DESIGN OF A SMALL HEAT EXCHANGER (SHELL-AND-TUBE TYPE)

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JUDUL: **DESIGN OF A SMALL HEAT EXCHANGER (SHELL-AND-TUBE TYPE)**

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I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Dedicated to my parents

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ABSTRACT

This project is mainly focusing on designing one type of a heat exchanger which is shell and tube heat exchanger. Step by step on designing, the software is build first to make the work on calculation easy and simple by using ε-NTU method. This method technically more simple than LMTD where it has to refer to a complex graph to calculate certain outputs that needed. The software used is Visual Basic. The language in the program consists of formulas of calculating parameters in heat exchanger such as heat transfer coefficient, heat transfer rate or heat capacity rate. This program design should match the heat exchanger software in the market. To design this heat exchanger, many considerations were taken. The shell size must be adaptable to the water flow rate. To determine how many tubes that are used also depends on the size of the shell. Water flow rate can be determined by using ball valve opening. The opening is decided to be 50%, 60%, 65%, 75% and 100%. To read the temperature, a thermometer digital is attached at inlet and outlet for both hot and cold fluid. The five readings were taken and take into calculation using the software that has been build. The manual calculation is done to check the program in the software whether it is compatible. From the results obtained, the heat transfer rate rise up when the mass flow rate increased. Lastly the most suitable and economical heat exchanger is decided. And to conclude, the simulation of heat exchanger in the software is compatible with the design as the result is same.

ABSTRAK

Projek ini berkisar tentang salah satu rekebentuk pengubah haba iaitu pengubah haba cangkerang dan tiub. Langkah demi langkah dalam merekabentuk, pertama sekali adalah membina satu perisian yang membolehkan kerja-kerja mengira lebih mudah dan senang dengan menggunakan kaedah ε-NTU. Perisian yang digunakan adalah Visual Basic. Bahasa yang digunakan di dalam program ini adalah mengandungi formula-formula tertentu dalammengira parameter yang terkandung di dalam pengubah haba ini seperti pekali pemindahan haba, kadar pemindahan haba, atau kadar kapasiti haba. Program ini haruslah menepati perisian pengubah haba yang terdapat di pasaran. Untuk merekabentuk pengubah haba ini, banyak langkah-langkah yang perlu diambil kira. Saiz cangkerang perlulah menepati kadar aliran air. Untuk menentukan berapa banyak tiub yang harus digunakan juga bergantung kepada saiz cangkerang. Kadar aliran air ditentukan melalui bukaan injap bebola. Bukaan tersebut adalah 50%, 60%, 65%, 75% dan 100%. Untuk mengambil bacaaan suhu, thermometer digital diletakkan pada masukan dan keluaran bagi kedua-dua cecair panas dan sejuk. Bacaan diambil dan dimasukkan ke dalam pengiraan menggunakan perisisan yang telah dibina. Pengiraan secara manual dibuat untuk memeriksa sama ada program di dalam perisian bertepatan dengan apa yang dikehendaki. Berdasarkan keputusan yang diperolehi, kadar pemindahan haba semakin meningkat apabila kadar aliran berat dinaikkan. Akhir sekali, pengubah haba yang terbaik dan ekonomi akan dipilih. Kesimpulannya, simulasi pengubah haba di dalam perisian adalah bertepatan dengan rekabentuk di mana keputusannya adalah sama.

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A_s	Heat transfer surface area
c	Capacity ratio
C_c	Heat capacity rate of hot fluid
C_h	Heat capacity rate of hot fluid
C_{max}	Maximum heat capacity rate
C_{min}	Minimum heat capacity rate
C_{p_c}	Specific heat of cold fluid
C_{p_h}	Specific heat of hot fluid
D	Diameter of heat exchanger
ε	Effectiveness
L	Length of heat exchanger
$\dot{m}_c$	Mass flow rate of hot fluid
$\dot{m}_h$	Mass flow rate of hot fluid
n	Number of tube passes
NTU	Number of Transfer Units
$T_{h,in}$	Temperature at the tubeside inlet
$T_{c,in}$	Temperature at the shellside inlet
$T_{h,out}$	Temperature at the tubeside outlet
$T_{c,out}$	Temperature at the shellside outlet
U	Overall heat transfer coefficient
$\dot{Q}$	Actual heat transfer rate
$\dot{Q}_{max}$	Maximum possible heat transfer rate

