HEAT TRANSFER ENHANCEMENT THROUGH THE USE OF VORTEX GENERATOR

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in fulfilment of the requirements for the degree of
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DECLARATION

I declare that this project report entitled "Heat Transfer Enhancement through the use of Vortex Generator" 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 report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature	: ....
Supervisor's Name	: ....
Date	: ....

ABSTRACT

The study focusses on the heat transfer performance of fluid flow with the presence of vortex generator inside a heat exchanger using a CFD model. The main purpose of a heat exchanger is to exchange heat between two fluids, the heat transfer performance is relatively important in a heat exchanger. Thus, vortex generator is introduced to improve the heat transfer in a heat exchanger. Fluid flow can be in steady flow, where the fluid leaves the system after exchanging heat, or also in oscillatory flow, where the fluid oscillates periodically in the heat exchanger. Two models involving steady flow and oscillatory flow are done in CFD modelling. The heat transfer performance is analyses by considering a heat transfer parameter which is Colburn-j factor for both steady and oscillatory flow. Colburn-j factor correlates with the Nusselt number, Reynolds number, and Prandtl number. Vortex generator provides a heat transfer enhancement in both steady flow and oscillatory flow. The study is compared with previous study and theoretical calculation. Since, oscillatory flow heat equation is not well established, steady flow heat equation is used in this study. However, the heat transfer behaviour in a steady flow and oscillatory flow varies. Hence, the heat equation in steady flow might not be suitable to be directly used in oscillatory flow conditions.

ABSTRAK

Kajian ini memberi fokus kepada ujikaji dinamik aliran bendalir (CFD) terhadap cara bendalir memindahkan haba dalam penukar haba melalui penggunaan penjana vorteks. Objektif utama penukar haba adalah untuk menukarkan haba antara dua bendalir. Kebolehan untuk memindahkan haba adalah sangat penting dalam penukar haba. Oleh itu, penjana vorteks diperkenalkan untuk meningkatkan kebolehan untuk memindah haba dalam penukar haba. Terdapat beberapa jenis aliran bendalir termasuk aliran seragam, dimana bendalir akan meninggalkan sistem selepas pemindahan haba telah berlaku; dan juga aliran berayun yang mengalir secara berayun dan berkala dalam penukar haba. Kajian terhadap kedua-dua model dilakukan melalui pemodelan CFD. Kebolehan pemindahan haba dianalisasi dengan mengambil kira parameter pemindahan haba yang dikenali sebagai Colburn-j factor untuk kedua-dua aliran seragam dan aliran berayun. Colburn-j factor menghubungkan antara nombor Nusselt, nombor Reynolds, dan nombor Prandtl. Penjana vorteks didapati meningkatkan kebolehan untuk memindah haba dalam kedua-dua aliran seragam serta aliran berayun. Kajian ini telah dibandingkan dengan kajian yang telah diterbitkan dan juga dengan pengiraan menggunakan teori. Oleh sebab persamaan pemindahan haba untuk aliran berayun belum mencapai tahap mapan, persamaan pemindahan haba untuk aliran seragam telah digunakan dalam kajian ini. Namun begitu, cara pemindahan haba dalam aliran seragam dan aliran berayun didapati agak berbeza. Oleh itu, keputusan kajian menunjukkan bahawa persamaan pemindahan haba untuk aliran seragam mungkin tidak begitu sesuai untuk digunakan dalam menganalisis aliran berayun.

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TABLE OF CONTENTS

CONTENTS			PAGE
DECLARATION			
ABSTRACT			**i**
ABSTRAK			**ii**
ACKNOWLEDGEMENT			**iii**
TABLE OF CONTENTS			**iv**
LIST OF TABLES			**vii**
LIST OF FIGURES			**viii**
LIST OF ABBREVIATION			**x**
LIST OF SYMBOLS			**xi**
CHAPTER	**INTRODUCTION**		**1**
1	1.1	Background	1
	1.2	Problem Statement	3
	1.3	Objectives	3
	1.4	Scope of Study	4
CHAPTER	**LITERATURE REVIEW**		**5**
2	2.1	Fluid Mechanics	5
		2.1.1 No-slip Condition	6
	2.2	Types of Flow	7
		2.2.1 Laminar Flow vs Turbulence Flow	7
		2.2.2 Steady Flow vs Unsteady Flow	8
		2.2.3 Oscillatory Flow	9

