LAMINAR FLOW IN RECTANGULAR WATER-COOLED MINICHANNEL

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"I hereby declare that I have read this report and in my opinion this report is sufficient in terms of the scope and quality for the award of Bachelor of Mechanical Engineering (Thermal-Fluids)"

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This report is submitted in partial fulfillment of the requirements for the award of Bachelor of Mechanical Engineering (Thermal Fluid) With Honours

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DECLARATION

"I hereby declare that this report is the result of my own work except for quotes as cited in the references."

Signature :

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Date : 10 APRIL 2009

DEDICATION

It is only befitting that I dedicate this humble work to the noble and illustrious Prophet, Muhammad *SallallahuAlaihiWasallam*, addressed by Allah SubhanahuWata'Ala as the "Unlettered" Prophet, yet, the Master of the most extensive knowledge, foretold in previous scriptures, and the Mercy for the Worlds.

Special dedication to my loving parents, Hj Misri bin Samingin and Normah binti Mohammad, to all my supported siblings and my big family, especially to my kind hearted supervisors Mrs Fatimah Al-Zahrah binti Mohd Sa'at and all lecturers in Faculty of Mechanical Engineering and also to all my dearest friends.

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ABSTRACT

With the rapid development of the information technology (IT) industry, the heat flux in integrated circuit (IC) chips cooled by air has almost reached its limit about 100 W/cm^2. Some applications in high technologies require heat fluxes well beyond such a limitation. Therefore the search of a more efficient cooling technology becomes one of the bottleneck problems of the further development of IT industry. The minichannel flow geometry offers large surface area of heat transfer and a high convective heat transfer coefficient. However, it has been hard to implement because of its very high pressure head required to pump the coolant fluid though the channels. A normal channel could not give high heat flux although the pressure drop is very small. A minichannel can be used in heat sink with a quite high heat flux and a mild pressure loss. A rectangular minichannel heat sink with size of 1mm x 1mm is analyzed computationally for single-phase laminar flow of water as coolant through small hydraulic diameter and a constant heat flux boundary condition is assumed. The effect of inlet velocity on pressure drop and thermal resistance are presented. The simulated result is validated with the well establish data in experiment paper and shows that the average of error is 2.712%. Pressure profile along the channel indicates that the pressure gradient is directly proportional to the inlet velocity. The increases of inlet velocity resulting the less heat gain by the water through the channel.

ABSTRAK

Dengan berlakunya perkembangan pesat didalam bidang Informasi Teknologi (IT), perubabahan aliran haba didalam cip litar cantuman, penyejukan menggunakan udara telah mencapai tahap yang tinggi sehingga 100 W/cm^2. Sesetengah penggunaan alat yang berteknologi tinggi memerlukan aliran pemindahan haba yg melebihi had penggunaan penyejukan udara. Jadi, kajian yang lebih efisen mengenai teknologi penyejukan telah mencapai masalah kritikal untuk pembangunan teknolgi IT pada masa akan datang. Jadi, aliran didalam saluran mini menawarkan luas pemindahan haba yang besar dan mencapai tahap pemindahan haba perolakan yang cekap. Bagaimanapun, ia adalah sukar untuk dilaksanakan kerana ia memerlukan tekanan yang tinggi untuk membenarkan bendalir melalui saluran mini. Saluran konvensional tidak dapat memberikan pemindahan haba yang besar walaupun mempunyai perbezaan tekanan yang rendah. Saluran mini bersegi empat bersaiz 1mm x 1mm telah dianalisis secara berkomputer untuk aliran air laminar satu phasa sebagai bahan penyejuk dan sempadan haba berterusan dianggap sebagai tetap. Kesan daripada halaju masukan terhadap perbezaan tekanan and rintangan termal dipersembahkan. Hasil simulasi ini telah disahihkan dengan data daripada jurnal eksperimen dan ia menunjukkan bahawa anggaran kesilapan sebanyak 2.712%. Profil tekanan sepanjang saluran mini mendapati bahawa kecuraman tekanan berkadar langsung dengan halaju masukan. Peningkatan halaju masukan juga akan menyebabkan haba perolehan kepada air berkurangan sepanjang saluran mini.

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NOMENCLATURE

A	=	Area, m^2
CFD	=	Computational Fluid Dynamics
C_f	=	Coefficient of Friction
d_h	=	Hydraulic Diameter, m
D	=	Diameter, m
g	=	Gravity Acceleration, m/s^2
mm	=	Millimeter, mm
P	=	Pressure, Pa
Re	=	Reynolds Number
Re_{cr}	=	Critical Reynolds Number
T	=	Temperature, ºC
2D	=	Two-dimensional
3D	=	Three-dimensional
µm	=	Micrometer, µm
ε / D	=	Effective Roughness Ratio
ρ	=	Density, kg/m^3
υ	=	Kinematics Viscosity, m^2/s
μ	=	Dynamics Viscosity, $N \cdot s/m^2$
V	=	Velocity, m/s
φ	=	Heat flux Density, W/m^2
ΔP	=	Pressure Drop, Pa

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CHAPTER 1

INTRODUCTION

Chapter One is focusing on the project background, project objectives, problem statements, scope of work and flow of the project.