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Heat exchanger is a device built for efficient heat transfer from one medium to another, whether the media are separated by a solid wall so that they never mix, or the media are in direct contact. They are widely used in space heating, refrigeration, air conditioning, power plants, chemical plants, petrochemical plants, petroleum refineries, and natural gas processing. One common example of a heat exchanger is the radiator in a car, in which a hot engine-cooling fluid, like antifreeze, transfers heat to air flowing through the radiator. To design a heat exchanger, many criteria have to be taken before making any decision. The important parameters of heat exchangers are collected and put a major consideration on it. In this project, the software needed to configure all the parameters to put in. From there, the software runs and the main point is to create a new windows program that is similar to another existed software of calculating heat transfer in market. The major purpose is to obtain a desired output by using this program. Thus, the ideal shell and tube heat exchanger is produced at the end.

1.2 PROJECT OBJECTIVES

The objectives of this project are:

i) To build a suitable software to design a shell and tube heat exchanger.

ii) To obtained the best specifications of heat exchangers.

iii) To design and build a small shell and tube heat exchanger to check the program.

1.3 PROBLEM STATEMENT

The shell and tube heat exchanger is one type of heat exchanger that is common used in industry. This is because it contains a large number of tubes packed in a shell with the axis parallel to that shell. There is a heat transferred when one fluid flows inside the tubes and other fluid flows outside the tubes through the shell. In reality, shell and tube heat exchanger is not suitable for use in aircraft and automotive purposes because the size is relatively large and also weighty. In this project, the main focus is in designing a small shell and tube heat exchanger which is available and easy to do an experiment in the lab. There is a choice of formula to utilize in defining the desired outputs. We can use the LMTD (Log Mean Temperature Difference) or ε-NTU (effectiveness-Number of Transfer Units). The method used in constructing the formula is using ε-NTU which is introduced in 1955 by Kays and London. This method is more greatly simplified heat exchanger analysis than LMTD. In this project, the problem stated are to check if the design is worked and is it possibly compatible with the software.

1.4 PROJECT SCOPES

This project is mainly concentrating on how to build a new window program by using certain software that is available in market. The point to build a program is to calculate the various outputs of shell and tube heat exchanger by applying a formula. The software used is Visual Basic and it utilized to create a new program of calculator. Designing a shell and tube heat exchanger by fabrication will then runs in total of five flow opening percentage which is 50, 60, 65, 75 and 100. The shell and tube heat exchanger then will be tested to get the result and distinguish which flow rate is suitable and economical.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Heat exchanger is one of devices that is convenient in industrial and household application. These include power production, chemical industries, food industries, electronics, environmental engineering, manufacturing industry, and many others. It comes in many types and function according to its uses.

So what exactly heat exchanger is? Heat exchanger is a device that is used to transfer thermal energy between two or more fluids, between a solid surface and a fluid at different temperatures and in thermal contact. There are usually no external heat and work interactions. In most heat exchangers, heat transfer between fluids takes place through a separating wall or into and out of a wall in a transient manner. (Shah R.K., 2003)

This chapter will discuss about the uses and application of shell and tube heat exchanger, type of heat exchangers, and shell and tube heat exchanger.

2.2 USES AND APPLICATIONS OF HEAT EXCHANGER

Heat exchangers are used to transfer heat from one media to another. It is most commonly used in space heating such as in the home, refrigeration, power plants and even in air conditioning. It is also used in the radiator in a car using an antifreeze engine cooling fluid. Heat exchangers are classified according to their flow arrangements where there are the parallel flow, and the counter flow. Aside from this, heat exchangers also have different types depending on their purpose and how that heat is exchanged.

