CFD SIMULATION OF SHELL AND TUBE TYPE HEAT EXCHANGER: EFFECT OF FLOW CONDITION

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DECLARATION

I declare that this project report entitled "CFD Simulation of Shell and Tube Type Heat Exchanger: The Effect of Flow Condition" is the result of my own work except as cited in the references.

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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 (Thermal-Fluid).

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DEDICATION

To my beloved mother and father

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ABSTRACT

Shell and Tube Heat Exchanger (SNTHE) is widely used in the industry for heating, cooling, condensation and boiling processes with water as the most commonly used cooling fluid. This study investigates performances of SNTHE using three different fluids; Ammonia for its higher specific heat capacity than water, Carbon Dioxide for its high thermodynamics properties and Isobutane for its green refrigerant characteristics. A functional CFD model of SNTHE is developed and temperature condition, temperature contour, velocity condition and velocity contour of three different coolants are studied. Unbaffled Shell and Tube Heat Exchanger is used to simplified the shell side fluid flow as the presence of baffle will make the shell side fluid flow more complex. The model is designed as cited in the journal by Pal (2016) and the setting was set according to his paper. Model with water was used for grid independency test and validation purpose. After validation, Ammonia, Carbon Dioxide and Isobutane were set as the working fluid. The velocity contour shows that the fluids have similar pattern where flow skewed toward the outlet and have similar penetration pattern too. However, Isobutane offer the best fluid penetration in area between the tubes followed by Ammonia and lastly Carbon Dioxide. As for the temperature distribution, due to different thermal conductivity, different results were obtained. Isobutane is the best in term of heat transfer with average outlet temperature of 340 K followed by Ammonia 350 K and lastly Carbon Dioxide which is 350K. However, Carbon Dioxide offers no significant heat transfer as it is a gas with low density and low viscosity. As a result, it is not very suitable to be used unless it is in liquid form. Hence, Isobutane is the best alternatives compared to Ammonia and Carbon Dioxide as a substitute for water as a cooling fluid.

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ABSTRAK

Penukar haba cengkerang dan tiub atau ringkasnya SNTHE digunakan secara meluas dalam industri untuk pemanasan, penyejukan, pemeluwapan dan proses mendidih. Cecair penyejukan yang sering digunakan dalam industri ialah air. Untuk projek ini, tiga cecair penyejuk berbeza yang digunakan adalah Ammonia, Isobutane dan Karbon Dioksida. Ammonia dipilih oleh kerana ia mempunyai kapasiti haba yang tinggi berbanding dengan air; Karbon Dioksida untik sifat thermodinamik yang tinggi dan Isobutane untuk kesifatan cecair penyejukan yang hijau. Model CFD untuk SNTHE telah dibina dan kontur halalaju, kontur suhu, agihan halalaju dan agihan suhu telah dikaji. Model SNTHE tanpa sesekat digunakan untuk mempermudahkan aliran cecair di sebelah cengkerang sebab kehadiran sesekat akan menyebabkan pengaliran di cengkerang lebih kompleks. Model ini direka berdasarkan kajian Pal (2016) dan penetapan ditetapkan mengikut kertas kerjanya. Pada permulaan, model ini diuji dengan air untuk ujian kebergantungan terhadap grid dan pengesahan. Selepas pengesahan, model ini dikaji dengan Ammonia, Karbon Dioksida dan Isobutane. Berdasarkan keputusan kontur halaju, ketiga-tiga cecair menunjukan aliran bendalir yang serupa dimana aliran bendalir condong ke arah keluar dan mempunyai corak penembusan yang sama. Walau bagaimanapun, Isobutane mempunyai penembusan cecair yang terbaik di antara tiub diikuti oleh Ammonia dan Karbon Dioksida. Bagi pengedaran suhu, oleh kerana kekonduksian haba yang berbeza, hasil berbeza diperolehi. Isobutane adalah terbaik dari segi pemindahan haba dengan purata suhu keluar 340 K diikuti oleh Ammonia 350 K dan akhir sekali Karbon Dioksida dengan suhu 350 K. Walau bagaimanapun, Karbon Dioksida tidak menunjukkan proses pemindahan haba yang ketara kerana ia adalah gas dengan kepadatan yang rendah dan kelikatan yang rendah menyebabkan ia tidak sesuai untuk digunakan. Oleh itu, Isobutane adalah alternatif yang terbaik berbanding Ammonia dan Karbon Dioksida untuk digunakan sebagai pengganti bendalir penyejuk.