	2.2.4	Wake Region	10
	2.2.5	Cross Flow	10
	2.2.6	Vortices	11
	2.2.7	Common Flow Up vs Common Flow Down	11
	2.3	Heat Transfer	12
	2.3.1	Convection	12
	2.3.2	Governing Equation	13
	2.3.3	Dimensionless Parameter	15
	2.4	Heat Exchanger	15
	2.5	Vortex Generator	16
	2.6	Heat transfer in Heat Exchanger	17
	2.7	Heat transfer in Oscillating Flow	18
CHAPTER 3		**METHODOLOGY**	**20**
	3.1	General Methodology	20
	3.2	Geometry	21
	3.3	Meshing	24
	3.4	Solver Setting	27
	3.5	Grid Independency Test and Results Validation and Verification	31
	3.6	Results Analysis	32
CHAPTER 4		**RESULT AND DISCUSSION**	**33**
	4.1	Grid Independency Test	33
	4.2	Results Validationa and Verification	34
	4.2.1	Steady Flow	34

		4.2.2 Oscillatory Flow	37
	4.3	Visualization of Steady Flow	40
		4.3.1 Comparison of with and without the presence of vortex generator	41
		4.3.2 Effects on different velocity	42
	4.4	Visualization of Oscillatory Flow	43
		4.4.1 Effects on different drive ratio	43
		4.4.2 Contour and Vector Plots for Drive Ratio of 1.2	45
		4.4.2.1 Temperature Contour Plot	45
		4.4.2.2 Vortex Contour Plot	47
		4.4.2.3 Velocity Vector Plot	49
		4.4.3 Contour and Vector Plot for Drive Ratio of 0.6	51
		4.4.3.1 Temperature Contour Plot	51
		4.4.3.2 Vortex Contour Plot	53
		4.4.3.3 Velocity Vector Plot	55
	4.5	Comparison between Steady and Oscillatory Flow	57
CHAPTER 5	**CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK**		**60**
	5.1	Conclusion	60
	5.2	Future Recommendations	62
REFERENCES			**63**
APPENDIX			**66**

LIST OF TABLES

TABLE	TITLE	PAGE
3.1	Flow configuration of vortex generator in heat exchanger	24
3.2	Name of each selections.	27
3.3	Boundary conditions used for the numerical studies. (Bhuiyan & Awais, 2019)	30
3.4	Properties of air and materials used (Bhuiyan & Awais, 2019)	31
4.1	Maximum velocity tabulated against different nodes	33
4.2	Results tabulated for all parameter with the presence of vortex generator.	34
4.3	Results tabulated for all parameter without the presence of vortex generator.	35
4.4	Colburn friction ratio for nine different Reynolds number	36
4.5	Results tabulated for all parameter with the presence of VG in oscillatory flow.	38
4.6	Results tabulated for all parameter without the presence of VG in oscillatory flow.	38
4.7	Colburn j factor ratio at three different drive ratio.	39

LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	Fluid at the surface approaches zero. (Cimbala & Cengel, 2006)	7
2.2	Flow with constant speed: (a) Laminar flow, low Re; (b) Turbulent flow, high Re (White, 2009)	8
2.3	Cross-flow across fins in heat exchanger (Cengel & Ghajar, 2011).	10
2.4	Representation of different flow configuration such as, a) Common flow up, b) Common flow down (Bhuiyan & Awais, 2019)	11
3.1	Flowchart for methodology.	20
3.2	Dimension for the length of the vortex generator in heat exchanger.	22
3.3	Dimension for the geometry of a single tube and a pair of vortex generator.	22
3.4	Flow configuration of vortex generator in heat exchanger	23
3.5	Complete geometry drawing in DesignModeller	24
3.6	Meshing of the geometry around the tubes and vortex generator.	26
3.7	Illustration of selections in the geometry	26
4.1	Graph comparison between experimental, numerical and current study.	36
4.2	Comparison of velocity against drive ratio for three different cases.	37
4.3	Comparison of Colburn Ratio for Steady and Oscillatory Flow	39