But the fact is that there are heat exchangers even in the circulation system of fishes and whales. The veins of these animals are intertwined such that one side is carrying cold blood and the other has cold blood. As a result, these species can prevent heat loss especially when they are swimming in cold water. In some whales, the heat exchanger can be found in their tongues. When it comes to the manufacturing industry, heat exchangers are used both for cooling and heating. Heat exchangers in large scale industrial processes are usually custom made to suit the process, depending on the type of fluid used, the phase, temperature, pressure, chemical composition and other thermodynamic properties. (Kakac, S. 2002)

Heat exchangers mostly can be found in industries which produce a heat stream. In this case, heat exchangers usually circulate the output heat to put it as input by heating a different stream in the process. The fact that it really saves a lot of money because when the output heat no longer needed then it can be recycled rather than to come from an external source as heat is basically recycled. When used in industries and in the home, it can serve to lower energy costs as it helps recover wasted heat and recycle it for heating in another process. Typically, most heat exchangers use fluid to store heat and heat transfer can take the form of either absorption or dissipation.

For instance, heat exchangers are used as oil coolers, transmission and engine coolers, boiler coolers, waste water heat recovery, condensers and evaporators in refrigeration systems. In residential homes, heat exchangers are used for floor heating, pool heating, snow and ice melting, domestic water heater, central, solar and geothermal heating. Of course, heat exchangers have different designs which depend on the purpose it is intended for. Brazed heat exchangers, a collection of plates which are brazed together, are used for hydronic systems like swimming pools, floor heating, snow and ice melting. The shell and coil heat exchanger design is best for areas with limited spaces as it can be installed vertically. Of course, for the highly industrial process, the shell and tube heat exchanger is the perfect solution.

2.3 TYPE OF HEAT EXCHANGERS

In industries, there are lots of heat exchanger that can be seen. The types of heat exchanger can be classified in three major constructions which are tubular type, plate type and extended surface type.

2.3.1 Tubular Heat Exchangers

The tubular types are consists of circular tubes. One fluid flows inside the tubes and the other flows on the outside of the tubes. The parameters of the heat exchanger can be changed like the tube diameter, the number of pitch, tube arrangement, number of tubes and length of the tube can be manipulate. The common type of heat exchangers lie under this categories are double-pipe type, shell-and-tube type and spiral tube type. The tubular heat exchangers can be designed for high pressure relative to the environment and high pressure difference between the fluids. These exchangers are used for liquid-to-liquid and liquid-to-vapor phase. But when the operating temperature or pressure is very high or fouling on one fluid side, it will used gas-to-liquid and gas-to-gas heat transfer applications.

2.3.1.1 Double-Pipe Heat Exchanger

According to Sadic Kakac, a double-pipe heat exchanger consists of smaller and larger diameter pipe where the smaller pipe fitted concentrically into the larger one in purpose to give direction to the flow from one section to another. One set of these tubes includes the fluid that has to be cooled or heated. The second fluid runs over the tubes being cooled or heated in order to provide heat or absorb the heat. A set of tubes is the tube bundle and it can be made up of several types of tubes such as longitudinally plain, longitudinally finned, and more. If the application requires an almost constant wall temperature, the fluids may flow in a parallel direction. It's easy to clean and convenient to disassemble and assemble. The double-pipe heat exchanger is one of the simplest. Usually, it is used for small capacity applications because it is so expensive on a cost per unit area basis. Figure 2.1 presents the model of double-pipe heat exchanger.

Figure 2.1: Double-pipe heat exchanger

Source: Ritai China

2.3.1.2 Shell-and-Tube Heat Exchanger

This exchanger is built of a bundle of round tubes mounted in a large cylindrical shell with the tube axis parallel to the shell to transfer the heat between the two fluids. The fluid flows inside the tubes and other fluid flows across and along the tubes. But for baffled shell-and-tube heat exchanger the shell side stream flows across between pairs of baffles and then flows parallel to the tubes as it flows from one baffle compartment to the next. This kind of exchanger consists of tubes, shells, front-end head, rear-end head, baffles and tubesheets. The different type of shell-and-tube heat exchangers depends on different application. Usually in chemical industry and process application, it is used as oil-coolers, power condensers, preheaters in power plants and also steam generators in nuclear power plants. The most common types of shell-and-tube heat exchanger are fixed tubesheet design, U-tube design and floating-head type. Cleaning this heat exchanger is easy. Instead of easily cleaning, it is also low in cost. But among all tube bundle types, the U-tube is the least expensive because it only needs one tube sheet. Technically, because of its construction in U shape, the cleaning is hardly done in the sharp bend. An even number of tube passes only can be achieved. The figure 2.2 shows the type of shell-and-tube heat exchanger.

