NUMERICAL INVESTIGATION OF NANOFLUID FLOW AND HEAT TRANSFER INSIDE A MICROCHANNEL

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This report is submitted in fulfilment of the requirement

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DECLARATION

I declare that this project report entitled "Numerical investigation of nanofluid flows and heat transfer inside a microchannel" is the result of my own work except as cited in the references

Signature	:	…………………………
Name	:	…………………………
Date	:	…………………………

APPROVAL

I hereby declare that I have read this project and in my opinion this project is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (with Honours).

Signature : ………………

Name of supervisor : ……………………….

Date : ………………

ABSTRACT

Microchannel is widely used in micro-electronics industry from time to time in achieving the lowest thermal resistance equipment. The objectives of this study are to simulate the nanofluid flows with correlation to velocity profiles generated in the study. In this study, nanofluid of alumina, Al_2O_3 with kinematic viscosity of 0.001028 $\mathrm{kg/ms^{-1}}$ is used as the working fluid inside the microchannel. Reynolds number of 140, 300 and 500 are used in configuring nanofluid flows and thermal conductivity of the microchannel. These low Reynolds numbers have developed to very small entrance region of 0.5mm, 2.0mm and 4.0mm with constant laminar and fully developed flow for the nanofluid. Higher Reynolds number results to higher velocity magnitude of 2.36%, 4.47% and 11.63% with constant percentage of increment. The Nusselt number is higher at the channel inlet and became closer to zero as it approached to the corner. Constant temperature gradient is observed throughout the microchannel in transverse y – direction where separation of solid and liquid boundaries is clearly visible.

ABSTRAK

Mikrosaluran banyak digunakan dalam industri mikro-elektronik dalam semasa ke semasa untuk mencapai peralatan tahan panas terendah. Objektif kajian ini adalah untuk mengaplikasi aliran cecair alumina dengan hubungkait pada corak kelajuan yang dihasilkan dalam kajian. Dalam kajian ini, nanofluid alumina, Al_2O_3 ***dengan kelikatan kinematik 0,001028*** kg/ms^{-1} ***digunakan sebagai airan kerja di dalam mikrosaluran. Nombor Reynolds 140, 300 dan 500 digunakan dalam mengkonfigurasi aliran nanofluid dan mengesan konduktivasi termal dalam mikrosaluran. Nombor Reynolds yang rendah ini telah menghasilkan panjang kemasukan yang sangat kecil iaitu 0.5 mm, 2.0 mm, dan 4.0 mm dengan aliran yang perlahan dan sama sepanjang mikrosaluran. Hasil Reynolds yang lebih tinggi menghasilkan kelajuan magnitud yang lebih tinggi iaitu 2.36%, 4.47% dan 11.63% dengan peratusan kenaikan yang sama. Nombor Nusselt yang lebih tinggi pada saluran masuk menghampiri kosong pada saluran keluar. Perubahan suhu yang sama dapat silihat di seluruh mikrosaluran dalam arah y melintang di mana pemisahan batas antara logam dan cair jelas terlihat.***

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LIST OF ABBREVIATIONS

CFD	Computer Fluid Dynamic
SIMPLE	Semi- Implicit Method for Pressure Linked Equations

LIST OF SYMBOL

A_c	=	Area of cross section, m^2
a	=	Width of the entrance of fluid channel, m
b	=	Height of the entrance of fluid channel, m
D_h	=	Hydraulic diameter, μm (D_h=4A/P)
P	=	Perimeter of entrance of fluid channel, m
k	=	Thermal conductivity, W/m.K
L_{ch}	=	Length of the channel, m
H_t	=	Height of a single reentrant cavity, m
N	=	Number of channel
Nu	=	Nusselt number
Pa	=	Static pressure, Pa
q''	=	Heat flux, W/cm^2
Re	=	Reynolds number
T	=	Temperature, K
u	=	Fluid velocity, m/s

SUBSCRIPT

nf	=	Nanofluid
Al_2O_3	=	Aluminium Oxide/Alumina
Avg	=	Average

CHAPTER 1

Introduction

1.1 Background of Study

Fluid flow in micro-passages such microchannel in current studies have developed to meet the demand for thermal-hydraulic control of microsystem. The research on microsystem analysis has developed from time to time in achieving low thermal resistance in micro-electronics industry.

