CFD STUDY OF AN OSCILLATORY FLOW ACROSS HEAT EXCHANGER

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A report submitted
fulfillment of the requirements for the degree of
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DECLARATION

I declare that this project entitled "CFD study of an oscillatory flow across heat exchanger" is the result of my own work except as cited in the references.

Signature : ....

Name : EDZZRY INDRAWAN BIN FAIZAL EDZUAN

Date : 17.7.2020

APPROVAL

I hereby declare that I have read this project and in my opinion this report is sufficient in t4erms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature : ....

Supervisor's Name : FATIMAH AL-ZAHRAH MOHD SA'AT

Date : 17/7/2020

DEDICATION

I dedicate this project report to my loved family members who have support me and showed unending support. They have helped me in making this project a success. I would also dedicate this project report to the field of research. The contents within this project report should be helpful for future researches and studies.

ABSTRACT

This study focuses on the study of oscillatory flow at various drive ratios across a heat exchanger by using CFD modelling. The primary goal of a heat exchanger is to exchange heat between two fluids, hence the performance of the heat exchanger in terms of heat transfer is significant. Fluid flow can be of either steady flow, where fluid exits the system after heat is exchanged, or of oscillatory flow, where the fluid stays in the system oscillating back and forth periodically in a heat exchanger. The geometry model for the heat exchanger was modelled using Ansys Design Modeler. Grid independency test was conducted to determine the appropriate grid size to be used when solving the model. Four models of oscillatory flow of different DR were solved using Ansys Fluent. The results obtained was compared with theoretical calculations to determine the validity. Several contour plots of velocity, vorticity, temperature, and pressure were plotted. Heat transfer performance was analyzed by obtaining the surface heat transfer coefficient at the tubes and thus obtaining the heat transfer rates. Higher drive ratio, DR, provides greater heat transfer within the heat exchanger and the tube banks due to the turbulence generation. Since oscillatory flow has yet to have conclusive equations to model the heat transfer, steady flow heat transfer equations are used.

ABSTRAK

Kajian ini memberi fokus terhadap ujikaji aliran berayun merentasi penukar haba pada nisbah pemacu yang berbeza dengan menggunakan kaedah pemodelan dinamik aliran bendalir. Matlamat utama penukar haba adalah untuk untuk memindahkan haba di antara dua bendalir. Oleh itu, prestasi penukar haba dari segi pemindahan haba adalah penting. Aliran bendalir boleh diklasifikasikan dalam dua bentuk iaitu aliran stabil, di mana bendalir keluar daripada sistem setelah pertukaran haba, atau aliran barayun, di mana bendalir berada di dalam sistem sambil berayun ulang-alik secara berkala di dalam penukar haba. Model geometri penukar haba telah dimodelkan menggunakan Ansys Design Modeler. Ujian kebebasan grid telah dilakukan untuk menentukan ukuran grid yang sesuai dalam menyelesaikan model. Empat model aliran berayun pada nisbah pemacu yang berbeza telah di diselesaikan menggunakan Ansys Fluent. Hasil yang diperolehi telah dibandingkan dengan pengiraan teori untuk menentukankan kesahihan. Beberapa plot kontur halaju, vortisiti, suhu, dan tekanan telah diplot. Prestasi penukar haba telah dianalisis dengan mendapatkan pekali permindahan haba permukaan pada tiub dan mendapatkan kadar pemindahan haba. Nisbah pemacu yang lebih tinggi memberikan pemindahan haba yang lebih besar diantara penukar haba dan susunan tiub oleh sebab pergolakan yg dihasilkan. Disebabkan aliran berayun belum mempunyai persamaan yang boleh memodelkan pemindahan haba dengan tepat, persamaan pemindahan haba untuk aliran stabil telah digunakan.

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Futhermore, my utmost gratitude is given to the faculty for giving me the opportunity to perform my final year project. Special appreciation to the chairman of the final year project committee, Dr. Fadhli bin Syahrial for the clear instructions and steps to provide a proper final year project report according to the guideline specified.

I would also like to thank my family members for giving me the opportunity to further my study, their unwavering support, and words of encouragement throughout my study.