Figure 2.2: U-tube shell-and-tube heat exchanger

Source: API Heat Transfer

2.3.1.3 Spiral-Tube Heat Exchanger

A spiral heat exchanger is a helical or coiled tube configuration. It consists of spirally wound coils placed in a shell or designed as co-axial condensers and co-axial evaporators that are used in refrigeration systems. The heat transfer coefficient is higher in a spiral tube than in a straight tube. Since the cleaning is impossible, the spiral tubes are suitable for thermal expansion and clean fluids. The biggest advantage of the spiral heat exchanger is its efficient use of space. A compact spiral heat exchanger can lower costs, while an oversized one can have less pressure drop, higher thermal efficiency, less pumping energy, and lower energy costs. Spiral heat exchangers are frequently used when heating fluids that have solids and therefore often foul the inside of the heat exchanger. Spiral heat exchangers have three types of flow arrangements. Firstly, the spiral flow and cross flow has one fluid in each. The spiral flow passages are welded at each side and this type of flow is good for handling low density gases which pass through the cross flow. This can be used for liquid-to-liquid applications if one fluid has a much greater flow rate than the other. A second type is the distributed vapor and spiral flow. The coolant moves in a spiral and exits through the top. The hot gases that enter will leave as condensate out of the bottom outlet. The third type is the countercurrent flow where both of the fluids will flow in opposite directions and are used for liquid-to-liquid applications. The spiral heat exchanger is good for pasteurization, heat recovery, digester heating, effluent cooling, and pre-heating. Figure 2.3 presents the spiral-tube heat exchanger.

Figure 2.3: Spiral tube heat exchanger

2.3.2 Plate Heat Exchangers

A second type of heat exchanger is a plate heat exchanger. It has many thin plates that are slightly apart and have very large surface areas and fluid flow passages that are good for heat transfer. This can be a more effective heat exchanger than the tube or shell heat exchanger due to advances in brazing and gasket technology that have made this plate exchanger more practical. Large heat exchangers are called plate and frame heat exchangers and there allow for periodic disassembly, cleaning, and inspection. There are several types of permanently bonded plate heat exchangers like dip brazed and vacuum brazed plate varieties, and they are often used in refrigeration. These heat exchangers can further be classified as gasketed plate, spiral plate and lamella.

2.3.2.1 Gasketed Plate Heat Exchangers

A gasketed plate heat exchanger consists of a series of thin plates that have wavy surface which function as separating the fluids. The plates come with corner parts arranged so that the two media between which heat is to be exchanged flow through interchange exclaim spaces. Appropriate deisgn and gasketing permit a stack of plates to be held together by compression bolts joining the end plates. Gaskets prevent leakage to the outside and direct the fluids in the plates as desired. The flow patern is generally chosen so that the media flow countercurrent to each other. Since the flow passages are quite small, strong eddying gives high heat transfer coefficients, high pressure drops, and high local shear which minimizes fouling. These exchangers provide a relatively compact and lightweight heat transfer surface. Gasketed plate are typically used for heat exchange between two liquid streams. This type can be found in food processing industries because of the compatibility to be cleaned easily and sterilized as it completely disassembled. Figure 2.4 presents the gasketed plate heat exchanger.

Figure 2.4: Gasketed plate heat exchanger

2.3.2.2 Spiral Plate Heat Exchanger

Spiral heat exchangers are formed by rolling two long, parallel plates into a spiral using a mandrel and welding the edges of adjacent plates to form channels. The distance between the metal surfaces in both channels is maintained by means of distance pins welded to the metal sheet. The two spiral paths introduce a secondary flow, increasing the heat transfer and reducing fouling deposits. These heat exchangers are quite compact but are relatively expensive due to the specialized fabrication. The spiral heat exchanger is particularly effective in handling sludges, viscous liquids, and liquids with solids in suspension including slurries.

The spiral heat exchanger is made in three main types which differ in the connections and flow arrangements. Type I has flat covers over the spiral channels. The media flow countercurrent through the channels via the connections in the center and at the periphery. This type is used to exchange heat between media without phase changes such as liquid-liquid, gas-liquid, or gas-gas. One stream enters at the center of the unit and flows from inside outward. The other stream enters at the periphery and flows towards the center. Thus the counterflow is achieved.

Type II is designed for crossflow operation. One channel is completely seal-welded, while the other is open along both sheet metal edges. The passage with the medium in spiral flow is welded shut on each side, and the medium in crossflow passes through the open spiral annulus. This type is mainly used as a surface condenser in evaporating plants. It is also highly effective as a vaporizer. Two spiral bodies are often built into the same jacket and are mounted below each other.

Type III, the third standard type is in principle similar to type I with alternately welded up channels, but type III is provided with a specially designed top cover. This type of heat exchanger is mainly intended for condensing vapors with sub-cooling of condensate and noncondensable gases. The top cover, therefore, has a special distribution cone where the vapor is distributed to the uncovered spiral turns in order to maintain a constant vapor velocity along the channel opening. The figure 2.5 and 2.6 presents the types of spiral plate.

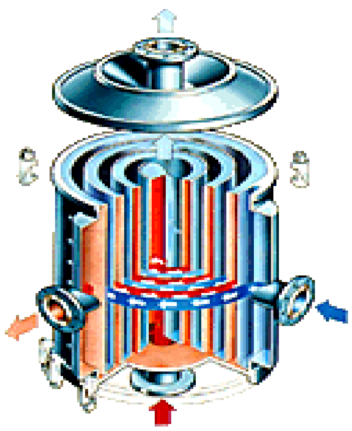


Figure 2.5: Spiral plate heat exchanger Type I

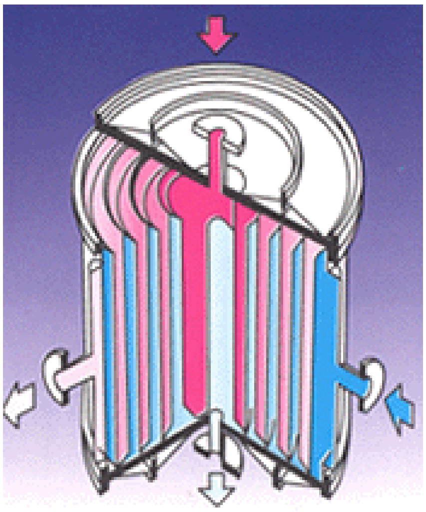


Figure 2.6: Spiral plate heat exchanger Type II

2.3.2.3 Lamella Heat Exchangers

The lamella type of heat exchanger consists of a set of parallel, welded, thin plates channels are lamellae placed longitudinally in a shell. It is a modification of the floating-type shell-and-tube heat exchanger. These flattened tubes, called lamellae are made up of two strips of plates, profiled and spot- or seam-welded together in a continuous operation. The forming of the strips creates space inside the lamellae and bosses acting as spacers for the flow sections outside the lamellae on the shell side. The lamellae are welded together at both ends by joining the ends with steel bars in between, depending on the space required between lamellae. Both ends of the lamella bundle are joined by peripheral welds to the channel cover which at the outer ends is welded to the inlet and outlet nozzle. The lamella side thus completely sealed in by welds. At the fixed end, the channel cover is equipped with an outside flange ring which is bolted to the shell flange. Figure 2.7 presents the lamella heat exchanger.

Figure 2.7: Lamella heat exchanger

2.3.3 Extended Surface Heat Exchanger

Extended surface heat exchangers are devices with fins or attachments on the primary heat transfer surface with the object of increasing heat transfer area. As it well known that the heat transfer coefficient on the gas side is much lower than those on the liquid side, finned heat transfer surfaces are used on the gas side to increase the heat transfer area. Fins are widely used in gas-to-gas and gas-liquid heat exchangers whenever the heat transfer coefficient on one or both sides is low and there is a need for a compact heat exchanger. The two most common types of extended surface heat exchangers are plate-fin heat exchangers and tube-fin heat exchangers.

2.3.3.1 Plate-Fin Heat Exchanger

The plate-fin heat exchangers are primarily used for gas-to-gas applications and tube-fin exchangers for liquid-air heat exchangers. In most of the applications, mass and volume reductions are particularly important. Because of this gain in volume and mass, compact heat exchangers are also widely used in cryogenic, energy recovery, process industry and refrigeration and air-conditioning systems. The fluid streams are separated by flat plates, between which are sandwiched corrugated fins. The plates can be arranged into a variety of configurations with respect to the fluid streams.