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LIST OF ABBEREVATIONS

SNTHE	Shell and Tube Heat Exchanger
CFD	Computational Fluid Dynamics
HE	Heat Exchanger
LMTD	Log Mean Temperature Difference
ODS	Operating Deflection Shape
AHU	Air Handling Unit
R600a	Isobutane
NH_3	Ammonia
CO_2	Carbon Dioxide

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LIST OF SYMBOLS

D = inner diameter of the tube

V = average velocity of the fluid

ρ = density of the fluid

μ = dynamic viscosity

$\dot{m}$ = mass flow rate

v = kinematic viscosity

Re =Reynolds Number

D_h =Hydraulic Diameter

h =Heat Transfer Coefficient

Nu =Nusselt Number

k =Thermal Conductivity

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Shell and Tube Heat Exchangers (SNTHE) are widely used in the industry as they have flexible designs. According to Chunnangad (2006), more than 35-40% heat exchangers are SNTHE. Usually, SNTHE are found in petrochemical and food industries. Their main purpose is to perform heating, cooling, condensation and boiling process. The main reason they are preferred in the industry is because they offer wide range of temperature change, and easy to be maintained.

Figure 1.1: Shell and Tube Heat Exchanger in food industry

Figure 1.2: Shell and Tube Heat Exchanger in petrochemical industry

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According to Pal (2016), SNTHE are popular in these industries because of its high rate of heat transfer in terms of volume and weight. Not only that, SHTHE can be built easily as it built from ranges tubes sizes with the strength to withstand the fabrication stress, shipping, fields erection stress and operation. Plus, the crucial SHTHE part like gasket, tubes screw can be replaced easily as all these components are easily found in the aftermarket. This makes the SNTHE to be maintained easily and cheaply.

In the industry, SNTHE are important for its ability to handle fluid of different temperature, flow rates, thermal properties and different expansion rates of metals. When mentioning handling fluids, it demotes the involvement of two or more liquids in the heat exchange process of convection and conduction. This is similar to mixing chamber where two different types of liquids with different temperature are mixed to achieve desired temperature. The difference between mixing chamber and SNTHE is that, SNTHE do not mixed the liquids to achieved desired temperature.

According to Aslam (2012), cross flow between tube banks and shell side are important aspects as it represents the ideal process in many important industry processes like flow in filtration, biological system, fibrous media or insulation material.

1.2 PROBLEM STATEMENT

Shell and Tube Heat Exchanger have been used for a century and lots of modifications and improvements are constantly done to increase the efficiency of the heat exchange rate. According to Anas (2016), shell and tube heat exchanger have gone through lots of improvement and modifications for the past century which includes the selection of better high thermal conductivity and durability material, better baffle design are determined by the optimum angle of the baffle. However, problems still occurred regarding the Shell and Tube Heat Exchanger like heat and flow problems.

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SNTHE today are equipped with baffles as the main supporter for the tubes and the baffles also provide certain behaviour of shell-side flow. However, there are some problems encountered by this device. The presence of baffle affects the shell-side flow. The subsequent flow contraction and expansion has caused flow separation at the edge of the baffle causing the pressure to drop significantly.

Besides that, there are issues of 'dead zones' at some areas near baffles. The 'dead zones' are area near baffles that are not reached by the fluid. The phenomenon could happen at certain condition of fluid flow like low fluid velocity, low mass flow rate, unstable of Reynolds number and poor shell and tube heat exchanger design. This 'dead zones' will greatly affect the heat exchange rate between the inner wall and outer wall as the dead zone are the part where the heat is not reach by fluid to carry out the heat exchange process (Wang, 2010).

1.3 SCOPE

1. To use CFD software to stimulate the flow.
2. To study the temperature distribution of three different type of coolants in Shell and Tube Heat Exchanger (SNTHE)
3. To study the flow condition of three different type of coolants in Shell and Tube Heat Exchanger (SNTHE)

Computational Fluid Dynamics (CFD) will be used to simulate the flow condition in the shell and the tube heat exchangers. Ansys, Design Modeler is used as the software to draw SNTHE model and to simulate the problem. Another scope is to study the relationship of different type of coolants and heat exchange rate. Coolants are identified in terms of chemical properties, heat properties to be used to simulate its performance towards heat

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transfer. The next scope of this study is to study the temperature distribution inside the Shell and Tube Heat Exchanger (SNTHE). Not only that, the flow condition such as velocity vector, velocity penetration are also further studies and identified their effect on the heat exchange process.

1.4 OBJECTIVE

1. To study a functional CFD model of Shell and Tube Heat Exchanger
2. To compare the temperature distribution of three different coolant in Shell and Tube Heat Exchanger.
3. To compare the flow condition of three different coolant in Shell and Tube Heat Exchanger.