FIGURE	TITLE	PAGE
4.4	Visualization of (a) temperature, (b) velocity, and (c) vorticity for (i) presence of (i) presence of VG and (ii) absence of VG	41
4.5	Visualization of (i) temperature contour, (ii) velocity vector, and (iii) vortex contour plot for (a) 1.37m/s, (b) 1.96m/s, and (c) 2.55m/s	42
4.6	Visualization of (i) temperature contour, (ii) vortex contour and (iii) velocity vector plot for drive ratio (a) 1.2 + VG, (b) 1.2 no VG, (c)0.9 + VG, (d) 0.9 no VG, (e) 0.6 + VG, and (f) 0.6 no VG	44
4.7	Temperature Contour Plot for Drive ratio of 1.2 (i) with and (ii) without the presence of vortex generator	45
4.8	Vorticity Contour Plot for Drive ratio of 1.2 (i) with and (ii) without the presence of vortex generator	47
4.9	Velocity Vector Plot for Drive ratio of 1.2 (i) with and (ii) without the presence of vortex generator	49
4.10	Temperature Contour Plot for Drive ratio of 0.6 (i) with and (ii) without the presence of vortex generator	51
4.11	Vortex Contour Plot for Drive ratio of 0.6 (i) with and (ii) without the presence of vortex generator	53
4.12	Velocity Vector Plot for Drive ratio of 0.6 (i) with and (ii) without the presence of vortex generator	55
4.13	Comparison of (a) temperature contour, (b) velocity vector, and (c) Vorticity contour plot for (i) steady and (ii) oscillatory flow	58

LIST OF ABBREVIATION

VG	Vortex Generator
TVG	Transverse Vortices
LVG	Longitudinal Vortices
CFD	Computational Fluid Dynamics

LIST OF SYMBOLS

Re	Reynolds number
Nu	Nusselt Number
P_r	Prandtl Number
L_c	Characteristics Length
µ	Dynamic Viscosity
ρ	Density
V	Velocity
v	Kinematic viscosity
h	Convection heat transfer coefficient
$\dot{Q}$	Rate of heat convection
A	Cross sectional area normal to fluid flow
Ts	Surface temperature
T_∞	Temperature of fluid away from the surface
K	Thermal conductivity
C_p	Specific heat
$\dot{m}$	Mass flow rate
u	Initial velocity
τ	Viscous stress
j	Colburn factor

f	Friction factor
P	Pressure
k	Wave number
t	Time
m’	Mass flux
θ	Phase shift
c	Speed of sound

CHAPTER 1

INTRODUCTION

In this chapter, a brief introduction on the background of the study relating to heat transfer enhancement using vortex generator will be presented. Problem statement arising from the heat exchanger will also be included in this chapter. Next, the objective of this study will be stated accordingly. Lastly, this chapter will also include the scope of this study.

1.1 Background

Heat exchanger is a device that involves exchange of heat between two fluids with different temperature; lower temperature fluid as cold fluid and higher temperature fluid as hot fluid. Heat transfer process occurs in the heat exchangers. It is an essential device to increase or decrease temperature of fluid especially in industries as machines in industries tends to overheat. Coolant is needed to prevent overheat and heat exchanger comes in handy to reduce the temperature of the coolant. When heat is extracted from the hot fluid, part of the heat is transferred into other forms of energy to achieve energy efficient as industries often consumes a high amount of energy. Reusing energy from waste heat helps to reduce the energy cost of industries. The reused heat can also be used in heating process where lesser additional energy is needed to heat the fluid when heat is reused and preheat the fluid before heating process.

There are several types of heat exchangers including compact heat exchangers and shell-and-tube heat exchanger. Shell-and-tube heat exchanger is the most widely used heat exchanger in industries. It contains a vast amount of tubes surrounded by a shell where the tubes are parallel to its shell. Heat transfer occurs when the first fluid flows in the tubes while the second fluid flows outside the tubes in the shell. Heat transfer among heat exchangers can be improved in many ways and one of the ways is by increasing pressure drop with a higher pumping power or by introducing vortex generator.

The main purpose of a vortex generators is to generate vortices in fluid flow by inducing secondary swirling flow around the vortex generators. Vortex generators can be installed through methods such as stamping, welding, embossing and punching on the fluid flow surface. Vortex Generators produce transverse vortices and longitudinal vortices (Bhuiyan & Awais, 2019).

Transverse vortices are two-dimensional flow which the axes are normal to the direction of fluid flow. Transverse vortices increase the intensity of turbulence by destabilizing flow while longitudinal vortices diminish poor heat transfer region. However, longitudinal vortices are three-dimensional flow with axes parallel to the flow direction (Oneissi, Habchi, 2016). Longitudinal vortices have a better heat transfer rate over transverse vortices. This is because longitudinal vortices include more heat transfer mechanism, the effect at the affected region also last longer as it continues further down the flow direction. Heat transfer rate of longitudinal vortices can be further improved by introducing delta winglets on fin-and-oval tube heat exchanger (Bhuiyan & Awais, 2019).

