STUDY OF HEAT TRANSFER IN PLATE HEAT EXCHANGER BY USING CFD SIMULATION

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## ABSTRACT

A plate heat exchanger is a type of heat exchanger which uses metal plates to transfer heat between two fluids. The metal plates that commonly used are stainless steel because of its ability to withstand high temperatures, its strength and its corrosion resistance. The basic working principle is very simple though; the channels that formed between the plates and corner ports are arranged so that the two fluid flows through alternate channels. The heat is transferred through the thin plate between the channels, and creating complete counter current flow for highest possible efficiency. No intermixing of the fluid or leakage to the surroundings will occur as gaskets around the edges of the plates seal the unit. The objectives of this study are to study the heat transfer performance of plate heat exchanger for heating diesel with hot water and to observe which configurations and parameters that gives the best results. In addition, the objective is to study and modeling the heat transfer of plate heat exchanger using simulation. Computational Fluid Dynamic (CFD) is a tool used in this simulation which consists of GAMBIT and FLUENT. Volume meshing in GAMBIT is an important part to be considered before doing simulation in FLUENT as a solver. Parameters that had been used were velocity and temperature of water. The velocity for both diesel and hot water were calculated using mass flow rate of 100L/min, 150 L/min and 200 L/min as a basic. The temperature of hot water varies from 60°C, 70°C and 80°C. Thus, this paper presents the simulation of heat transfer in plate heat exchanger model for parallel and series configurations. It is observed that lower velocity and high temperature of water gives better heat transfer performance. Parallel configuration is selected for the best configuration in this study.

## ABSTRAK

Penukar Haba Plat (Plate Heat Exchanger) adalah sejenis penukar haba yang menggunakan plat logam untuk pemindahan haba antara dua cecair. Plat logam yang biasa digunakan adalah keluli tahan karat (stainless steel) kerana keupayaannya untuk menahan suhu yang tinggi, kekuatan dan ketahanan kakisan. Prinsip kerja asas adalah sangat mudah, laluan yang membentuk antara plat dan kedudukan sudut disusun supaya kedua-dua aliran bendalir melalui laluan yang ditetapkan. Haba dipindahkan melalui plat nipis antara saluran, dan mewujudkan aliran bertentangan yang lengkap bagi mencapai kebarangkalian kecekapan tertinggi. Tiada percampuran (intermixing) cecair atau kebocoran kepada persekitaran akan berlaku kerana gasket di sekitar pinggir plat digunakan untuk meterai unit. Objektif kajian ini adalah untuk mengkaji prestasi pemindahan haba penukar haba plat untuk pemanasan diesel dengan air panas dan untuk mengenalpasti konfigurasi dan parameter yang manakah memberikan hasil yang terbaik. Di samping itu, objektif kajian adalah untuk mempelajari dan melakar pemindahan haba untuk penukar haba plat menggunakan simulasi. Dinamik Bendalir Komputeran (CFD) adalah alat yang digunakan dalam simulasi ini yang terdiri daripada GAMBIT dan FLUENT. Jumlah dagangan bersirat (volume meshing) dalam GAMBIT adalah satu bahagian penting yang perlu dipertimbangkan sebelum melakukan simulasi dalam FLUENT sebagai penyelesai. Parameter yang telah digunakan ialah halaju dan suhu air. Halaju bagi kedua-dua diesel dan air panas telah dikira menggunakan kadar aliran jisim (mass flow rate) 100L/min, 150 L / min dan 200 L / min sebagai asas. Suhu air panas berbeza dari 60 ° C, 70 ° C dan 80 ° C. Oleh itu, kertas kerja ini membentangkan simulasi pemindahan haba dalam plat model penukar haba untuk konfigurasi selari dan siri. Adalah diperhatikan bahawa halaju yang lebih rendah dan suhu air yang tinggi memberikan prestasi haba pemindahan yang lebih baik. Konfigurasi selari dipilih sebagai konfigurasi terbaik dalam kajian ini.

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# CHAPTER 1

# INTRODUCTION

## 1.1 BACKGROUND OF STUDY

A heat exchanger is a device which used to transfer thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact. Plate heat exchanger is one of the most common heat exchanger used in industries such as oil and gas processing system because of its compactness, easy maintenance and good heat transfer characteristics. As its name implies, this type of heat exchanger consists of a series of thin, corrugated plates which are pressed together in a rigid frame to form an arrangement of flow channels with alternating hot and cold fluids.