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CHAPTER 2

LITERATURE REVIEW

2.1 Heat Exchanger

According to Yong (2015), heat exchangers (HE) are devices that transfers heat between one or more fluids. Fluids are usually separated by the solid wall to prevent the fluid from mixing or contacting each other. HE is very important in the industry as it is widely used in air conditioning, chemical plants, natural-gas processing, sewage treatment, space heating, petrochemical plants, petroleum refineries and power station. One of the conventional HE examples is internal combustion engine where engine coolant flows through radiator coils. At the same time, air passes through coils and cooled the coolant and heats the air. In heat exchanger, there are four basic flow configurations, counter flow heat exchanger, parallel flow heat exchanger, mixed flow heat exchanger and hybrid heat exchanger (Yong et al., 2015).

2.1.1 Counter Flow Heat Exchanger

In counter flow heat exchanger, two fluids flow in opposite directions. This type of flow allowed the biggest temperature different between both fluids to occur. Hence it is the most efficient heat exchanger in term of heat exchange rate compared to other heat exchangers.

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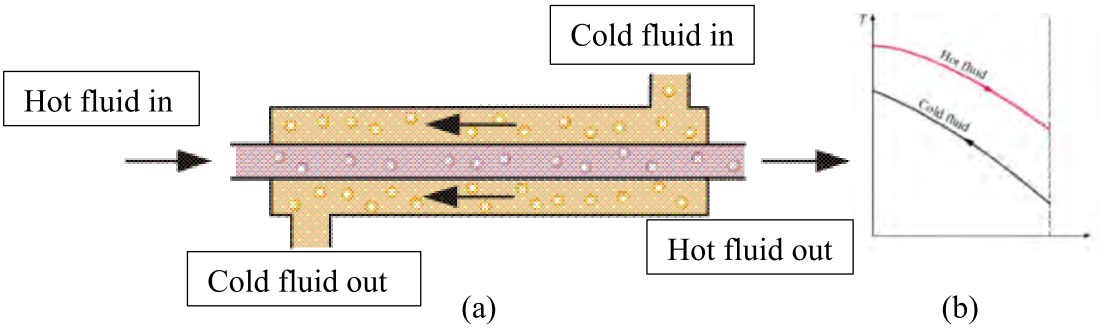

Figure 2.1: (a) Counter Flow, (b) temperature profile of cross flow (Cengel and Ghajar, 2015)

According to Zhang (2016), plate heat exchanger is one of the common types of counter flow heat exchanger. Plate heat exchanger is mainly build with plates and frames. The plates are thin and large in surface area and the plates are equally separated. The gaps between the plates are usually small as small fluid flow is required to enhance the heat transfer process.

There are two types of plate heat exchangers, closed loop and open loop. For closed loop plate heat exchanger, the plates are permanently bonded by brazing and welding. Closed looped applications are like refrigeration cycle. Well for open loop plate's heat exchanger, the plates are mounted and assembled like gasket. Because of these features, it allows the plates to undergo cleaning, inspection or disassembly easily.

The plate heat exchanger will carry out heat transfer by means of conduction and convection. There are two types of plates in the plate heat exchanger. Upward flow plates and downward flow plates. These plates are arranged alternatively and the hot fluid will flow in upward flow plates while the cold will flow in downwards flow plats or vice versa (Zhang et al., 2016).

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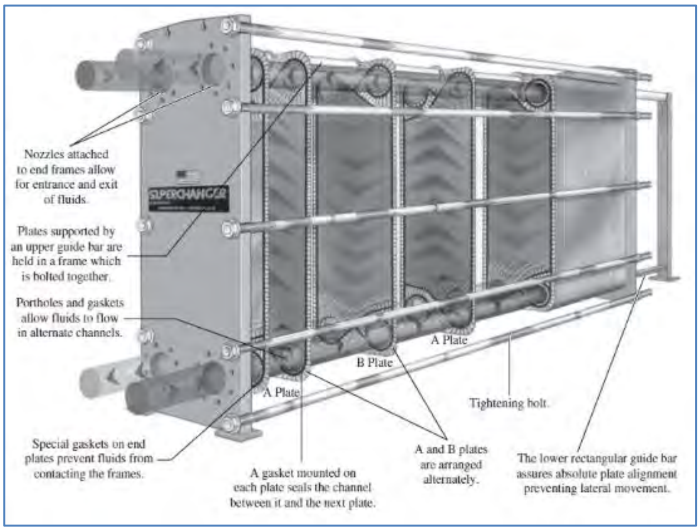

Figure 2.2: Plate Heat Exchanger (Cengel and Ghajar, 2015)

2.1.2 Parallel Flow Heat Exchanger

In parallel flow heat exchanger, the fluid flows parallelly in the same direction. Although it is less efficient than counter flow heat exchanger in terms of heat transfer, however, this kind of flow provide a more uniform wall temperature. For parallel flow type of heat exchanger, there is no specific type of heat exchanger as it can be applied for vertical and horizontal flow heat exchanger (Cengel and Ghajar, 2015).