1.2 Problem Statement

Heat exchangers have a wide aspect of applications especially in energy related devices. Heat exchanger with higher heat transfer rate is highly needed in many industries. Accompanied with higher heat transfer rate is increasing pressure drop, often associated with higher pumping power and thus higher cost. Therefore, alternatives are essential to results in cost effective heat exchanger. Introducing vortex generator has been one of the alternatives that is used in improving heat transfer rate for many situations. Vortex generator creates vortex that helps to increase the efficiency of the heat exchanger. In some situation, fluid flows in different conditions such as oscillatory flow in thermoacoustic devices and ocean wave. Improving heat transfer in this type of flow is also necessary. The use of vortex generator in oscillatory flow condition needs to be investigated.

1.3 Objectives

The objectives of this study are:

1. To solve CFD models of fluid flow and heat transfer of a heat exchanger with the presence of vortex generator.
2. To validate/verify the CFD models of heat exchangers with the presence of vortex generator.
3. To analyse the heat transfer performance of heat exchanger with the presence of vortex generator in two different flow conditions.

1.4 Scope of Study

This study will focus primarily on enhancing heat transfer in fluid flow by introducing vortex generator in two different types of flow which are steady flow and oscillatory flow. The study only covers the use of Computational Fluid Dynamics to model the fluid dynamics of flow using specific simulation software. The study only compares the difference between steady flow and oscillatory flow. Experimental results will not be covered in the study. The pressure drop penalty is not covered in this study. Other parameters such as geometry arrangements and vortex types are not covered in this study. Circular tubes are used in this study and other tube shapes are not included in this study.

CHAPTER 2

LITERATURE REVIEW

In this chapter, few terms are introduced based on the reviews on several research that had been done. This chapter will include the review on fluid dynamics, heat exchanger, vortex generator, and heat transfer enhancement. Research on heat transfer enhancement using vortex generator is also discussed in this chapter.

2.1 Fluid Mechanics

Fluid is defined as a substance where it will continuously deform whenever it is exposed to shear stress. Fluid mechanics is the study of fluid flow in stationary condition or moving condition. Fluid can be in liquid or gas forms. Fluid mechanics is a wide field of study since fluid flow appears in all aspect of everyday life. Numerical computer techniques can be done to simulate the mechanics of fluid by using computational fluid dynamics (CFD) method (White, 2009).

There are several types of fluid flow including steady and unsteady flow, oscillatory flow, laminar and turbulence flow. Besides, due to the fluid dynamics, several flow characteristics region could occur such as wake region which is a disturbed flow that will be discussed later. Also, with the introduction of many techniques and new technologies, flow configuration can also be modified such as common flow up and common flow down which represents the fluid flow direction.

It is known that the mass flow rate of a fluid is the product of the fluid density, fluid volume, and cross-sectional area that is normal to the fluid flow.

$$\dot{m} = \rho A V \quad (2.1)$$

where $\dot{m}$ is the mass flow rate, ρ is the fluid density, A is the cross-sectional area normal to fluid flow, and V is the fluid velocity. Fluid velocity, V, can also expressed as in Eq. (2.2), where u is the initial velocity.

$$V = u + \frac{\partial u}{\partial x} \partial x \quad (2.2)$$

2.1.1 No-slip Condition

When fluid flow is bounded by a solid surface such as walls, the fluid exerts a force on the solid surface knowingly as surface drag. Fluid molecules tend to achieve equilibrium with the wall surfaces where

$$V_{fluid} \equiv V_{wall} \qquad T_{fluid} \equiv T_{wall} \quad (2.3)$$

Therefore, fluid velocity on the surface wall is zero, knowingly as the no-slip condition. Fluid flow approaching to the normal is gradually decreasing till it reaches zero when it is in contact with the solid surface. This conditions also acts as the boundary condition where the velocity of the fluid at the wall is zero (Cimbala & Cengel, 2006).

Figure 2.1 shows the velocity profile of fluid when it is approaching the surface. Fluid viscosity is the main factor that contributes to the no-slip condition. Viscous effect of the fluid nearest to the surface has the highest fluid viscosity. Viscosity is known to be a measure of internal resistance of the fluid to flow. Viscosity can also be defined as a measure of 'stickiness' of the fluid towards the surface (Cimbala & Cengel, 2006).