### 1.1.1 Plate Heat Exchanger

A plate heat exchanger is a type of heat exchanger which uses metal plates to transfer heat between two fluids. The metal plates that commonly used are stainless steel because of its ability to withstand high temperatures, its strength and its corrosion resistance. The basic working principle is very simple though; the channels that formed between the plates and corner ports are arranged so that the two fluid flows through alternate channels. The heat is transferred through the thin plate between the channels, and creating complete counter current flow for highest possible efficiency. No intermixing of the fluid or leakage to the surroundings will occur as gaskets around the edges of the plates seal the unit. The corrugation of the plates provides a suitable passage between the plates, support of each plate against the adjacent one and a strong turbulence resulting in maximum heat transfer efficiency.

The plates provide each of the fluids with large heat transfer area because each of the plates has a very large surface area. As a result a plate type heat exchanger compared to a similarly sized of shell and tube heat exchanger, is capable of transferring much more heat because of the larger area of the plates provides over tubes. Due to the high heat transfer efficiency, plate type heat exchangers are usually very small when compared to a shell and tube type heat exchanger but with the same heat transfer capacity.

### 1.1.2 History of Plate Heat Exchanger

Based on document Plate and Frame Heat Exchanger (1986); Gary Hulbert stated that the idea for designing plate heat exchanger was first developed by Dr. Richard Seligman, the founder of the Aluminium Plant and Vessel Company Ltd in 1923. The company is now known worldwide as APV. Commercial development of the plate heat exchanger resulted basically from the ability for high heat transfer rates at low differential temperatures; which exactly the feature that makes the plate heat exchanger so famous in geothermal applications. The original plate heat exchanger consisted of cast gun metal plates enclosed in a frame which is similar to a filter press. In the early 1930’s the introduction of pressed thin gauge stainless steel plates produced a machine that has developed into modern plate and frame heat exchanger.

### 1.1.3 Heat Transfer

Heat transfer is a science that studies the energy transfer between two bodies due to temperature difference. In theory, thermal energy is related to the kinetics energy of molecules on a microscopic scale. When material’s temperature increases, the thermal agitation of its constituent molecules will increase. Then the areas which contain greater molecular kinetic energy will pass this energy to areas with less kinetic energy. So when an object or fluid is at different temperature than its surroundings, the heat transfer will occur in such a way that the body and the surroundings reach thermal equilibrium.

Generally there are three types of heat transfer which are conduction, convection and radiation. Conduction is the transfer of heat within an object or between two objects in contact. Convection heat transfer occurs when a fluid (liquid or gas) comes in contact with a material of a different temperature. For natural convection, it occurs when the flow of a fluid is primarily due to density differences within the fluid due to cooling or heating of that fluid. Meanwhile, forced convection occurs when the flow of fluid is primarily due to pressure differences. Radiation is the transfer of heat from one object to another by means of electro-magnetic waves. Radiation does not require objects to be in contact or fluid flow between those objects, it occurs in the void of space (that's how the sun warms us). Transfer of thermal energy can also occur with any combination of the three. In my study which relates to plate heat exchanger, it consists of heat transfer by conduction and convection.

## 1.2 PROBLEM STATEMENT

Heat transfer is the most important parameter to be measured as the thermal performance and heat transfer efficiency of the plate heat exchanger. As a comparison, plate heat exchangers are competitive with shell and tube units because of high heat transfer efficiency and attractive features even though built of costlier materials. Besides that, many studies have been done using both experimental and numerical analysis based on working fluid (water/water) which has small viscosity compared to other types of fluid. In order to investigate more, fluid with higher viscosity should be used to observe the outcome of heat transfer performance. By using CFD simulation, the performance of plate heat exchanger can be optimized and at the same time, it can reduce the operation cost and time when using experimental analysis.

## 1.3 OBJECTIVES

The objectives of this study are:

(i) To study the heat transfer performance of plate heat exchanger for heating diesel with hot water

(ii) To observe which configurations and parameters that gives the best results

(iii) To study and modeling the heat transfer of plate heat exchanger using CFD simulation

## 1.4 SCOPES OF STUDY

In order to achieve the objectives above, there are five scopes of this study defined which are:

(i) The working fluid used for this study are diesel and water

(ii) There are two parameters that will be the manipulated variables which are temperature and velocity

(iii) Both parameters above will be investigated in term of their effect using two kind of distinct configurations which is series and parallel; both counter-current

(iv) The study concerned with turbulent flow regimes using k-ε equation

(v) The application of CFD simulation to model the heat transfer and to compare which configuration is a better choice

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

The purpose of this chapter is to provide a literature review of past research effort such as journals or articles or documents related to heat transfer of plate heat exchanger experimentally and numerically. In addition, review of other relevant research studies are made to provide additional information in order to understand more of this study.