1.1 Project Background

Microchannel and minichannel cooling has made the high heat flux removal in such applications as microprocessor cooling, cooling of high power electronic equipment, compact heat exchangers, and even compact fuel cells possible. The small hydraulic diameter increases the heat transfer coefficients in these passages.

The development of new applications needing the cooling of components in a confined space has motivated recent studies aiming at predicting the fluid flow in mini- and micro-channels. Surprisingly, the frictional pressure losses measurements reported in the literature do not agree each other although accurate techniques have been used in the small size channels which have been investigated. More surprising is the tendency which is often reported to depart from conventional channels behavior.

The majority of researchers working in this field realize the benefits of two phases flow systems to meet the cooling requirements for high heat fluxes. The heat transfer improvement gained by a two-phase system (given the same heat flux and mass flux) is well documented in conventional sized channels, and current research is ongoing in the microchannel region. However, the total pressure drop, pumping requirements and system complexity are greatly increased in a two-phase flow system.

A study of the influence of the experimental uncertainties shows a considerable importance of the precise knowledge of the hydraulic diameter. An inaccurate evaluation of this quantity can lead to a huge error in the friction factor calculation. As the heat flux densities increased in automotive, aerospace, air separation and cryogenic industries, the use of compact evaporators became quite widespread. The plate-fin evaporators are used quite commonly in these applications. Again, looking at their dimensions, the lower limit of about 600 μm(micrometer) may be considered as the boundary of the next range. The channels employing hydraulic diameters between 600 μm and 3 mm (millimeters) are referred to as minichannels.

The miniaturization of flow channels, initiated by microelectronics, has opened further application fields today. One example is chemical reaction engineering, where many reactions take place in the gaseous phase, so that liquid educts have to be evaporated. If batches are small, danger of explosion exists and/or thermal decomposition due to high heating surface temperatures may occur, then the evaporation of the educts in minichannels is advantageous. Furthermore, the miniaturization of channel dimensions permits to reduce the size of the devices, so that requirements of minimum construction volumes and large power-to-weight ratios can be met, like for example in mobile fuel cell systems. For the design of these compact evaporators, generally accepted correlations are required to calculate the heat transfer coefficients and the pressure drop.

The hydraulic diameter range of about 50 to 600 μm is considered to fall under the classification of microchannel. Small heat pump devices employing microchannels are being fabricated with the silicon fabrication technology. Flow boiling in channels smaller than 30 to 50 μm requires especially clean fluids. The pumping power requirements are also significantly higher. However, boiling inside such small passages provides a very effective way of fluid movement, as well as relatively large heat dissipation capabilities for specialized applications. To sum up the definitions based on the above discussion, the following ranges of hydraulic diameters can be classified as below:

1. Conventional channels - > 3 mm
2. Minichannels - 600 μm to 3 mm
3. Microchannels - 50 μm to 600 μm

1.2 Project Objectives

This part will discuss deeply about the project objectives. This project is developing with the following objectives:

(a) To computationally simulate laminar flow in rectangular minichannel by using Computational Fluid Dynamics (CFD) software. There are many types of CFD software, but for this project GAMBIT version 2.2 and FLUENT version 6.2 are used.

(b) To study and understand on how to create and meshing geometry in GAMBIT and selecting the right solver to compute in FLUENT and know how to use both software effectively.

(c) To study on how minichannel characteristic and the application in this new microfluid era technologies.

(d) To study the pressure drop and heat transfer along the single phase rectangular minichannel.

(e) The simulation result will be validated by comparison on other establish data from experimental journal.

1.3 Problem Statements

In this new era of nano technologies, the development of new applications needing the cooling of components in a confined space such as minichannel cooling has made the high heat flux removal in such applications as microprocessor cooling, cooling of high power electronic equipment, compact heat exchangers, and even compact fuel cells possible. So, research in this field is very important to know the flow in the channel, heat transfer rate, pressure losses and limitation of minichannel.

Flow in small hydraulic diameter channels is becoming increasingly important in many diverse applications. The previous studies addressing the effects of the channel size on the flow patterns, and heat transfer and pressure drop performance are reviewed.

As the heat flux density in increased in automotive, aerospace, air separation and cryogenic industries, the use of compact evaporators become quite widespread. The plate fin evaporators are used quite commonly in these applications. The application in the field microelectronic created entirely new paradigms. The evolution of ink jet printing technology showed that importance of small dimension passage fluid flow.

Nowadays, compact heat exchangers, such as plate fin heat exchanger, are extensively utilized in many practical applications, for example, chemical processes, aero space power and thermal management systems for their high performances, including high heat transfer coefficient and good stability. To reach higher performance in designing and operations, it is essential to understand associated mechanisms of fluid flow and heat transfer particularly flow distribution and pressure drop in these heat exchangers and systems. Moreover, these issues are also important for designing electronic cooling devices, which not only require high capability of heat transfer, but also keeping electronic chips at low and uniform temperature.