Fluid flow in general can be characterized to three different stages which are laminar, transition and turbulent. The movement of adjacent fluid particles in highly ordered motion and smooth streamlines shows the fluid are in laminar motion whereas turbulent can be characterized by velocity fluctuations and highly disordered motion of fluid flow. The transition from laminar to turbulent flow is unsteady and difficult to predict, it happens over some region where fluid flow fluctuates between laminar and turbulent before it becomes fully develop region (Cengel & Cimbala, 2014).

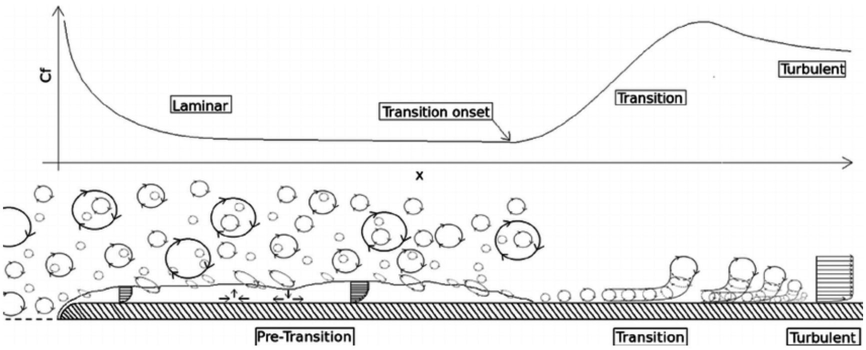

Figure 1.0 Fluid flow varies along contact geometry (Coronella, 2008)

Osborne discovered that flow regime depends mainly on the ratio of inertial forces to viscous forces in the fluid. This ratio is called Reynolds number and when the fluid becomes turbulent, the Reynolds number at that point is called critical Reynolds number (Osborne & Incropera, 1985).

It is better to have an accurate values of Reynolds number in determining the flow region of liquid flows as studied made by (Cengel & Cimbala, 2014) in macro-scale study. For macroscale study, the Reynolds number in transition from laminar to turbulent flow under most practical conditions is in the range of $0 \leq Re \leq 4000$ for liquid flow inside macrochannel. That is,

$$\mathrm{Re} \leq 2000, \text{ laminar flow}$$

$$2000 \leq Re \leq 4000, \text{ transitional flow}$$

$$\mathrm{Re} \geq 4000, \text{ turbulent flow}$$

The critical Reynolds number at which the flow become turbulent is different for different geometries and flow conditions. Avoiding flow disturbances and pipe vibrations in such carefully controlled laboratory experiments could maintain the Reynolds numbers.

Microchannels are defined as flow passages that have hydraulic diameters in the range of 10 to 200 micrometers. The evolution of microchannel have developed to several decades of improvements and received considerable attention in major application areas, such as advanced heat sink designs and micro fuel cell system. The development of understanding the fluid flow in microchannel is essential for the optimum design and effective operation of the microsystem. In this study also, the flow of the fluid inside the microchannel is analysed numerically with dimension of the microchannel for the fluid flows are 57 µm x 180 µm with length of 10mm. Two solid boundaries are separated with walls and fluid flows of the microchannel.

The working fluid used in the study is Alumina nanofluid, $Al_2O_3$and water with volume fraction of 1% and 1-100nm nanoparticles. Alumina nanofluid, Al_2O_3 is chosen due to its properties of good convection heat transfer for micro-cooling technologies and any other micro-scale channels.