## 2.2 PLATE HEAT EXCHANGER

Nowadays, plate heat exchangers are used widely as a better choice for higher efficiency in thermal performance. As stated by H. Dardour, S. Mazouz, A. Bellagi, (2009), in the majority of the industrial applications, the plate heat exchanger is the design of choice because of its characteristics which are easy-to-maintain, compact design, light weight and because of the many advantages it offers. Minimal maintenance, cost effectiveness and especially high efficiency are the most important criteria that are making studies on plate heat exchanger is a big challenge for researchers to develop and produce plate heat exchanger achieving the best possible performance in terms of efficiency and economical considerations.

### 2.2.1 Performances of Plate Heat exchanger

Before this, plate type heat exchangers are not widely used because of the inability to seal the large gaskets between each of the plates. Because of this problem, plate type heat exchangers have only been used in small, low pressure applications. Nevertheless, new improvements have been made in gasket design and overall heat exchanger design to allow some large scale applications of the plate type heat exchanger. As the developments arise, large plate type heat exchangers are replacing shell and heat exchangers and becoming more common.

The PHE consists of a pack of gasketed corrugated metal plates, pressed together in a frame. The gaskets on the corners of the plates form a series of parallel flow channels, where the fluids flow alternately and exchange heat through the thin metal plates. The number of plates, their perforation, the type and position of the gaskets and the location of the inlet and outlet connections at the covers characterize the PHE configuration, which further defines the flow distribution inside the plate pack. The flow distribution can be parallel, series or any of their various possible combinations. (Jorge A.W. Gut, Jose M. Pinto 2003). From **Figure 2.1**, it shows the basic flow principle of plate heat exchanger in parallel.

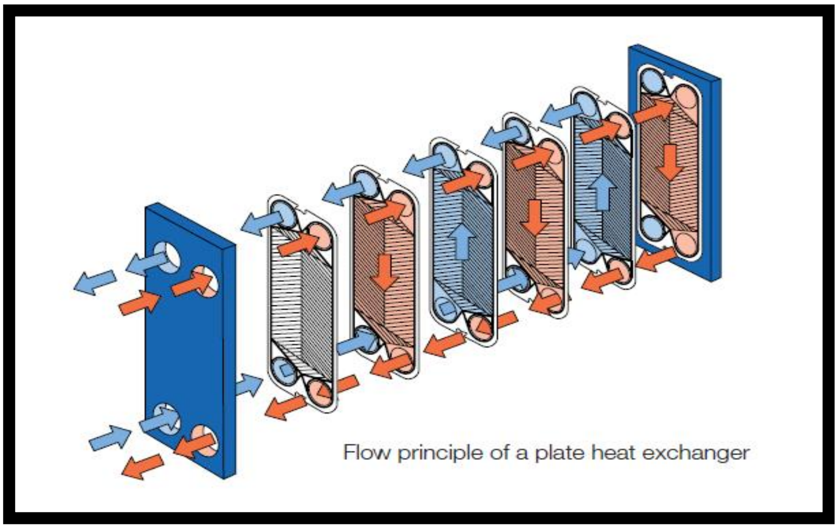
Flow principle of a plate heat exchanger

**Figure 2.1**: Flow Principle of Plate Heat Exchanger

Source: Heat Exchanger Engineering Techniques book, Michael J. Nee

Li Xiao-wei and Meng Ji-an and Li Zhi-xin stated that plates are the basic heat transfer elements in plate heat exchangers, so the basic way to improve the performance of plate heat exchangers is to improve the flow and heat transfer performance of the plates. The best plates should have high heat transfer coefficients, low pressure drop and high pressure endurance. In this study, the heat transfer performance will be investigated for heating the diesel using hot water system. The best configurations will be selected based on the heat transfer performance. The heating process is necessary to maintain better flow ability of diesel in diesel engine. The flow ability of diesel will be worse as soon as the temperature started to decrease because of the high viscosity of diesel.

