THE EFFECT OF PLATE GEOMETRY ON FLOW AND HEAT TRANSFER ACROSS A PARALLEL PLATE HEAT EXCHANGER

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SUPERVISOR DECLARATION

"I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Automotive)"

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This thesis is submitted as partial fulfilment of requirements for the award of Bachelor of Mechanical Engineering (Automotive) (Hons.)

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DECLARATION

"I hereby declare that the work in this thesis is my own except for summaries and quotations which have been duly acknowledged."

Signature: ………………….

Author: CHO WEI YANG

Date: ………………….

To my beloved father and mother

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ABSTRACT

When a flow is flowing past a blunt body or solid boundaries, there will be formation of flow patterns and interactions between flow and the solid bodies. Other than that, heat transfer can also take place if there is a temperature difference between the flow and solid bodies. In this study, a pile of parallel-plates was considered as the solid bodies. A simplified model of parallel-plate heat exchanger was chosen as the computational domain in order to study of effect of plate geometry and channel dimensions on the flow and heat transfer across a parallel-plate heat exchanger. There will be an oscillatory flow where the flow moves back and forth across the solid boundaries. The study was carried out using ANSYS software. Drawing of the computational domain, meshing of the domain, solver settings and validation of the model were carried out before the study can be recognized. After having done validation, the results and data from the original model were compared with other three cases. One of the three cases has round-shaped edges for its parallel-plates heat exchanger. The remaining two cases have triangle-shaped edges with one having two times longer edge length of the other one. All the cases were compared in terms of vorticity contours, total and average surface heat flux and last but not least, velocity profile inside the channel. The study shows that the shape of the edge affects the flow and the heat transfer of the system. Vortices discontinuities were eliminated through the changing of edge shapes. Heat energy transfer across the surface also changes when the shape of the edge changes.

ABSTRAK

Apabila sesuatu aliran mengalir melepasi satu badan pepejal, akan berlakunya pembentukan corak aliran dan interaksi antara aliran dan badan pepejal. Tambahan pula, pemindahan haba juga boleh berlaku sekiranya terdapat perbezaan suhu antara aliran dengan badan pepejal tersebut. Badan pepejal dalam kajian ini adalah timbunan plat yang diaturkan secara selari. Satu model penukar haba plat-selari yang mudah dijadikan sebagai domain untuk mengkaji tentang kesan penukaran geometri plat dan jarak antara plat terhadap aliran dan juga pemindahan haba melalui penukar haba plat-selari. Aliran berayun yang mana aliran tersebut akan beralir pergi dan balik akan dipilih sebagi jenis aliran dalam kajian ini. Kajian ini dijalankan melalui penggunaan perisian ANSYS. Lukisan domain, 'meshing' untuk domain, penetapan penyelesaian dan juga pengesahan domain perlu dijalankan supaya kajian ini boleh diiktiraf. Setelah mengesah kesesuaian model original, data model tersebut dibandingkan dengan tiga model yang lain. Salah satu model mempunyai sisi yang bulat. Dua model mempunyai sisi segi tiga dan salah satu mempunyai sisi yang dua kali lebih panjang daripada model yang satu lagi. Semua model yang tersebut dibandingkan melalui kontur kepusaran, pemindahan tenaga haba dan profil halaju dalam saluran. Kajian ini menunjukkan perubahan dari segi aliran dan permindahan haba dalam sistem apabila bentuk sisi diubah.

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LIST OF ABBREVIATIONS AND SYMBOLS

Re	=	Reynolds number
ρ	=	Density
$Vavg$	=	Average velocity
D	=	Geometry characteristic length
μ	=	Dynamic viscosity
v	=	Kinematic viscosity
CFD	=	Computational Fluid Dynamics
$\dot{Q}$	=	Rate of heat transfer
k	=	Thermal conductivity
A	=	Surface area
$\frac{dT}{dx}$	=	Temperature gradient
h	=	Convection heat transfer coefficient
T_s	=	Surface temperature
T_∞	=	Surrounding temperature
σ	=	Stefan-Boltzmann constant
ε	=	Emissivity of the surface
δ_k	=	Thermal penetration depth
ω	=	Angular frequency
C_p	=	Constant pressure heat capacity per unit mass
δ_v	=	Viscous penetration depth.
BR	=	Blockage ratio

LIST OF ABBREVIATIONS AND SYMBOLS

y_o	=	Half distance between parallel plates
l	=	Length of heat exchanger
PLIF	=	Planar Laser Induced Fluorescence
PIV	=	Particle Image Velocimetry
SIMPLE	=	Semi-Implicit Method for Pressure-Linked Equations

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

When a flow is flowing past a blunt body or solid boundaries, there will be interactions between the flow and the solid bodies. In this study, the solid boundaries will be a pile of parallel-plates acting as heat exchangers. There will be formation of various flow patterns when a flow flows past the parallel-plates. Other than flow patterns, there is also interaction in terms of heat transfer since the parallel-plates will be acting as heat exchangers. The temperature difference around the plates region will cause the occurrence of heat transfer between the flow and the plates due to the temperature gradient. The focus of this research is to study how the changes in the plate geometry (shape or dimensions of parallel-plate) may disturb or affect the flow and heat transfer across a parallel-plate heat exchanger. In discussing the flow and heat transfer across a parallel-plate heat exchanger, the working medium used is very important too. Oscillatory flow which the flow will propagate forth and back will be used in this research.