1.2 Problem Statement

Reynolds number is very significant in nanofluid microchannel flows to determine the flow and heat analysis throughout the micro-scale system. However, the applicability of Reynolds number in micro-scale system is still under investigation whether it is usable for micro-scale system or not. Hence, this study is done to investigate the Reynolds number in nanofluid-microchannel flow together with the applicable of this Reynolds number range for macro-scale channel to the micro-scale channel.

1.3 Objectives

There are two main objectives in this study which are:

1. To simulate the nanofluid flow at various Reynolds number.
2. To investigate the velocity profile of nanofluid flow at various Reynolds number.

1.4 Scope of Project

The scopes of this project are:

1. The microchannel is rectangular in shaped with hydraulic diameters maximized to $200\mu m$.
2. Reynolds number of 140 – 500 are investigated in the studies.
3. Alumina nanofluid, Al_2O_3 with kinematic viscosity of 0.001028 kg/ms^{-1} and concentration of 1% as the working fluid used in the study.
4. The heat flux of 90 W/cm^2 is constant throughout the channel as the heater is located at the top wall of the fluid channel.

1.5 General Methodology

As to achieve good computational fluid dynamics results, the steps below are to be followed accordingly.

1. Literature review
   Journals, articles, or any materials regarding the project will be reviewed.

2. Pre-processing (Designing)
   Fluid flows in turbulent and the fluctuation of critical Reynolds number will be defined and determined through the analysis of research. The velocity profile of nanofluid flow at various Reynolds number will be identified through designing of the microchannel at the operating condition.

3. Solver (Mesh Generation)
   The design of the microsystem is decomposed into cells with structured quadrilateral geometry specified to the design proposed. This discretization process acquires good meshing size with correct estimation of spatial derivatives to obtain good meshing result.

4. Post-processing (Numerical)
   Velocity profile of nanofluid flows is analysed through Fluent 6.1 with generated meshed volume of microchannel.

5. Validation
   The numerical result must be tallied to the proposed data to achieve a correct fluid velocity profile at various Reynolds number (Esionwu-k, Marker, & Claus, 2014).

CHAPTER 2

Literature Review

2.1 Introduction

This literature review will be focussing on the nanofluid flows inside microchannel. The objectives of this study are to identify velocity profile and to simulate nanofluid flow inside microchannel. In this chapter, previous studies that are related to nanofluid flows in microchannel are reviewed. The findings of this studies are studied and summarized in the form of tables and figures. This chapter is separated into three parts which are nanofluid characteristics, significance of nanofluids in relation to Reynolds number and factors affecting the nanofluid flows.

2.2 Nanofluid Characteristics

Several scholars have taken numerous studies about the nanofluid over centuries. At present, water and refrigerants are commonly used as working fluids inside microchannel, the mixture of conventional fluids is proposed with the use of nanoparticles (1-100 nm in diameter) to improve the heat transfer performance of conventional fluids by enhancing thermal conductivity inside the microchannel. The use of nanofluids have proved to be a very effective way for cooling systems inside microchannel due to nanoparticle separation to the base fluid. It has been proved that nanofluids have better heat transfer performance than the base liquid and a good substitutional for working fluids inside microchannel (H. Zhang, Shao, Xu, & Tian, 2013).

Recently, the study of different nanofluid such as CuO-water or Al_2O_3-water has been a great interest among researcher in improving thermal performance of nanofluids flow in microchannel. (Jung, Oh, & Kwak, 2009) examined the performance of alumina (Al_2O_3) with a diameter of 120 nm nanofluids with various particle volume fractions shown an increment of

32% rather than distilled water at a volume fraction of 1.8% volume percent without major friction loss.

The study of nanofluid flow characteristics of low Reynolds number around a heated circular cylinder are studied by (Vegad, Satadia, Pradip, Chirag, & Bhargav, 2014) which resulted to increment of local Nusselt number over cylinder surface in nanoparticle fraction as well as increment of nanofluids flow strength. The study proved that local heat flux drops along cylinder wall while nanoparticles fraction increased together with Reynolds number along the cylinder wall until the outlet.