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LIST OF ABBEREVATIONS

CFD	Computational Fluid Dynamics
HWA	Hot-wire Anemometry
DR	Drive Ratio
PISO	Pressure-Implicit Splitting Operators

LIST OF SYMBOL

α	=	Womersly number
L_C	=	Characteristic length
μ	=	Dynamic viscosity
ρ	=	Density
ω	=	Angular frequency
R_e	=	Reynolds number
V	=	Velocity
v	=	Kinematic viscosity
h	=	Convection heat transfer coefficient
$\dot{Q}$	=	Rate of heat convection
A	=	Area of heat transfer
T_{LMTD}	=	Log mean temperature difference
ΔT_i	=	Temperature difference at the inlet
ΔT_e	=	Temperature difference at the outlet
Nu	=	Nusselt number
k	=	Thermal conductivity
P_r	=	Prandtl number
C_p	=	Specific heat

CHAPTER 1

INTRODUCTION

1.1 Background

Heat exchangers are devices that allow the transfer of thermal energy between two or more fluids of different temperatures. Cengel and Boles (2015) defined heat exchangers as a device where two moving fluids exchange heat without mixing. Both heating and cooling processes involve the use of heat exchangers. Heat exchangers are commonly used in applications where heating and cooling of a fluid stream of concern and evaporation or condensation of single- or multicomponent fluid streams (Shah & Sekulic, 2003). Other uses of heat exchangers can be seen in room heating, refrigeration, air-conditioning etc. Heat exchangers mainly work on the basic principle of convection (in each fluid) and conduction (between the thin walls and the fluid). Therefore, selection of proper heat exchangers is vital due to various factors that influence heat transfer rates depending on need of different applications.

There are several ways to classify heat exchangers which include differentiating them by their flow configuration, construction method, or the method at which they transfer heat. In this study, crossflow heat exchanger is the main focus. Crossflow heat exchangers are defined by the flow of fluid that is perpendicular to one another. This type of heat exchanger is further classified into two different classifications, namely mixed and unmixed flow. The differences between mixed and unmixed flow is that in mixed flow, the fluid is free to move in the transverse direction while in unmixed flow, the presence of fins only allows the fluid to move in the direction of the flow itself (Spakovszky, 2019).

In heat exchangers, tube banks are the most common type of configuration when it comes to transferring heat. The arrangements of the tube banks are usually either in-line or staggered with respect to the direction of flow. These tube banks are further classified based on their crosswise and streamwise pitch-to-diameter ratio, wherein having a ratio smaller than 1.25^2 are referred to as compact, while having a ratio larger than 4 are considered to be widely-spaced (Beale, 2011). In the case of internal flow in the tube banks, heat transfer analysis can be calculated by analysing a single tube, and multiplying the results by the amount of tubes present. However, for the case of external flow over tube banks, the tubes will affect the flow pattern and turbulence across the pipe, therefore affecting heat transfer to and from the pipes.

Heat exchanger that operates under oscillatory flow is a crucial component of thermoacoustic engines and coolers (Ilori, Jaworski, & Mao, 2018). The oscillating flow in thermoacoustic systems allows the transfer of energy within its internal component to produce acoustic power (engine) or to pump heat (cooler). Therefore, it is necessary to design an optimum heat exchanger to have thermoacoustic engines with high performance.

In this project, oscillatory flow over tube banks will be studied with the aid of Computational Fluid Dynamics (CFD) software such as ANSYS Fluent. The use of CFD will allow for easier analysis of the oscillatory flow with the help of computer simulation. It also eliminates the need for experimenting without compromising the accuracy of the results.

1.2 Problem statement

There are many different types of flows across tube banks. The general focus in this study is the oscillatory flow of fluid motion across tube banks. Fluid in an oscillatory flow moves in a manner in which it changes direction over time (including reverse motion). Some observations on oscillatory flow can be seen in situations such as water flow in oceans, blood circulation flow, and thermoacoustic engine.

There are many case studies as well as established researches that have been done towards heat transfer and fluid dynamics of fluid across tube banks especially in the case on steady one-directional flow. However, there are limited studies and literatures regarding oscillatory motion of fluid on the same subject. Therefore, in this project, the oscillatory flow of fluid across tube banks will be studied, simulated and recorded.

1.3 Objective

The objective of this project is:

1. To use CFD to model cross flow over tube banks.
2. To analyse fluid flow characteristics of oscillatory cross flow.
3. To analyse heat transfer characteristics of oscillatory cross flow.

1.4 Scope of study

The scopes of this study are:

1. Limited to the use of CFD only.
2. Only using two dimensional (2D) models.
3. Focuses on oscillatory flow only.
4. Use of circular tubes as heat exchanger.