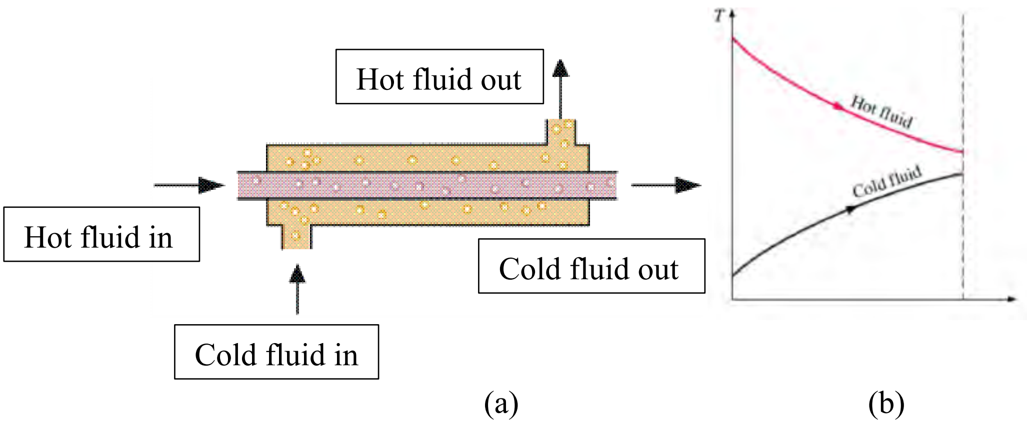

Figure 2.3: (a) Parallel Flow, (b) Temperature Profile (Cengel et al., 2015)

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2.1.3 Cross Flow Heat Exchanger

In cross flow heat exchanger, Brogan (2011) stated that the fluid flows at 90 degrees. For this kind flow, its efficiency is lower than counter flow but higher than parallel flows. According to Cengel and Ghajar (2015), cross flow heat exchanger can be classified as mixed and unmixed flow.

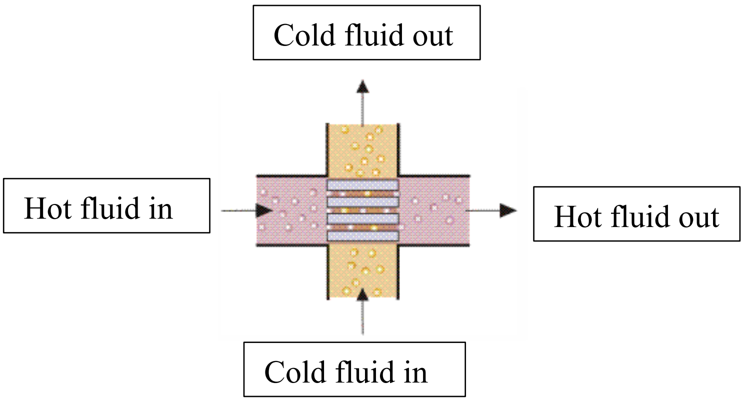
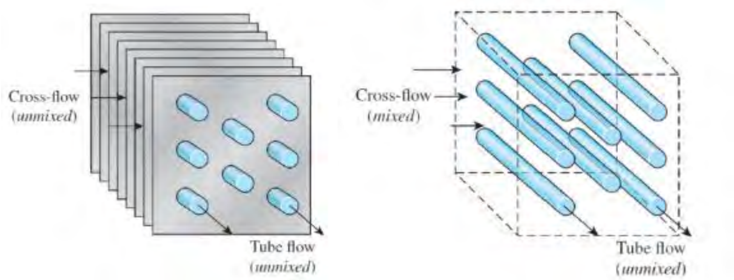


Figure 2.4: Cross Flow (Brogan, 2011)

Based on the Figure 2.5 (a), it can be observed that the flow is unmixed as the fluids are forced to flow through plate fins interfin spacing in the transverse direction. Cross-flow in (b) is categorized as mixed as the fluid is free to move in transverse direction without being confined to the plate as the model in Figure 2.5 (a).



(a) Both fluids unmixed (b) one fluid unmixed, one fluid mixed

Figure 2.5: Different flow configuration in cross-flow heat exchanger (Cengel et al., 2015)

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