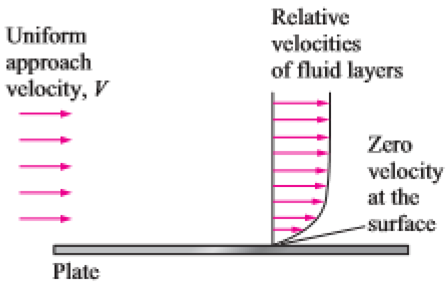

Figure 2.1 Fluid at the surface approaches zero (Cimbala & Cengel, 2006).

2.2 Types of Flow

Characteristics of a fluid is highly affected by the properties of the fluid. Fluid velocity leads to laminar and turbulence flow; viscosity leads to viscous and inviscid flow; density leads to compressible and incompressible flow; changes of fluid properties over time leads to steady and unsteady flow; external force leads to natural and forced flow. The classifications of these fluids ease the analysis of the fluid flow and to study the characteristics of these fluid flows.

2.2.1 Laminar Flow vs Turbulence Flow

Laminar flow is known to be a flow that flows with low velocity and steady throughout the flow. Turbulent flow is known to be fluid flow that flows with high velocity and fluctuating throughout the flow. Transition flow is a flow where the flow continuously interchanges between steady flow and turbulent flow. Figure (2.2) shows the fluid flow in turbulent flow and laminar flow.

The flow classification is dominated by the maximum velocity inside the flow. Reynolds number is a dimensionless parameter that represents the maximum velocity, V_{max}.

The type of flow can be defined by referring to the Reynolds number of the fluid (Re) (White, 2009).

$0 < Re < 10^{3}$: Laminar Flow

$10^3 < Re < 10^4$: Transition Flow

$10^4 < Re < \infty$: Turbulent Flow

In turbulent flow, since the molecular diffuses at a higher speed, mass, momentum and heat transfer also increases. However, turbulent flow often associates with higher friction, heat transfer and mass transfer coefficient. Shear stress and heat flux of the wall is comparatively higher in turbulent flow compared to laminar flow.

Although turbulent flow flows in high velocity and unsteady, however the flow is steady when averaged over time. Flow of turbulent flow can be predicted by taking average.

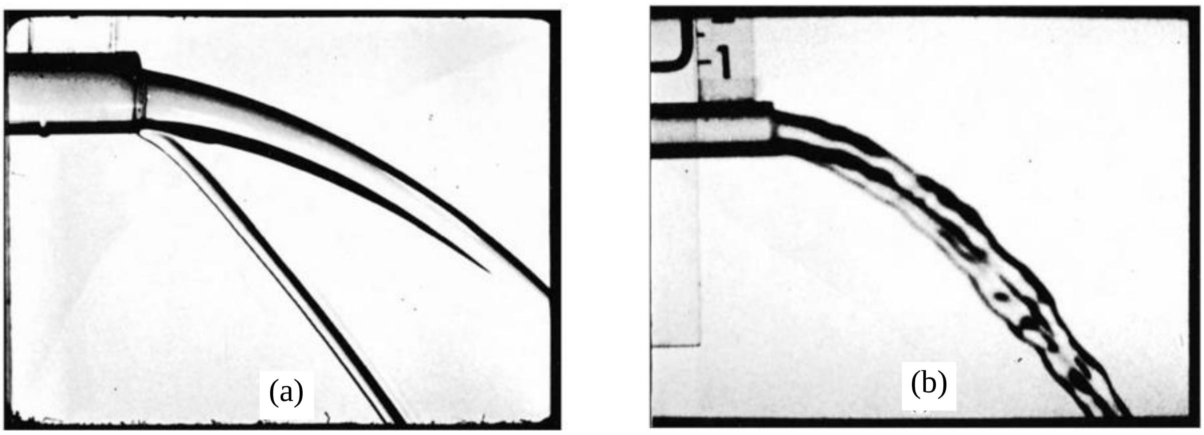

Figure 2.2 Flow with constant speed: (a) Laminar flow, low Re; (b) Turbulent flow, high Re (White, 2009)

2.2.2 Steady Flow vs Unsteady Flow

Steady flow is often characterised as time independent fluid flow where the parameters of the fluid flow does not change with varying of time and location which means: