lead to preferable improvement in the heat transfer than the use each of enhancement techniques separately (Webb, 1994). The effect of thermal conductivity of liquids on heat transfer enhancement was previously made achievable by combine particles with base fluid (Maxwell, 1881). However, sediment, high-pressure drop erosion, and clogging caused by those small particles had tended the technology far to use the nanoparticles. Further enhancement in heat transfer has become essential. On coolant side, the low thermal conductivities of traditional fluids (water, ethylene and glycol oil) is considered as a fundamental obstacle to improve heat exchangers performance. To overcome this limitation, thermal conductivities of traditional heat transfer liquids can be improved by suspending nanoparticle, with the sizes less than 100 nm, to these fluids (Lee et al., 1999). These called ‘nanofluids’ was first presented by Choi in 1995, Figure 1.2. In general, nanoparticles materials used in nanofluids synthesis are Cu, CuO, Al_2O_3, TiO_2, SiO_2 etc. Thermal conductivity of nanofluid is depending on different parameters such as type, shape, size and concentration of solid particles in addition to the type of the base fluid (Eastman et al., 2001; Kihm and Chon, 2005; Peterson and Li, 2006; Mintsa et al., 2009; Chandrasekhar et al., 2010 and Lin et al., 2011).

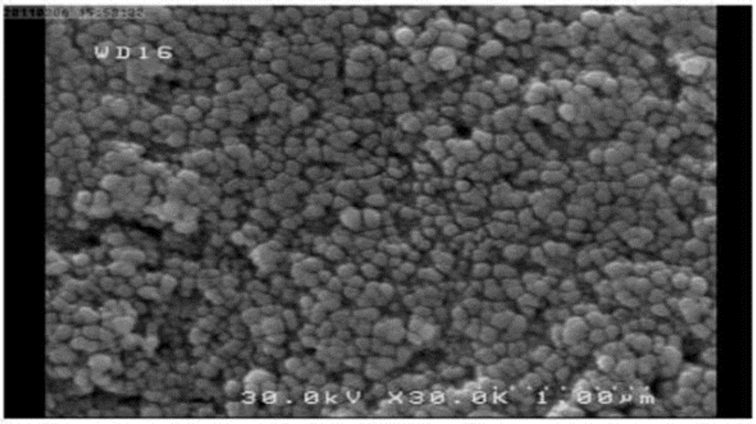

Figure 1.2: FESEM image of dispersed Al_2O_3 nanoparticles.
(Heyhat et al. 2012).

It is known that the thermal conductivity of the fluid effect directly on convective heat transfer coefficient. Several studies found that the improvement in heat transfer increased with particle volume fractions (Santra et al., 2009; Tahir and Mital, 2012; Bianco et al., 2011; Heris et al., 2013). Therefore, using nanofluid instead of traditional heat transfer can potentially lead to further improvement heat transfer of heat exchangers. The viscosity of nanofluid is also an important parameter in predicting the performance of heat exchangers because it affects the amount of pumping power of these devices. The viscosity of nanofluid has been studied by many researches (Chevalier et al., 2007; Chen et al., 2008; Pastoriza-Gallego et al., 2011). were observed that the viscosity of nanofluid raised with nanoparticles volume fraction. Other researchers observed that the viscosity of nanofluid increased when the particle size decreased (Namburu et al., 2007a; Pastoriza- Gallego et al., 2011).

Recent years, the subject of nanofluid has received great attention in research because of improved thermal conductivity of these fluids. For example, the convective heat transfer in smooth tube and duct has been numerically and experimentally studied by many researches (He et al., 2009, Santra et al., 2009; Rostamani et al., 2010; Bayat and Nikseresht, 2012; Abbasian and Amani, 2013). However, there are no numerical and experimental studies have been done on the heat transfer, and flow characteristics of nanofluid in circular pipe heat exchanger with rod insert fixed in the inner wall of a tube. In addition, the effect of different slant angle of rod inserts fixed on the surface of tube on thermal-hydraulic performance using nanofluids has never been reported. Therefore, the current study aims to fill the literature gap in this area.