An example of application of oscillatory flow is as used in a reactor. Besides thermoacoustics, this knowledge has been adapted into other technology such as oscillatory flow reactor. Through different configurations of the reactor, it can serve different purposes. The most common configuration is to operate as a mixer. Having an oscillating flow can enhance the mixing as the mass and heat transfer rates are increased significantly due to the back and forth movement. Oscillatory flow mixing technology can also be found widely in chemical and process engineering. Another application of oscillatory flow, which is also the focus of our research, is a thermoacoustic heat exchanger. This heat exchanger extracts and supplies heat obtained from the thermoacoustic system.

The main working medium behind thermoacoustics is a type of flow called oscillatory flow. This flow is formed from sound waves with amplitudes high enough to transfer heat from one place to another. On the other hand, sufficiently high temperature gradient can also be used to create sound waves of high amplitudes. This flow plays an important role because the oscillatory flow will move back and forth expanding and contracting in order to do work.

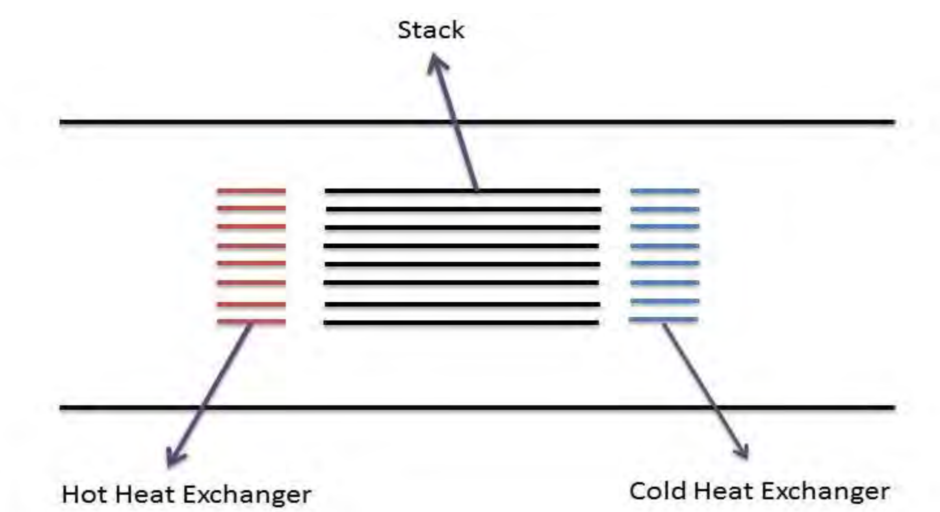

Figure 1.1: Illustration on position of heat exchangers and stack.

A simple explanation about devices using thermoacoustics principle may be explained with the aid of Figure 1.1. Generally the thermoacoustic effects occur within an area inside the device where structures shown in Figure 1.1 are placed. The structures, in general, contain a pile of solid metal known as ‘stack’. This ‘stack’ is sandwiched between a pair of heat exchangers with temperature gradient. Thermoacoustic effects occur when the oscillatory flow inside the device interacts with the ‘stack’. Depending on the source of energy, the interaction between the flowing fluid and the solid surface of the stack may produce either cooling effect or power.

The heat exchangers at the ends of 'stack' are responsible to effectively remove heat from the system and provide cooling capacity to the refrigerated space that is attached to the system. On the other hand, if the heat exchangers provide a high enough temperature gradient to the fluid, such that allows the fluid particle to excite, power will be produced. The energy produced may then be harnessed for other useful application.

1.2 PROBLEM STATEMENT

The challenge in commercializing the thermoacoustic technologies lies, among others, on understanding the behavior of the flow and heat transfer phenomena inside the system. Current analytical solution used in designing the thermoacoustic system is based on a one-dimensional linear model. However, in practical system, the flow may consist of irregularities such as natural convection, streaming and vorticity. It is pertinent that these effects are investigated so that a proper understanding may be gained. This involves the fundamental knowledge of oscillatory flow. The study on heat transfer phenomenon in a heat exchanger across oscillatory flow is important. There are many types of heat exchanger and the parallel-plate heat exchanger is one of them. As the geometry of the parallel-plates structure is changed, the flow properties near the plates will also change. This may somehow affect the interactions between the oscillatory flow and the solid surfaces. The changing of geometry may also create disturbances or other effects on the flow. The usual shape of the plates is rectangle with sharp edges. It will be interesting to study what changes may be observed if the shape of the plates is changed for example, to round edges or to other shapes.