### 2.2.2 Advantages and Disadvantages

From Heat Exchanger Engineering Techniques, Michael J. Nee stated plate heat exchangers are preferred over shell and tube heat exchangers in some applications. They are well suited to counter flow construction, thus maximizing the Log Mean Temperature Difference (LMTD) correction factor. Their construction minimizes the need for welding. Plate heat exchangers often have a competitive advantage when the available pressure drop is high (5 to 10 psi) and when most of it is used in selecting heat exchanger. The reason is the plate heat exchanger is relatively short length of travel.

In the mean time, the turbulent flow inside will help to reduce deposits which would interfere with heat transfer. Its pluses are that it occupies high heat transfer efficiency, less space, simple in maintenance and easily cleaned on both streams. Plate heat exchanger required no extra space for dismantling and its capacity can be increased by introducing plates in pairs. Therefore, when corrosion is an issue, the plate heat exchangers have more advantage because it is manufactured with stainless steel. Due to the plate thicknesses are thinner resulting in a decrease in metal resistance. Besides that, the herringbone shape breaks up any laminar or transition flow component present thus acting like a turbulator. The conditions are additive in improving the heat transfer rate. Moreover, these pluses can and often occur on both streams.

On the other hand, there are also several disadvantages of plate heat exchangers; the main objection is the possibility of leakage. Plate heat exchangers are not available with extended surface other than that of stretching occurs in the stamping process. They are not recommended when fluid particles are larger in diameter than the stamped depth of the plates. The pressure and temperature limits are low when compared to shell and tube units, roughly 400 psi and 375°F. Besides that, plate heat exchangers are not readily adaptable to low pressure vapor or gas. In general, the plate heat exchangers are less efficient in high fouling services and made from costlier materials.

### 2.2.3 Numerical Analysis for Co-Current

H. Dardour, S. Mazouz, A. Bellagi, (2009) presented an analysis paper of co-current plate heat exchanger and its numerical simulation results. From known data which are the hot and cold fluid streams inlet temperatures, heat capacities and overall heat transfer coefficients, a 1-D mathematical model based on the steady flow energy balance for a differential length of the device is developed resulting in a set of N first order differential equations with boundary conditions where N is the number of channels.

For specific heat exchanger geometry and operational parameter, the problem is numerically solved using the shooting method. This simulation allows the prediction of the temperature map in the heat exchanger and the evaluation of its performances. A parametric analysis is performed to evaluate the influence of the R-parameter on the ε-NTU values. For practical purposes, the effectiveness-NTU graphs are elaborated for specific heat exchanger geometry and different operating conditions.

### 2.2.4 Experimental and Numerical Heat Transfer

Flavio C.C. Galeazzo, Raquel Y. Miura, Jorge A.W. Gut, Carmen C. Tadini, (2006) studied a four-channel plate heat exchanger developed by using CFD as shown in **Figure 2.2** and **Figure 2.3**. There were two kinds of arrangements that have been tested which are parallel and series, both counter-currents. From **Figure 2.4** and **Figure 2.5,** the distributions are shown in term of temperature and velocity, which lead to comparison between numerical predictions and experimental results for heat load obtained from 1D plug-flow model and 3D CFD model. The experimental procedure was conducted using water as working fluid on hot and cold sides of plate heat exchanger.

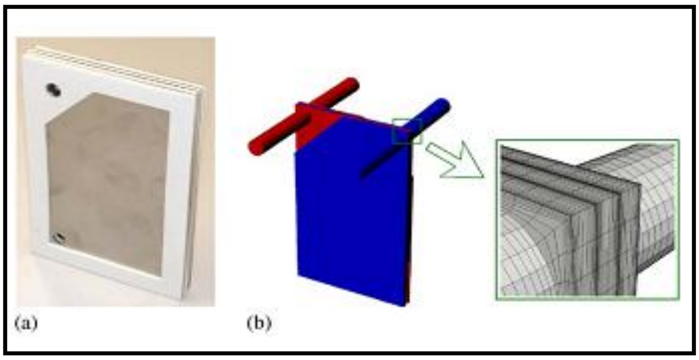


**Figure 2.2**: (a) The plate pack of the PHE used in this study, (b) The CFD representation of the fluid domain for series flow arrangement showing a mesh detail
Source: Flavio C.C. Galeazzo, Raquel Y. Miura, Jorge A.W. Gut, Carmen C. Tadini, (2006)

