COMPARISON OF LAMINAR AND TURBULENT MODEL OF NANOFLUID FLOW IN MICROCHANNEL

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A thesis submitted in fulfilment of the requirement for the degree of Bachelor of Mechanical Engineering (with honours)

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DECLARATION

I have declared that this thesis entitled "**Comparison of Laminar and Turbulent Model of Nanofluid Flow in Microchannel"** is the result of my own word except have cited as in the references and quality for the award for degree of Bachelor of Mechanical Engineering (with honours).

Signature : ....

Name : ....

Date : ....

DEDICATION

I would like to dedicate my thesis to my beloved father and mother, Hamzah Bin Ibrahim and Maznah Bt Ishak

My supervisor, Dr Ernie Bt Mat Tokit

And dear friends

APPROVAL

I hereby declare that I have read this report and in my opinion this report is sufficient in terms of scope and quality as a partial fulfilment for degree of Bachelor of Mechanical Engineering (with honours).

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Supervisor's Name : ....

Date : ....

ABSTRACT

This study compared the nanofluid flow and heat transfer in microchannel using laminar and turbulence model. The simulations work is done using ANSYS and Fluent softwares. The nanofluid used is alumina, Al_2O_3 with 100nm size particles and 1% volume concentrations as the cooling fluid. The heat sink for the rectangular microchannel consists of 1 cm^2 silicon wafer. The channel size is 180μm, width 57μm with the length 10mm. This microchannel are separated by the 43μm gap. The simulations performance is to evaluate fluid flow and heat transfer in terms of temperature profile, heat transfer, velocity profile, entrance length and Nusselt number for both laminar and k-εpsilon model. From the simulations results, the temperature rises along from the inlet to the outlet of the channel. The higher temperature are predicted at the heat sink top wall at the channel outlet. The temperature increases the linearly along the channel for the solid and fluid regions. At the channel inlet, the higher value for the Nusselt number is predicted, then decrease until approaching constant value. The entrance lengths for the k-εpsilon model is shorter compared to the laminar model due to the early fully developed. The velocity gradient for laminar much higher compared turbulence. The percentage error of entry length are predicted between laminar and turbulence models which are 18.23% and 4.6% respectively. The percentage deviation of Nusselt number between laminar and turbulence models are predicted to be 146.77% and 28.75% respectively.

ABSTRAK

Kajian ini membandingkan aliran nanofluid dan pemindahan haba di saluran mikro menggunakan model laminar dan pergolakan. Kerja simulasi dilakukan dengan menggunakan perisian ANSYS dan Fluent. Nanofluid yang digunakan ialah alumina, Al2O3 dengan zarah saiz 100nm dan kepekatan isipadu 1% sebagai cecair penyejuk. Sinki haba untuk saluran mikro segi empat tepat terdiri daripada wafer silikon 1 cm2. Saiz saluran adalah 180µm, lebar 57µm dengan panjang 10mm. Microchannel ini dipisahkan oleh jurang 43µm. Prestasi simulasi adalah untuk menilai aliran bendalir dan pemindahan haba dari segi profil suhu, pemindahan haba, profil halaju, panjang pintu masuk dan nombor Nusselt untuk model laminar dan k-epsilon. Dari hasil simulasi, suhu meningkat dari salur masuk ke salur keluar saluran. Suhu yang lebih tinggi diramalkan pada dinding atas sinki haba di saluran saluran. Suhu meningkatkan linear di sepanjang saluran untuk kawasan pepejal dan bendalir. Di salur saluran, nilai yang lebih tinggi untuk nombor Nusselt diramalkan, kemudian berkurang sehingga menghampiri nilai malar. Panjang pintu masuk untuk model k-epsilon adalah lebih pendek berbanding dengan model laminar disebabkan oleh perkembangan awal. Kecerunan halaju bagi laminar lebih tinggi berbanding pergolakan. Kesalahan peratusan panjang kemasukan diramalkan antara model laminar dan pergolakan yang masing-masing 18.23% dan 4.6%. Peratusan peratusan nombor Nusselt antara model laminar dan pergolakan dijangka masing-masing sebanyak 146.77% dan 28.75%.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

d_h	-	Hydraulic Diameter
H_{ch}	-	Height of microchannel
H_{w1}	-	Substrate thickness on insulated side of microchannel heat sink
H_{w2}	-	Substrate thickness on heated side of micro- channel heat sink
k	-	Thermal conductivity
Nu	-	Nusselt number
q”	-	Heat flux
Re	-	Reynolds number
T	-	Temperature
T_{in}	-	Fluid inlet temperature
T_m	-	Fluid bulk temperature
W	-	Width of micro-channel heat sink unit cell
W_{ch}	-	Width of micro-channel
$W_{w1,w2}$	-	Half-thickness of wall separating micro- channels
μ	-	Dynamic viscosity
ρ	-	Density