1.3 MOTIVATION OF STUDY

Often the other parameters are taken into consideration when studies are carried out regarding the oscillatory flow or heat transfer near solid structures. Geometry and gap dimensions however get less attention as compared to other parameters. Considering the fact that changing geometry will affect the contact surface of the plate and also the possibility of creating disturbances to the flow, researches should be carried out more about this factor. The purpose of this study is to gain more information on the effect of geometry of the parallel-plates on the heat transfer and flow so that this concept appears attractive to the industry sooner.

1.4 OBJECTIVES

There are several objectives in completing the study. The objectives are to:

i) Study the thermoacoustic heat exchanger and to understand the working principle and knowledge related to it.

ii) Formulate simplified models for the purpose of comparison of flow and heat transfer between different geometries.

iii) Validate the model with available published work; experimental or theoretical data.

iv) Analyze the results and study the effect of parallel-plates geometry on the flow and heat transfer around the heat exchanger.

1.5 SCOPE

There are several parameters that can be manipulated in order to study the factors affecting the flow and heat transfer such as the mean pressure, velocity amplitude, frequency and also phase difference. However in this study, the focus will only be on the effect of geometry of the parallel plates on the flow behavior of the system. This involves several different shape of the edge of the heat exchanger plates. The parallel plates in this research will be used to represent the heat exchangers used in real thermoacoustic devices. This research will cover only the oscillatory flow encountered in a thermoacoustic system. A simplified model of parallel plates will be formulated for the research.

CHAPTER 2

LITERATURE REVIEW

2.1 FLOW

Over the years, numerous researches had been carried out in the field of thermoacoustics. In thermoacoustic applications, fluid may be considered as the working medium. One important aspect that needs to be understood is the flow of the fluid. Flow is the propagation of fluid from one place to another along a stream. There are three phases of fluid flow; laminar, transition and turbulent flow. As shown in figure 2.1, laminar flow is the early stage of a flow where it is often represented by smooth and highly-ordered motion. When the flow velocity increases, the flow will change gradually from small fluctuations in the motion to large fluctuation. In this situation, the fluid is said to be in the transition stage. Transition stage happens gradually instead of sudden changing of phase in between laminar and transition. Transition is a phase in between laminar and turbulent. If the velocity of fluid keeps on increasing, the flow will finally reach turbulent phase where the motion of flow is random and highly-disordered. Fluctuation in velocity can also be seen in turbulent phase. Cengel and Ghajar (2010) mentioned that the rapid fluctuations during turbulent flow resulting in intense mixing of the fluid enhances heat and momentum transfer between fluid particles. These in turn increase the friction force on the surface and the convection heat transfer rate. When the flow becomes fully turbulent, heat transfer coefficient will become maximum value. The heat transfer rate will be of greater amount compared to in laminar stage. The friction coefficient too will become maximum when the flow is fully turbulent. This will requires more input to overcome the large friction forces.

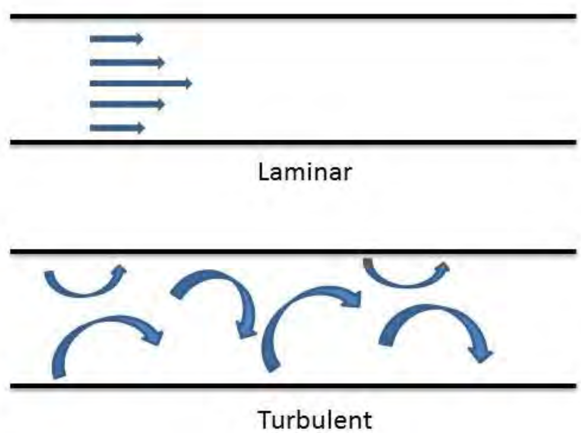

Figure 2.1: Illustration of laminar and turbulent flow.

The classification of the three phases mentioned earlier is made possible with the help of a dimensionless number, the Reynolds number. Reynolds numbers, Re, was discovered by Osborne Reynolds in 1880s. He found out that the flow regime or the order of the flow is highly dependent on the ratio of inertial forces to viscous forces in the fluid. Inertial force can be considered as the amount of force a fluid put up to resist any change in its motion. Viscous force can be explained as the shear force experienced by the flow when it flows past a solid body. In easier analogue, viscous force can be considered as frictional force. Reynolds number can be expressed as;

$$\text{Re} = \frac{\text{inertial forces}}{\text{viscous forces}} = \frac{\rho V_{avg} D}{\mu} \tag{2.1}$$

where ρ is the density of medium, V_{avg} is the average velocity of the flow, D is the geometry characteristic length and μ is the dynamic viscosity of the medium. Reynolds number can also be expressed in terms of kinematic viscosity;

$$\text{Re} = \frac{V_{avg} D}{\nu} \tag{2.2}$$