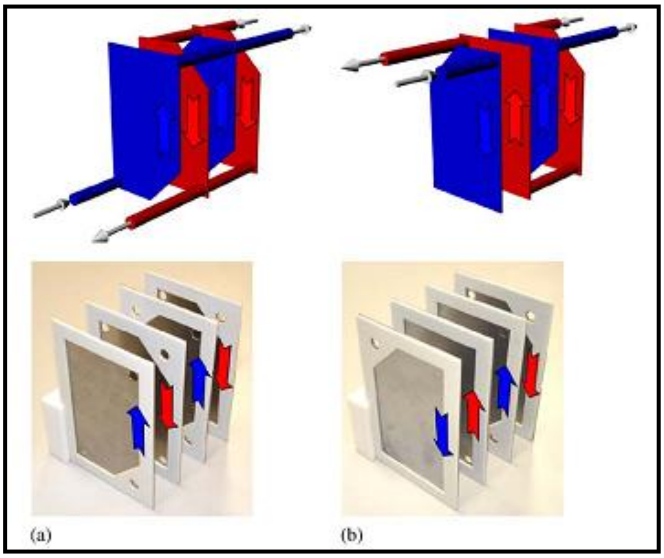


**Figure 2.3**: Expanded CFD representation and opened plate pack for (a) parallel arrangement and (b) series arrangement
Source: Flavio C.C. Galeazzo, Raquel Y. Miura, Jorge A.W. Gut, Carmen C. Tadini, (2006)

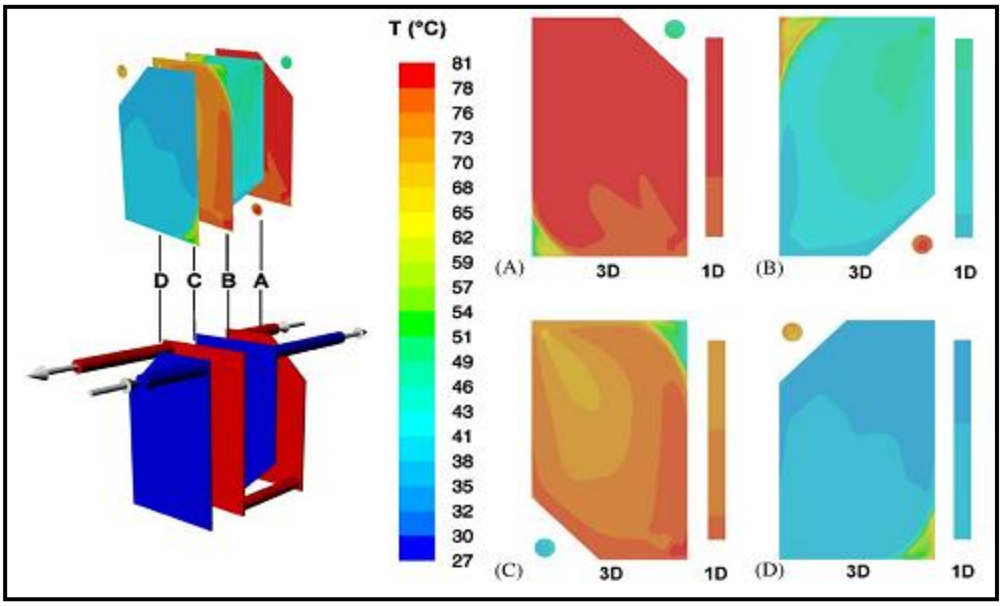


**Figure 2.4**: Midplane temperature distribution for the channels of a series flow arrangement: 3D and 1D model results

Source: Flavio C.C. Galeazzo, Raquel Y. Miura, Jorge A.W. Gut, Carmen C. Tadini, (2006)