1.4 Scope of Work

This project will concentrate on simulating laminar flow in rectangular minichannel. This concept and the correct calculation must be known to get the correct value for each parameter that has been studied. The detailed scope for this project is:

(a) The dimension of the channel that has been studied on this project is 1 milimeter x 1 milimeter cross-sectional area and 420 millimeters length. The material used for this minichannel wall is aluminum. The entrance part of minichannel analysis is neglected because this study is focus on investigation of flow characteristic in minichannel.

(b) Reynolds Number is taken from 600 - 1800. This is because to develop fully laminar flow in pipe or minichannel, the value for laminar region must be taken below 2100 approximately. This Reynolds number is used to determine average velocity as the compute inlet velocity for the minichannel.

(c) The heat flux supplied to the fluid is constant at 11 W which is corresponding to a mean heat flux density equal to 6400 W/m^2 due to the size of the channel.

(d) Three Dimension (3-D) simulation by using three dimension double precision (3DDP) for fluent version selection.

(e) This study only considers a single phase flow condition. The application of single-phase heat transfer enhancement in conventional sized passages has been widely accepted and developed area of research.

1.5 Project Flow Chart

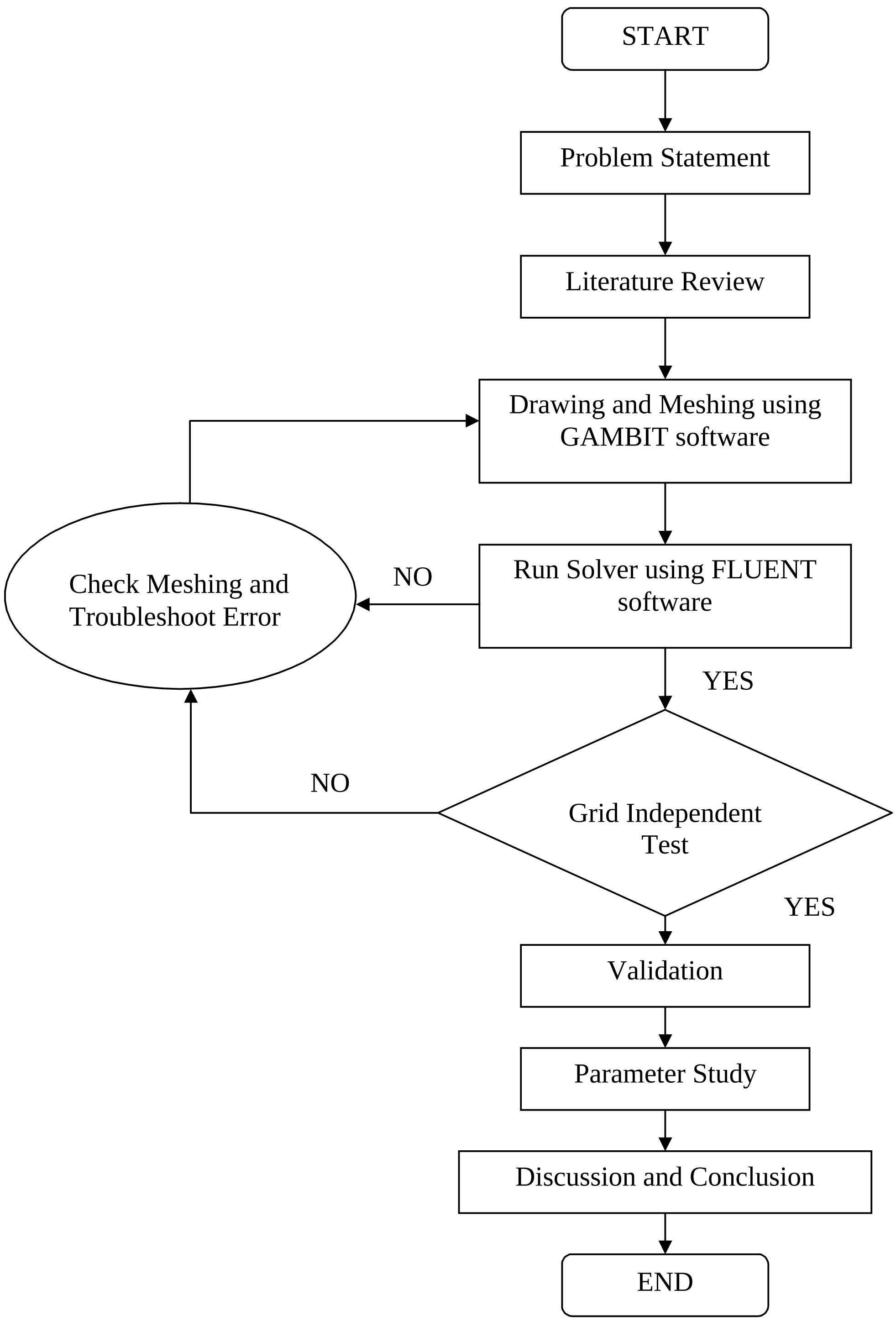

Figure 1.1: Flowchart for the Project