2.3 Reynolds number and its significance.

There are many experimental researches that have been done by researchers in configuring fluid flow and thermal conductivity inside microchannel. Experiments on flow characteristic at very low Reynolds numbers for liquid flow in microchannel have been done by Xiwen Zhang (X. Zhang et al., 2016). They tested deionized water and kerosene in rectangle cross-section microchannel with width 2.7 – 20 μm and depth of 20 – 45 μm under very low Reynolds number condition ($10^{-5} \leq \mathrm{Re} \leq 10^{-2}$) thus provide a correlation to the flow of Newtonian fluid in a smooth micrometer-sized consistent with classical theory of laminar flow.

Experiment on effect of the inlet conditions in the transition region has been performed by (D.V., J., & J.P, 2014) with three different inlet geometries of 1.05 mm, 0.85 mm, and 0.57 mm with equal length of 200 mm. The use of water as cooling fluid inside single copper microchannel are tested which resulted to the enhancement of friction factors and Nusselt numbers for critical Reynolds number of 2000. (Kim, 2016) Byongjoo Kim has performed a study to explore the validity of theoretical correlations in predicting fluid flow and heat transfer characteristics based on conventional sized of microchannel. 10 different rectangular microchannels with hydraulic diameter of 155 – 580 μm and Reynolds number ranging from 30 to 2500 are tested. The critical Reynolds number of 1700 to 2400 are obtained with decreased of aspect ratio from 1.0 to 0.25. The single phase laminar friction factors in the microchannel has obeyed to the conventional Poiseuille flow theory.

Investigation of three dimensional heat transfer in silicon microchannel by (Qu & Mudawar, 2002) proved that the temperature rise along the flow direction in the solid and fluid can be approximated as linear. The length of the flows developing region are affected by increasing Reynolds number to 1400 which fully developed flow may not be achieved as Reynolds number are affected by the thermal conductivity as it approaching to the channel outlet. Measured temperature distribution is well predicted by CFD prediction on validity of conventional theory and numerical solution of laminar Navier-Stokes equations as correlations used in comparisons.

2.4 Factors affecting fluid flow of nanofluid

(Peiyi & Little, 1983) has reported that there are many factors in which affecting the fluid flow and at the same time affecting the value of the friction factor in microchannel. Surface roughness is one of the factors that affects the fluid flow from transition to turbulent mostly by increasing of drag coefficients in turbulent flow in microscale channel. In this case, significant roughness is presented but friction factors measured in smooth channel agreed with macroscale theory -in rectangular microchannel. Thus, making the friction factor too small that it can be negliable in this microchannel.

There are two parameters that essential to Reynolds number in nanofluid studies whereas there are the inlet velocity and the kinematic viscosity of nanofluid which the Reynolds number are depended on. To keep the Reynolds number constant for heat transfer enhancement in the microchannel, the increment of inlet velocity has a major role in reaching constant Reynolds same as important of increment of nanoparticles volume fraction of nanofluid (Akbarinia, Abdolzadeh, & Laur, 2011).

The flow instabilities, uncommon heat transfer rates and increased pressure drop caused by fluid acceleration during phase change persist as important look out on the experimental investigation on the microchannel. Stability of nanofluid to application areas of nanofluid are studied by (ŞİMŞEK, 2016) together with the effect of surfactant, lowering the surface tension on the thermal performance and pumping power of nanofluids in microchannel. The comparison of convection heat transfer coefficient and pumping power for different coolant are performed in achieving a steady laminar flow in the micro scale channel. The experiments are performed using spherical gold nanoparticles of (10, 50 and 100 nm), volumetric concentration of (0.00064% - 0.0052%) and flow rate of (100 – 140 µm/min) on the nanofluid performance of 70 µm x 50 µm rectangular copper microchannels in determining the surfactant effect.