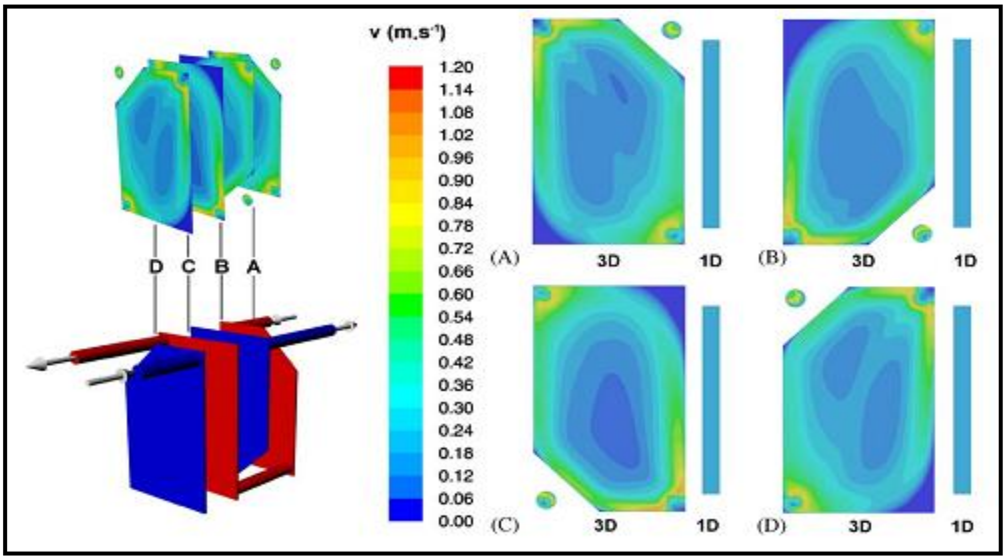


**Figure 2.5**: Midplane velocity distribution for the channels of a series flow arrangement: 3D and 1D model results

Source: Flavio C.C. Galeazzo, Raquel Y. Miura, Jorge A.W. Gut, Carmen C. Tadini, (2006) For CFD part, the sensitivity of the simulation to the turbulence modeling was investigated and solved using laminar flow model, k-ε turbulence model with wall functions and the k-ε turbulence model with enhanced wall treatment. Most flow inside the exchanger was verified as laminar; however there were turbulent regions especially near the plate ports. In order to correctly model the flow and heat transfer, the k-ε turbulence model with enhanced wall treatment model was preferred and have way better agreement with the experimental results.

### 2.2.5 Modeling with Generalized Configurations

S.G. Kandlikar and R.K. Shah (1989) developed a method to calculate an approximate thermal effectiveness for large exchangers, where the effects of the end plates and the changes of passes are less significant and thus can be neglected. The analytical solution of the system of equations in matrix form was studied by T. Zaleski and A.B. Jarzebski (1973) for exchangers with series and parallel flow arrangements. Since this solution for the method may lead to numerical problems on the calculation, it is not recommended to exchangers with large number of channels. S.G. Kandlikar and R.K. Shah (1989) and M.C. Georgiadis and S. Macchietto (2000) has used the finite difference method for the simulation of plate heat exchangers. They have simulated and compared using several configurations. Then it was verified that higher effectiveness is achieved when the exchanger is symmetrical (both streams with the same number of passes) with the passes arranged for counter current flow in the channels. The same results were obtained by T. Zaleski and K. Klepacka (1992) when analyzing the thermal effectiveness of various plate heat exchanger configurations.

Jorge A.W. Gut and Jose M. Pinto (2003) presented a plate heat exchanger modeling framework that is suitable for any configuration. The purpose of developing the model is to study the influence of the configuration on the exchanger performance. The study for variation of the overall heat transfer coefficient throughout the exchanger with respect to the assumption of a constant value is also investigated. The mathematical modeling of a plate heat exchanger is developed in algorithmic form. Finally a simulation example is shown, where the effect of the assumption of constant overall heat transfer coefficient is analyzed.

### 2.2.6 Effectiveness Charts for Counter Flow Corrugated

Harika Sammeta, Kalaichelvi Ponnusamy, M.A. Majid. K. Dheenathayalan, (2011) prepared analysis charts for 9-plate counter flow corrugated plate heat exchanger which is modeled and simulated using CFD. The performance of the plate heat exchanger is analyzed using the obtained simulated data in the form of charts such as effectiveness, ε versus number of transfer units, NTU at constant capacity ratio, R and so on. The problem was numerically solved using the finite volume method with FLUENT and **Figure 2.6** shows how the results of temperature contours looks like. From this paper, it is observed that the temperature difference for counter flow agrees with the fundamental concepts of counter flow heat exchangers.