CHAPTER 2

LITERATURE REVIEW

In this chapter, detail discussion on the information and research that had been done on the topic which is "CFD study of and oscillatory flow across heat exchangers". Some of the related terminology will be discussed in this section which includes flow characteristics, flows over heat exchangers, performance of heat exchangers, etc.

2.1 Types of flow

In this section of the report, the types of flows that are present will be defined and explained further in detail.

2.1.1 Internal flow

Internal flow is a fluid that flows through confining walls where the flow is guided from a defined inlet and exits an outlet (Johnston, 1976). Cengel and Cimbala (2017) defined internal flow if the fluid is bounded by solid surfaces. Fluid that flows in a duct where the liquid is partially filling the duct and there is a free surface that is classified as open-channel flow. Examples of this type of flow are fluid flow through a pipe, duct, or channel. An example of this type of flow can be seen by flow of water in pipes.

2.1.2 External flow

External flow is defined as the motion of fluid around a body which is immersed in the fluid medium (Polezhaev, 2011). Examples of external flow are flow of air around an aerofoil, and flow of air around a moving car. Figure 2.1 shows an illustration of external flow.

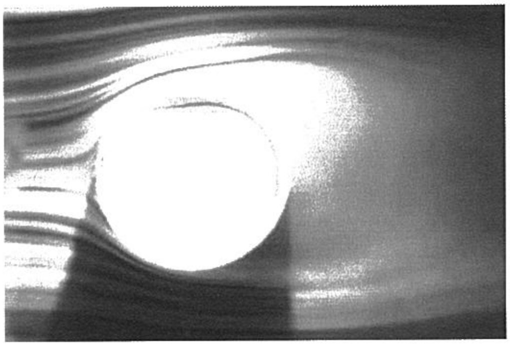

Figure 2.1: Illustration of external flow (Cengel & Cimbala, 2017)

2.1.3 Steady flow vs unsteady flow

The flow of fluid can be classified into two different flow conditions, namely steady flow and unsteady flow. Steady flow is the condition of flow when the fluid properties at any point in the system exhibits no change with respect to time. These fluid properties include temperature, density, pressure, velocity and etc. Unsteady flow or non-steady flow is a flow condition where the fluid properties of the system depend on time.

2.1.4 Cross flow

Cross flow is the type of flow where one fluid flows through pipes or tubes while the other fluid flows across the tubes in a perpendicular direction (Yoo, Kwon, & Kim, 2007). These types of heat exchangers usually operate for heat transfer between a liquid and a gas

(Bengtson, 2019). Examples of the application of cross flow heat exchanger configuration can be seen in car radiators and evaporator coil for air conditioning units. Figure 2.2 illustrates the cross flow situation.

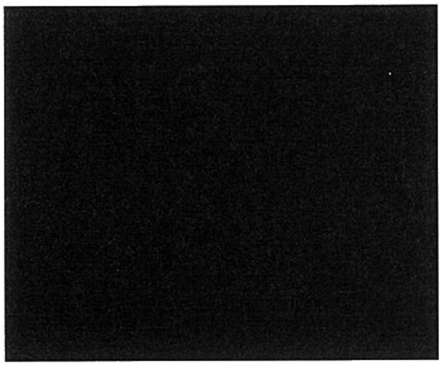

Figure 2.2: Illustration of cross flow

2.1.5 Oscillatory Flow

Oscillation can be defined as the forward and backward motion of a thing between two locations or points. This motion can be periodic which means it repeats itself in a steady cycle. Hence, oscillatory flow can be defined as a flow of a fluid moving back and forth in a regular cycle between two positions. Two forms of oscillatory flow have been studied. The first type is unidirectional oscillation about a mean pulsating flow which consists of two components; the steady and unsteady components. An example of this type of flow is the flow of blood in the arteries. The second type of oscillatory flow is reciprocating flows, which fully changes direction in the reverse direction cyclically with zero mean velocity (Jalil, 2019). There are various advantages to understanding oscillatory flows. Other examples of oscillatory flows are oscillation of the working fluid in thermoacoustics engines, and waves under the ocean.

In oscillatory flow, the velocity shape profile is dictated by the Womersley number. Womersley number, Wo, is a dimensionless parameter used most commonly in biofluid mechanics and biofluid dynamics. It is named after John R. Womersley (1907 – 1958) for his contributions towards blood flow in arteries. The Womersley number is usually denoted by α and is represented in Eq. (1).

$$\alpha = L_C\sqrt{\frac{\omega\rho}{\mu}} \tag{1}$$

where α is the Womersley number, L_C is the characteristic length (m), ω is the angular frequency of oscillation (rad/s), ρ is the density of the fluid (kg/m^3), and μ is the dynamics viscosity of the fluid (N·s/m^2). The Womersley number shows the ratio of transient inertia force to the shear force.