Considering particle migration of nanofluid, particle clustering and particle interactions with the wall, the nanofluid flow are affected due to possible heat transfer enhancement with more complex nanoparticle-based fluid interactions as well as different preparation methods in preparing nanofluid that lead to inconsistencies in research projects on nanofluids. The study of particle migration on nanofluid is performed (Bahiraei, 2016) by taking Brownian motion and viscosity of nanofluids into account in stabilizing nanoparticle along the microchannel.

In addition, in this paper the study of heat transfer are discussed thoroughly together with thermal conductivity, heat dissipation and convective heat transfer inside fluid channel as it is counter related to the objectives of the study in identifying velocity profile and simulate nanofluid flow inside microchannel.

Table 2.1 Result of critical Re determined by previous researchers.

Author	Nanofluid	Hydraulic Diameter	Results	Remarks
Tuckerman & Pease (1981)	Water	86 µm - 95 µm	Critical Re = 2300	constant heat flux
Dirker et al. (2012)	Water	h_d= 1.05, 0.85, 0.57 mm. length =200 mm,	$1800 \leq Re \leq 2300$, Cr Re = 2000	Enhancement of friction factors and Nusselt number due to the effect of the inlet condition
Trinh (2016)	Deionized water and FC770	10 mm	Re = 30 - 2500	To explore the validity of current studies
Weilin Qu, Issam Mudawar (2002)	Water	width = 57 µm, depth = 180 µm, distance wall = 43 µm	Critical Re = 1400	Navier-Stokes equation as comparison used as correlations
Byongjoo Kim (2016)	Water	Aspect ratio = 1.0 - 2.5	Re = 1700 - 2400	Validity of theoretical correlations based on conventional sized channels
Jung, Hoo and Kwak. (2009)	Aluminium dioxide, Al2O3	170 nm	Re correlated to thermal conductivity of nanofluids.	Investigate the effect of volume fraction of nanoparticles to convective heat transfer and fluid flow in microchannel
Choi et al. (2002)	Water	53 µm and 81.2 µm 9.7 µm and 6.9 µm	Critical Re= 2000 Critical Re= 500	Thermal conductivity increased with increase of grain size

Wu and Little (1983)	Water	45.5 µm and 83.1 µm	Re<1000 = laminar Re>3000=turbulent 900-3000=transition	Glass and silicon channels
Hegab et al.(2002)	R134a	112 µm to 210 µm	Transition= 2000 to 4000	Aluminium Microchannel
Yu et al. (2014)	Methanol	57 µm - 267 µm	Re = 50-850	Early laminar transition does not exist.
Zhang et al. (2013)	Nanofluids Al203	5.0 µm - 17.4 µm	Re = 600 - 20000	Pr= 5.7 - 7.3, nusselt correlation to Pr number.
Judy et al. (2002)	Water Methanol Isopropanol	50 µm - 100 µm 15 µm - 150 µm 75 µm - 125 µm	Critical Re = 2300	Adiabatic boundary condition for silica microchannel and single-phase flow

CHAPTER 3

Methodology

3.1 Introduction

This chapter provides a detail description of the methodology or how this whole project proceeds. This chapter also focus on what kind of method being used to obtain the necessary data for velocity profile and nanofluid flow inside microchannel. As can be observe in the flow chart provided in Figure 3.1, the figure shows the step required to successfully achieve the aim of the study in finding critical Reynolds number of nanofluid in transition flows inside microchannel.

The microchannel is created in 3D domain using GAMBIT software. After successfully created the volume of 3D domain, the 3D domain is meshed throughout each surfaces of the volume by aligning the node number to correct estimation. This cells with structured quadrilateral geometry need to be designed closely to one another at the inlet and getting distant as it come out to the outlet which results to velocity profile and critical Reynolds of nanofluid in the microchannel.

When the design and meshing process are done, the domain is analyzed through FLUENT ANSYS 6.1 computer software whereas the simulation data is obtained in relation to the analytical solutions on available resources.

The methodology of this project is summarized in the flow chart as shown in Figure 3.1.