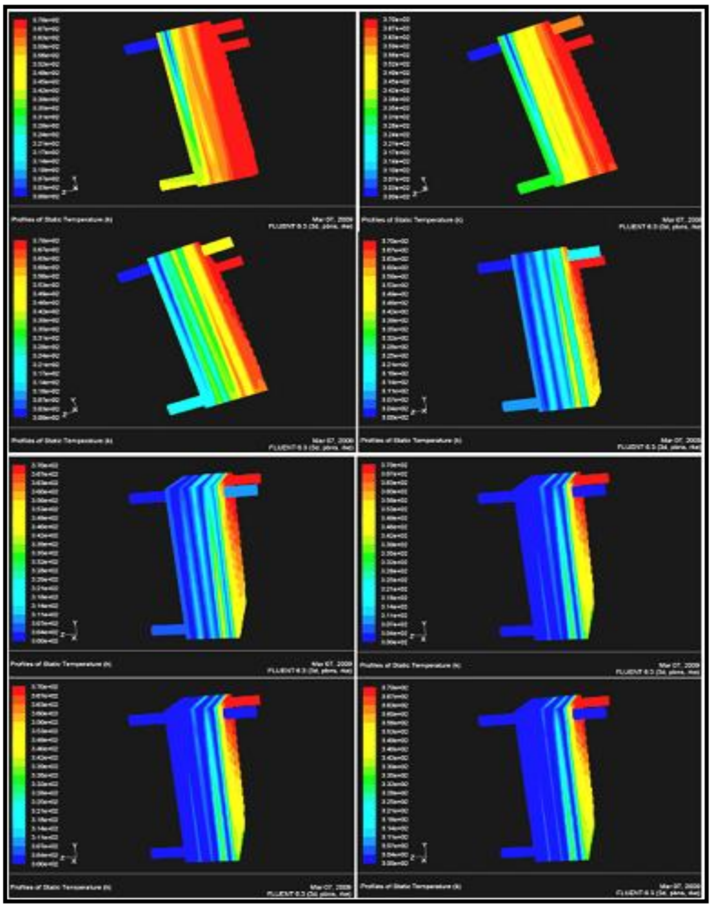

**Figure 2.6**: Temperature contours of 0.005 kg/s hot flow rate for various cold flow rates

Source: Harika Sammeta, Kalaichelvi Ponnusamy, M.A. Majid. K. Dheenathayalan, (2011)

### 2.2.7 Heat Transfer Fouling and Fluid Flow

Kho and Müller-Steinhagen (1999) investigated the effect of flow distribution inside the channel of a plate heat exchanger with flat plates. CFD simulations were performed using CFX (ANSYS, Canonsburg, USA). Different distributors were tested numerically for obtaining a more homogeneous flow distribution and thus reducing fouling. The geometry of the channel was modeled with grid of 45,000 elements using the *k*-ε turbulence model. The plate wall temperature was specified as boundary condition and flow and heat transfer were simulated for incompressible flow under steady state conditions. As shown in **Figure 2.7**, the results of contours are obtained by using four different kinds of distributions.

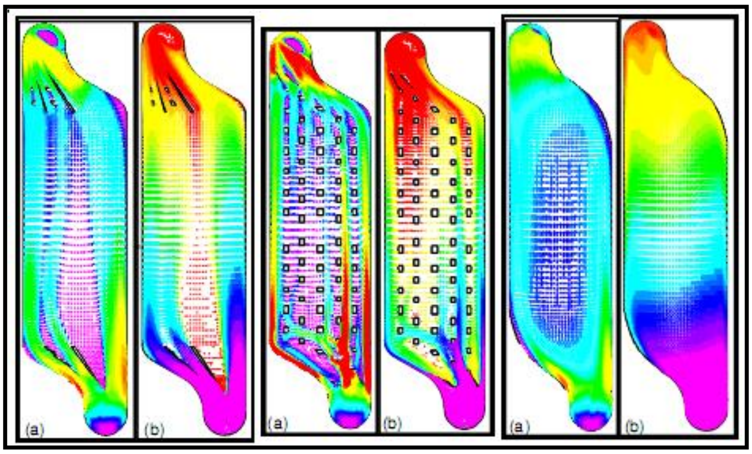


**Figure 2.7**: Flow and temperature distribution for distributor design C, G and H
Source: Kho and Müller-Steinhagen (1999)

### 2.2.8 Effect of Flow Arrangement on the Pressure Drop

The pumping power is an important constraint for the design of plate heat exchanger which is proportional to the pressure drop. Moreover, plate heat exchangers have pressure limitations due to the extensive use of gaskets; thus, the maximum pressure is also a design constraint that depends on the pressure drop. This investigation has been done by Raquel Y. Miura, Flavio C.C. Galeazzo, Carmen C. Tadini, Jorge A.W. Gut (2008) in order to study the effect of flow arrangement on the pressure drop.