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Nanofluid is a mixture that usually made from two or more different substances with the two-phase flow. This fluid contains a small size of particles. Nanofluid also called nanoparticles. These fluid are produced by dispersing the particles in a fluid base for example water, oil and ethylene alcohol. Nowadays, nanofluid are widely used in biological, pharmaceuticals, lubrication industries and transportation. According to Akbar et al., (2017), this nanofluid plays as important part in the transportation as a coolant. The nanofluid provides the best efficiency in heat transfer, for example engines, pumps, radiators and small other components. Small vehicles can travel long distance using a little fuel. This will lead to less pollutions.

According to Kai & Peter (2014), nanofluid possesses enhanced thermophysical properties such as higher thermal conductivity and convective heat transfer coefficient as compared to the base fluid which is water. Nanofluid has the high quality of thermal properties and interesting potential applications. The nanofluid is much more stable thus make it attractive to the solution of cooling application.

Microchannel is a channel that a usually used in microtechnology. Micro means the channel with small size and small volume. Commonly microchannel has a hydraulic diameter below 1mm. Microchannel is one of the example of the microfluidics. Microchannel heat sink is a transfer of heat using a small channel. This channel used as the passage for the nanofluid to flow. According to (Manay & Sahin, 2016), nowadays technology development have increase such as developed devices which become smaller, faster and more powerful. Due to that performance, thus that devices will reach higher temperature value. Thus, this microchannel become good alternative as a cooling system.

In fluid mechanics, the boundary layer is a thin layer of fluid flow between the surfaces of solid for example surface inside the pipe and the fluid where the effect's viscosity is significant. There are three types in boundary layer which is laminar, transition and turbulent. This three types of boundary layers can be determined by the value of the Reynolds number which are laminar, transitions and turbulence. Reynolds number is the most important of the dimensionless quantity. Reynolds number are used to identify the different patterns fluids flow. Reynolds number contain three patterns which are laminar, transitions and turbulent. At low Reynolds number flow which is below 2000 is laminar "streamlines". At high Reynolds number flow which is over 4000 is turbulent "sinuous". The transition is between laminar and turbulent. Normally turbulent are most for the piping systems. Critical Reynolds number is a changing of flow from laminar to turbulent. The higher critical Reynolds numbers are depends on the upstream condition. The lower critical is value less sensitive. Values for the smooth circular pipes and tubes are below 2000. Critical Reynolds number is the Reynolds number which become turbulent. For internal flow inside circular pipe, the critical Reynolds number can be occurs on 2300. For the flow non-circular pipes, the Reynolds number are depend on the hydraulic diameter, Dh. (Cengel & Cimbala, 2014, pp. 347–352).

As we can see, in this study is all about the comparison of the laminar and turbulence flow for model inside microchannel. Then, the discussion about the fully develop flow for the laminar and turbulent inside the channel. Next, to find the entrance of fully developed regions and make comparison between laminar and turbulence. Next, the comparison between laminar and turbulence with theoretical value of Nusselt number.

1.2 Problem Statement

Flowing of nanofluid through rectangular microchannel can be identify through some process based on its parameter and thermal-physical properties. The laminar becomes turbulence flow at the critical Reynolds number. Does the critical Reynolds number are applicable for the nanoflow in microchannel analysis. The results will be difference for each difference of the geometries and flow conditions. Internal flow for the laminar flow are flowing in regularly and arranged along the channel. The energy and momentum will be transfer by molecules diffusion. For the turbulent flow, the flowing motions are in swirling like a whirlpool in transportation of mass, momentum and energy to other region. This is much faster and swiftly than molecular diffusion. Whenever the flow is steady, the whirling motion still causes fluctuations in values of velocity, temperature, pressure and density. So, the turbulence flow will link with the high value of friction, heat transfer and mass transfer coefficients.

1.3 Objectives

The following objectives of this study are:

i. to determine the entrance length,

ii. to determine the velocity gradient, and

iii. to determine the Nusselt number

of nanofluid flow using laminar and k-epsilon model.