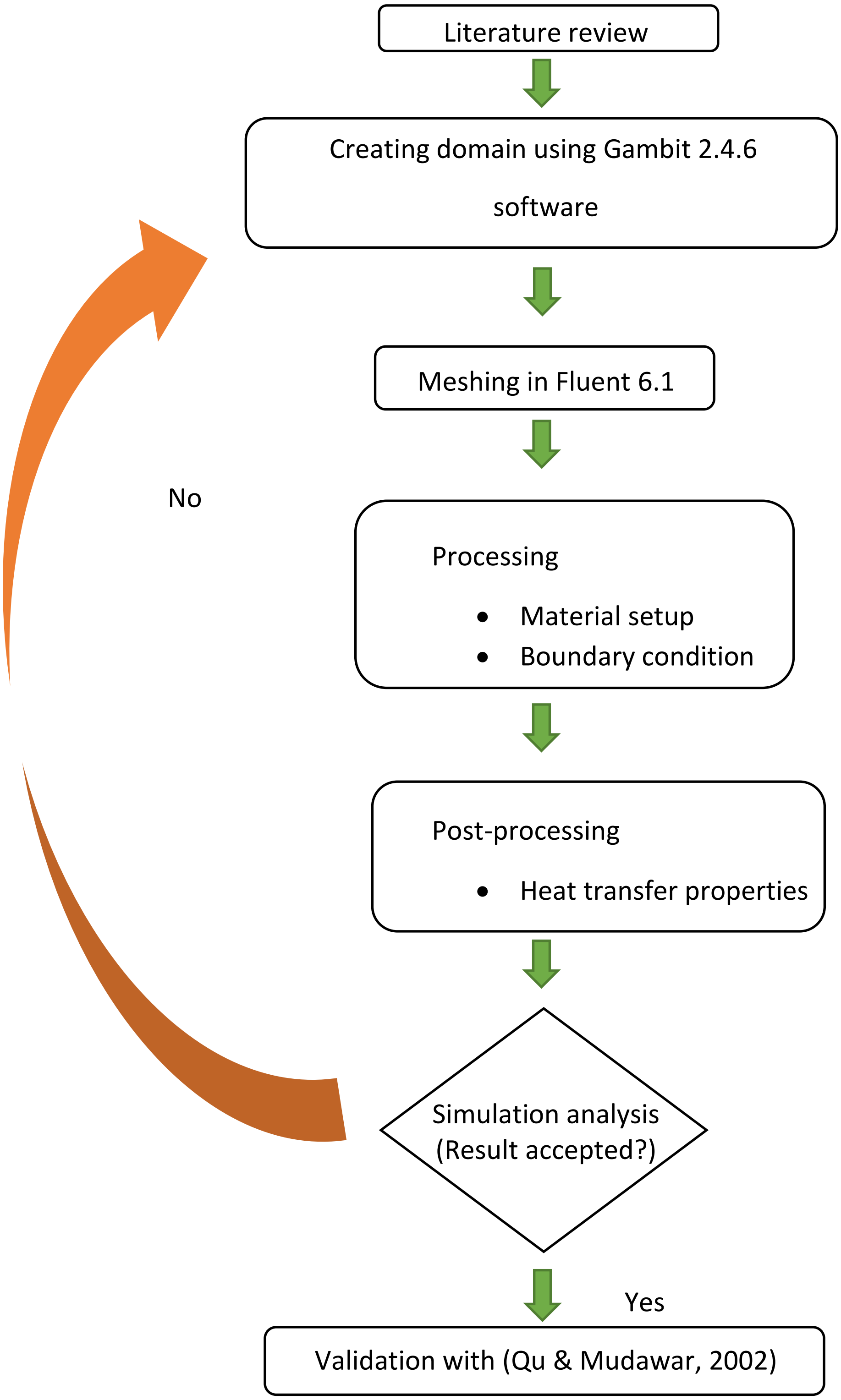

Figure 3.1 General methodology done in research