1.2 Problem Statement

The global warming and the emission of carbon dioxide led to find way to improve the thermal performance of a heat exchanger. The heat exchangers have been used in many engineering applications and industrial devices such as power plant, car radiator refrigeration, air-conditioning, solar thermal systems, petrochemical industry, process industry, heat recovery process, cooler system for electronics devices, chemical reactor and refrigeration system etc. Lately the methods of heat transfer enhancement played essential role in order to improve the efficiency and the thermo-hydrodynamic performance of heat exchanger, which can improve the overall thermal efficiency for processes and systems. Therefore, methods of heat transfer enhancement are applied in order to reduce the cost, size and material of the heat exchanger. Some of applications need to design small size of heat exchanger for aerospace application and the cooling system for the computer and electronics devices. In addition, the changing in the geometrical parameters in order to increase the heat transfer rate are accompanied by increasing the pressure drop penalty. Moreover, the poor thermal conductivity and limitation of thermophysical properties of traditional fluids (pure water, engine oil and ethylene glycols) led to prepare new fluids, which can enhance the heat transfer. Nanofluid flow studies could lead to major steps forward in developing the next-generation coolants for numerous engineering applications. Their better capabilities in thermal properties can provide greater energy efficiency, smaller heat exchanger, low operation cost, and a much cleaner environment. Recently, many methods were used to enhance the thermophysical properties of fluids by increasing the thermal conductivity. One of the most important method is adding the metallic nanoparticles, which have high thermal conductivity (aluminum, gold, copper, etc. to the base fluid to increase thermal conductivity of the fluid. The advantages of using the nanofluids as working fluids led to test nanofluids in present study with inserts. This study aims to answer the following questions:

- What is the effect of different angle of rod inserts in tube on thermal-hydraulic performance?
- What is the performance of nanofluids flowing in circular pipe heat exchanger?

The hypothesis of the research are as follows:

Double pipe heat exchanger with rod inserts will enhance heat transfer.

- Offer of double pipe with rod inserts will increase the friction factor and pressure drop.
- Nanofluid will enhance heat transfer in double pipe heat exchanger.

1.3 Objectives of the Study

The objectives of the present work are:

i. To analyze the effects of different slant angles of the rods inserts α (20°, 25°, 35°, and 45°) with pitch distance (30mm) on the Nusselt number, pressure drops and skin friction coefficient in circular tube.
ii. To study the effect of nanofluids with different types of nanoparticles, different particle sizes, and several volume fractions on the Nusselt number, pressure drops and skin friction coefficient in circular tube.
iii. To examine the turbulent flow regimes (Reynold number Re in the range of 7500- 20000) and heat flux on the thermal performance and flow regions in the tube.
iv. To evaluate Performance Evaluation Criteria by using vortex generator in enhance tube and comparing it with the previous work.

1.4 Scope of the Work

the scopes of this research are to study the effect of rod inserts fitted on the inner wall of the tube with nanofluid as base fluid by simulation. software used: ANSYS FLUENT 14.5. The simulation is based on:

i. Stable governing steady-state Navier-stokes, continuity, momentum and energy equations with incompressible flow are employed in these simulations with K- ε RNG model
ii. The angles of the rod inserts are 20°, 25°, 35° and 45° fitted on the inner wall of the tube with pitch distance 30mm.
iii. Four types of Nano powders are studied; Al_2O_3, SiO_2, ZnO and CuO.
iv. Different nanoparticles concentrations are examined. They are 1, 2, 3, And 4%. Water is considered as base working fluids
v. Four solid particles diameters are tested, namely; 10, 20, 30, 40, 50 and 60 nm.
vi. Reynolds number is varied from 7,500 to 20,000 to cover turbulent flow regime.
vii. In the numerical modeling, the Low Reynolds number k-ε RNG model of Launder and Sharma (1974) was employed to simulate the turbulent flow regime.

1.5 Outline of the Thesis

There are 5 chapters in this thesis. The following is a brief outline of the synopsis of each chapter: The first chapter begins with an Introduction to the study. Following are the other key sections encompassing the Background to the study, the Problem Statement, Research Objectives and Research Questions, the scope of the current research, and the Outline of the thesis.

The second chapter is the review of the Literature which presented in 3 parts that cover the overview to the chapter; Nanofluids and reviews the use of various aspects of inserts in heat exchanger including Helical Screw Tape Inserts, Vortex-Generator(VG) Inserts, Twisted Tape Inserts, Louvered Strip, Conical Strip, Perforated Plate, Conical Strip, Butterfly Plate and Rod Inserts as well a range of other related aspects of the study in relation to the existing literature.

The third chapter, which also consists of 6 parts of the proposed numerical methodology used in this stuffy. Presented and discussed are the preamble to numerical methodology, an overview of CFD, its modeling, the physical model and the assumptions for the equations and boundary conditions, respectively. The final part of the chapter focuses on the thermophysical properties of nanofluids.

In Chapter 4, the focus is on the research outcomes and discussion in relation to the present study.

Chapter 5 presents the Conclusions derived from the outcomes of the current research while Recommendations are also made for further research related to the field of this study.

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Sadiq R. NFAWA, Siti, U. M., Nor Mariah, A. (2016). Heat transfer enhancement of nanofluid in a double pipe heat exchanger with rod inserts. Case study in thermal engineering. CSITE-D-00084.

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