Feldmann and Wagner (2012) reported that the velocity profiles of oscillating flow can be in the shape of a parabola, M-profile or a flat profile with increasing frequency. Figure 2.3 shows the velocity profile at different Womersley number.

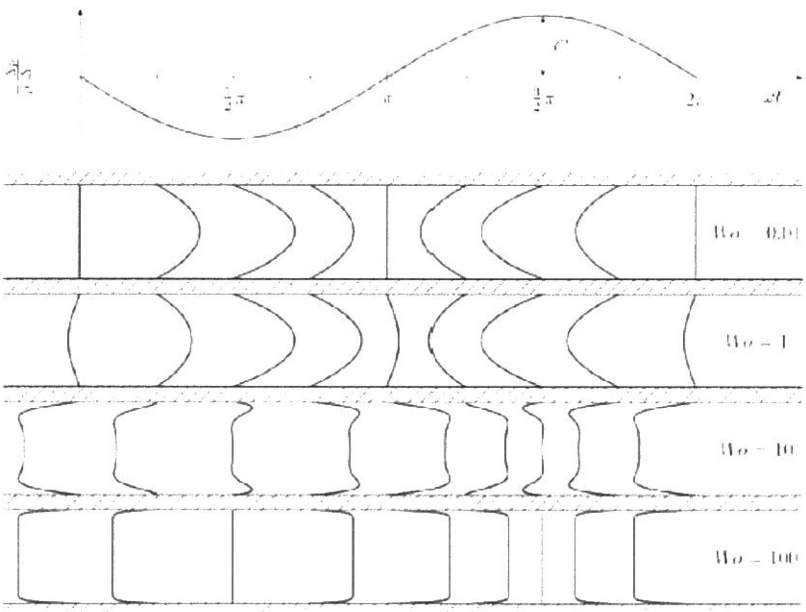

Figure 2.3: Velocity profiles of oscillatory flow at different Womersly number (Schoenmaker, 2017)

2.2 Flow over tube banks

In flow over tube banks, the fluid undergoes external flow. The tube banks act as an obstacle that obstructs the flow of the fluid. In this sub-section, the flow characteristics of the fluid in external flow will be discussed and explained such as no-slip condition, separation, stagnation and etc.

2.2.1 Boundary layer

Formation of a boundary layer begins when the first layer of the fluid flow adjacent to the surface is undergoing a no-slip condition. This motionless layer slows down the particles of the next fluid layer due to friction between the particles of the neighbouring layer. This process continues until a distance of δ from the plate beyond which the free-stream velocity remains unchanged. Figure 2.4 shows the development of boundary layer for different flow regimes.

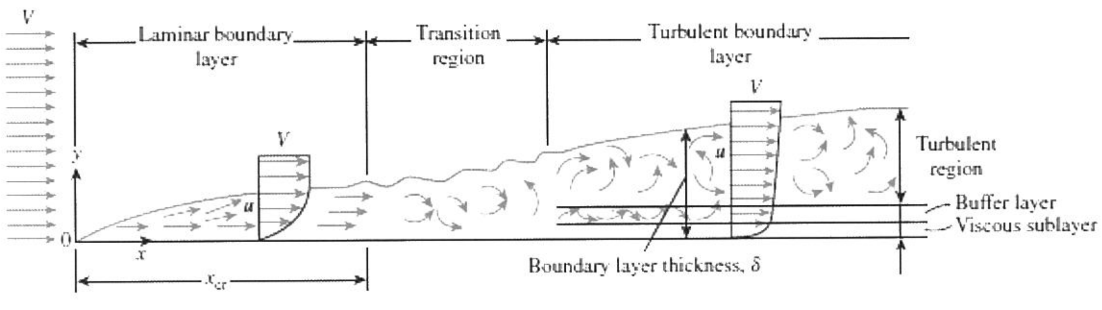

Figure 2.4: Development of boundary layer for different flow regimes (Cengel & Ghajar, 2015)

The boundary layer thickness, δ, is typically defined by distance y from the surface at $u = 0.99V$. This imaginary line of $u = 0.99V$ separates the flow into two regions: the boundary