1.4 Scopes

The scopes of this study are based on the following based parameter:

i. The microchannel is rectangular with hydraulic diameter of 86.58 μm.
ii. The Reynolds number of the nanofluid flow is 500.
iii. The turbulent model used is k-epsilon.
iv. The nanofluid used is laminar with 100nm particles and concentration of 1%.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The purpose of this chapter is to make a comparison between laminar and turbulence flow inside microchannel. The comparison will make based on value of Nusselt's that will get from the simulations. Next, the comparison between simulation and theoretical for the value of entry length. Then, the discussion for the fully develop of nanofluid inside rectangular microchannel. This chapter to provide a clear view about the concepts for laminar and turbulent flow and makes the theory easier to be understand.

2.2 Nanofluid Characteristics

Nanofluid have shown many curios properties in few decades. It became well-known due to widely used in industries, biomedical and so on. Nanofluid have found to acquire highly thermophysical properties such thermal conductivity and heat transfer coefficient.

Based on (Wang, Xu, & S. Choi, 1999), the thermal conductivity of the nanofluid will increase by decreasing the size of particles. By increasing the pressure drops, it's also same as increasing heat transfer. Based on (Momin, 2013), value for temperature changes will showing the changing by the presence of the nanoparticles of the nanofluid. The higher particle volume concentrations, so the Nusselt number will decrease for the horizontal inclination. However, for the vertical inclination, by increasing of particle volume concentration (0% to 4%), it shows that the Nusselt number remain constant.

2.3 Critical Reynolds Number and Its Significant

Reynolds number is a ratio between inertia forces to viscous force. This signify flow whether bounded or unbounded. This also show the pattern of flow such as turbulent or laminar. This flow depend on the property of fluid, characteristic or equivalent diameter. The critical Reynolds number functions as determination of flow from laminar to turbulence. The critical Reynolds number is to provide condition in boundary flow become turbulent from the laminar. This depend on the density, velocity, and viscosity of fluid in flow. This flow with respect to the surface and a characteristic length for example pipe. Transitions of turbulent also depend on the surface roughness.

Re (Reynolds number) for circular and non-circular channel.

Re < 2000; signify laminar flow,

2000 < Re < 4000; signify transition flow,

4000 > Re; signify Turbulent flow.

Reynolds (1883) with the classic experiment which is dye visualisation, it was proposed to differentiate of the criterion between laminar and turbulent flow for example in pipe flow. From the experimental studies, the results show value for the critical Reynolds number is 2100.

$$Re = \frac{DVp}{\mu}$$

Where : D = The hydraulic diameter of pipe (m)

v = The kinematic viscosity (m^2/s)

p = The density of the fluid (kg/m^3)

μ = The dynamic viscosity (kg/m.s)

At low Reynolds number usually dominated by the viscous effects, are commonly laminar flow. This laminar flow are typically with dynamic action and more stagnant. At higher Reynolds number which is turbulent with a lot slight and large whirl motion. Next, from the Reynolds conclusions, he found that there must be another critical velocity. Reynolds have done experiment by the measuring the pressure drop of some length to determined critical velocity. From the result of experiment, he found that for low speed the pressure loss must be proportional to the first power of velocity and must be varying with higher power that beyond to the lower critical velocity.

Akbarinia, Abdolzadeh, & Laur (2011) have done experiment analysis about the enhancement of the heat transfer by adding the nanofluids in microchannel with constant Reynolds number. The flow for nanofluid is laminar, steady stated and incompressible. The value Reynolds number are depends to the kinematic viscosity and inlet velocity of the nanofluid. By increasing the volume fractions in nanoparticles, the kinematic viscosity of nanofluids will increase. From that, results stated the flow for the nanofluid is laminar.

Zhang et al. (2016), have done the study about the flow resistance in laminar flow by using low Reynolds number in microchannel. The value for Reynolds number is between $10^{-5} < Re < 10^{-2.}$ Under the condition of low Reynolds number, the flow for the Newtonian is consistent in a smooth microchannel sized with the classic theory for laminar flow.

Majid, Mostafa and Alireza (2014), have done the numerical study about the turbulent flow for the nanofluid which is alumina Al_2O_3 inside the horizontal tube. The results of the study were compared between the experimental model and data and have been acceptable. From the result of the study, it shows that Nusselt number are depends on Reynolds number. By increasing Reynolds number, the Nusselt number will increasing.

Aghaei, Sheikhzadeh, Dastmalchi, & Forozande (2015), investigate the effect volume fractions of the nanoparticles on the average Nusselts number, skin friction factor and pressure drop. The results show that average Nusselt number depend on Reynolds number. By increasing value Reynolds number, will increase the average Nusselt number at all volume fraction. This result can be accepted because of the increasing in conductivity of nanofluid. The other causes is due to acceleration random motion of nanoparticles. Next, the skin friction factor is vary with the Reynolds number. As increasing the Reynolds number, the skin friction factor will decrease.

Rimbault, Nguyen, & Galanis (2014), has done the experimental on investigation of the hydraulic and thermal fields of a CuO water nanofluid (0.24%, 1.03% and 4.5%) flowing inside a microchannel heat sink at various volume fraction under both laminar and turbulent flow. From the study, the result shows for CuO-water have same as water for laminar-turbulent transition behaviour. The transition has occurs at the value of critical Reynolds number which is 1000. Thus, this is due to the surface roughness of the microchannel heat sink

Qu & Mudawar (2002), investigate of the fluid flow that use water a cooling fluid and heat transfer in a silicon rectangular microchannel heat sink. The result shows that the temperature rise which is flow nanofluid along channel can be approximated as linear flow. The length for the developing region is depend on the Reynolds number. As increasing Reynolds number will increase the length of the developing region. But, fully developed flow cannot be achieved at high Reynolds number. This is due to the Reynolds number affected by the thermal conductivity as it approaching to the channel outlet.

So, in this study will discuss about to determine the entrance length and velocity gradient at the fully developed regions. The discussion about the Nusselt number. This Nusselt number are depends on the Reynolds number. **Table 2.1** shows the result of critical Re determined by previous researchers.

Table 2. 1 : The result of critical Re determined by previous researchers.

Author	Nanofluid	Hydraulic Diameter	Results	Remarks
Sohel et al	Cu-H2O, Cu-EG, Al2O3-H2O, Al2O3-EG	200, 400, 600 μm		Diameter increase, thermal entropy rates generation increase
Rimbault, Nguyen, & Galanis	CuO - water	29 nm	Critical Re = 1000	Both nanofluid show similar laminar-turbulent transition behaviours as water.
Zhang	nanofluids Al203	5.0 μm - 17.4 μm	Re = 600 - 20000	Pr = 5.7-7.3, nusselt correlation to Pr num.

Khafeef & Albdoor	Al2O3-H2O and Cu-H2O	width = 57 µm depth = 180 µm, Separate wall = 43 µm	Re = 100-400	Both heat transfer and pressure drop increase, with increasing Re, while the friction factor of the MCHS is increase
Jung, Hoo and Kwak	Aluminium dioxide, Al2O3	170 nm	Re correlated to thermal conductivity of nanofluids.	Investigate the effect of the volume fraction of nanoparticles to convective heat transfer and fluid flow in the microchannel
Yu et al.	Methanol	57 µm - 267 µm	Re = 50 - 850	Transition does not exist at the arly laminar

CHAPTER 3

METHODOLOGY

3.1 Introduction

Nowadays, with development of sciences, people or industry have produced many types of product with more complex. They realizes that with the decreasing of size give more advantages. More compact more advantages with more functionalities. Researcher have been explored the advantages of the nanofluid and microchannel. Nanofluid functioning as the cooling media, vehicles cooling, and biomedical applications. The ability of nanofluid itself regarding to its parameter such as thermal conductivity and heat transfer compared to the base fluid. The research focusing on the effect of the nanofluid on boundary layer inside the microchannel. Thus, this methodology have been done to get more overview about this simulations studies and give detail description on how the project is conducted.

3.2 Flowchart

To obtain the objectives of this studies, the step of the flowchart are followed:

i. Literature review: The reference from all sources such as journal and articles that are related to this project will be reviewed and studied. This are needed to ascertain the objectives.

ii. Domain design and model mesh: Design and meshing the rectangular microchannel heat sink using GAMBIT software according to the dimensions. Discretizing by giving the grids to the geometry. Setup the boundary for example inlet, outlet, fluid, solid and wall.

iii. Mesh independence test: Meshing the model with different meshed size at the size wall or y-direction. The different meshes are **40 × 25 × 150**, **45 × 25 × 150**, **50 × 25 × 150** and **55 × 25 × 150**

iv. Processing: Solve the equation by setup the material which is nanofluid and silicon and setup the boundary conditions which are inlet velocity, inlet temperature.

v. Post-processing: Simulation the model of microchannel and boundary flow will be done to get the data. In order to validate the CFD technique, the result is compared with (Qu & Mudawar, 2002). If the result not acceptable, then the simulation will be repeated will different parameter.

vi. The expected outcomes will be analyse consists of graphs and calculations.

vii. A complete report on this project will be written at the end of this projects.

The simplification of methodology are shown in the flowchart as **Figure 3.1**. It has been done from the beginning until finishing. This is to make sure that the work has been done smoothly by following the systematic and true path.

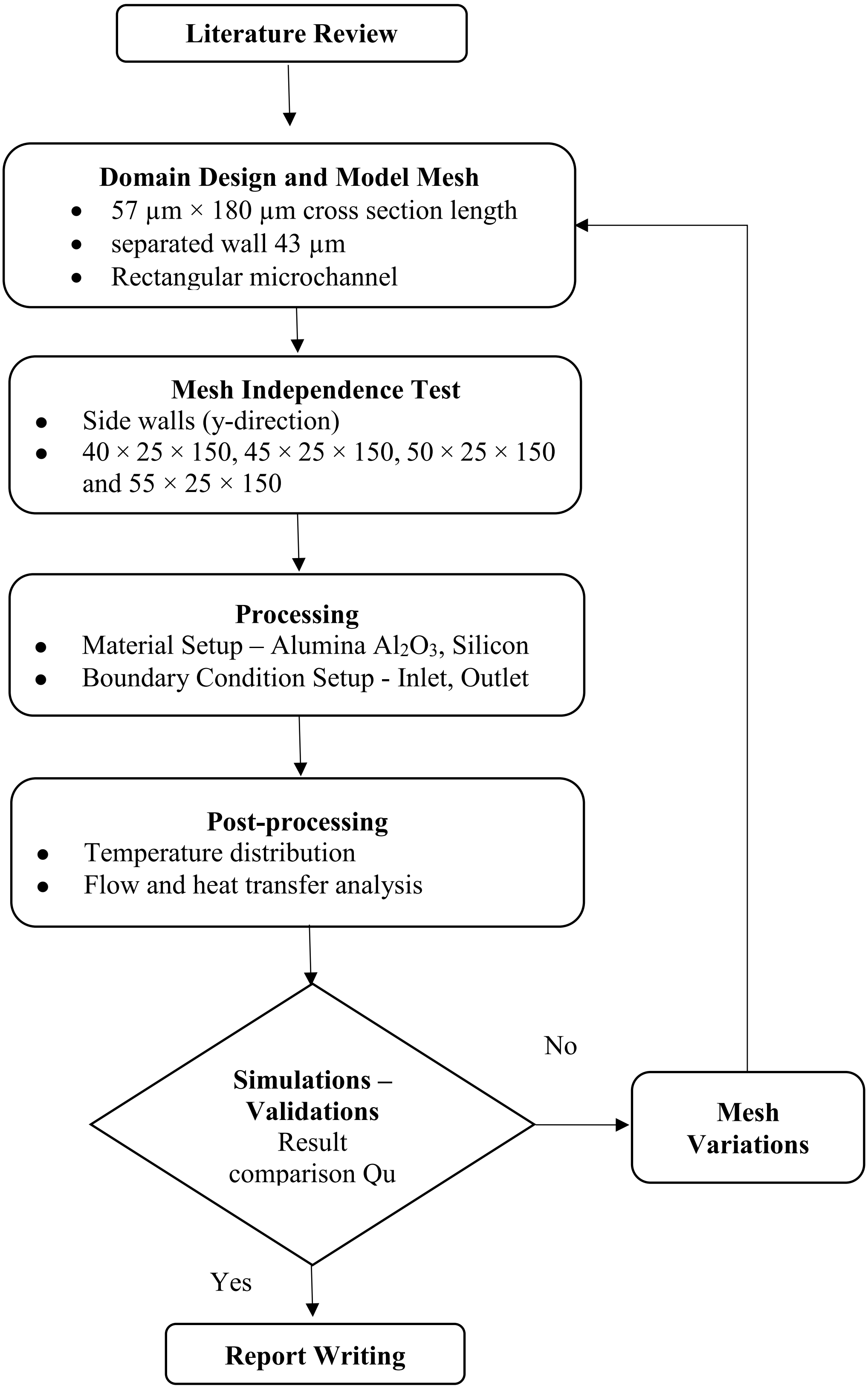

Figure 3. 1: Flow chart of the methodology