The corrugated sheets that are sandwiched between the plates serve both to give extra heat transfer area and to give structural support to the flat plates. There are many different forms of corrugated sheets used in these exchangers but the most common types are plain fin, plain-perforated fin, serrated fin and herringbone fin.

The flow channels in plate-fin exchangers are small which means that the mass velocity also has to be small to avoid excessive pressured drops. This may make the channel prone to fouling which, when combined with the fact that they cannot be mechanically cleaned, means that the plate-fin exchangers are restricted to clean fluids. Plate-fin heat exchangers have been established for use in gas turbines, conventional and nuclear power plants, propulsion engineering, refrigeration, heating ventilating, and air-conditioning, waste heat recovery systems, in chemical industry, and for the cooling of electronic devices. Figure presents the plate-fin heat exchanger.

Figure 2.8: Plate-fin heat exchanger

2.3.3.2 Tubular-fin Heat Exchangers

These types are used in gas-to-liquid exchanges. The heat transfer coefficients on the gas side are generally much lower than those on the liquid side and fins are required on the gas side. A tubular-fin heat exchanger consists of an array of tubes with fins fixed on the outside. The fins on the outside of the tubes mat be normal on individual tubes and may also be transverse, helical or longitudinal. Longitudinally fins are commonly used in double-pipe or shell-and-tube heat exchangers with no baffles. The fluids may be gases or viscous liquids. Alternately, continuous plate-fin sheets may be fixed on the array of tubes. Fins are attached to the tubes. This type of exchangers are used in ventilating, heating, refrigeration and air conditioning system. Figure 2.9 presents the tubular-fin heat exchanger.

Figure 2.9: Tubular-fin heat exchanger

2.4 SHELL AND TUBE HEAT EXCHANGER

As stated earlier, the shell and tube heat exchanger is the most reliable and versatile. They are commonly used in process industries, as a condenser in conventional and nuclear power stations, steam generators in pressurized water reactor power plants and feedwater heaters, and also proposed for many alternative energy applications like ocean, thermal and geothermal instead of refrigeration and air conditioning. Shell-and-tube heat exchangers provide relatively large ratios of heat transfer area to volume and weight and they can be cleaned easily. They offer flexibility to meet almost any service requirements. It can be designed for high pressure relative to the environment and high-pressure differences between the fluid streams. The major components of this exchanger are shell, tubes, front-end head, rear-end head, baffles and also tube sheets.

2.4.1 Shell Types

The TEMA (Tubular Exchanger Manufacturers Association) has identified the various types of front head, rear head, and shell that have been standardized. The types are classified into alphabetic character. The most common shell type is E-shell because it is simple and cheap. The fluid enters at one end of the shell and leaves at other end. It has one pass on the shell side. Tubes may have single and multiple passes and supported by transverse baffles. (Kakac, S. 2002)

F-shell is come with longitudinal baffle and two shell passes. It is used when units in series are required, with each shell representing one unit. The pressure drop in F-shell is higher than E-shell. Other types are J-shell and X-shell. In the J-shell, the flow is divided where the single nozzle is at the middle of the tubes and two nozzles located at near both ends. This shell is used for low pressure drop design because it has only 1/8 pressure drop of E-shell. When it is function as a condenser, it has two inlets for vapor phase and one central outlet for the condensate. The X-shell's pressure drop is extremely low. It has no baffles at all. The two fluids are over the entire length of the tubes and flowing crossed. It usually used for vacuum condensers and low-pressure gases. (Kakac, S. 2002)

The G-shell's split flow has horizontal baffles with the ends are removed and the shell nozzles are 180˚ in angle apart at the middle point of tubes. Compare to E-shell, both have same pressure drop. The G-shell can be used for single-phase also but it always used as horizontal thermosiphon reboiler. The longitudinal baffle serves to prevent flashing out of the lighter components of the shell fluids. The H-shell is a double split flow similar to the G-shell but with two horizontal baffles and two outlet baffles. The K-shell is a kettle reboiler with tube bundle located in the bottom of the shell covering 60% of the shell diameter itself. (Kakac, S. 2002) Figure 2.10 presents the standard shell types and front and rear-end head types according to TEMA (Tubular Exchanger Manufacturers Association).

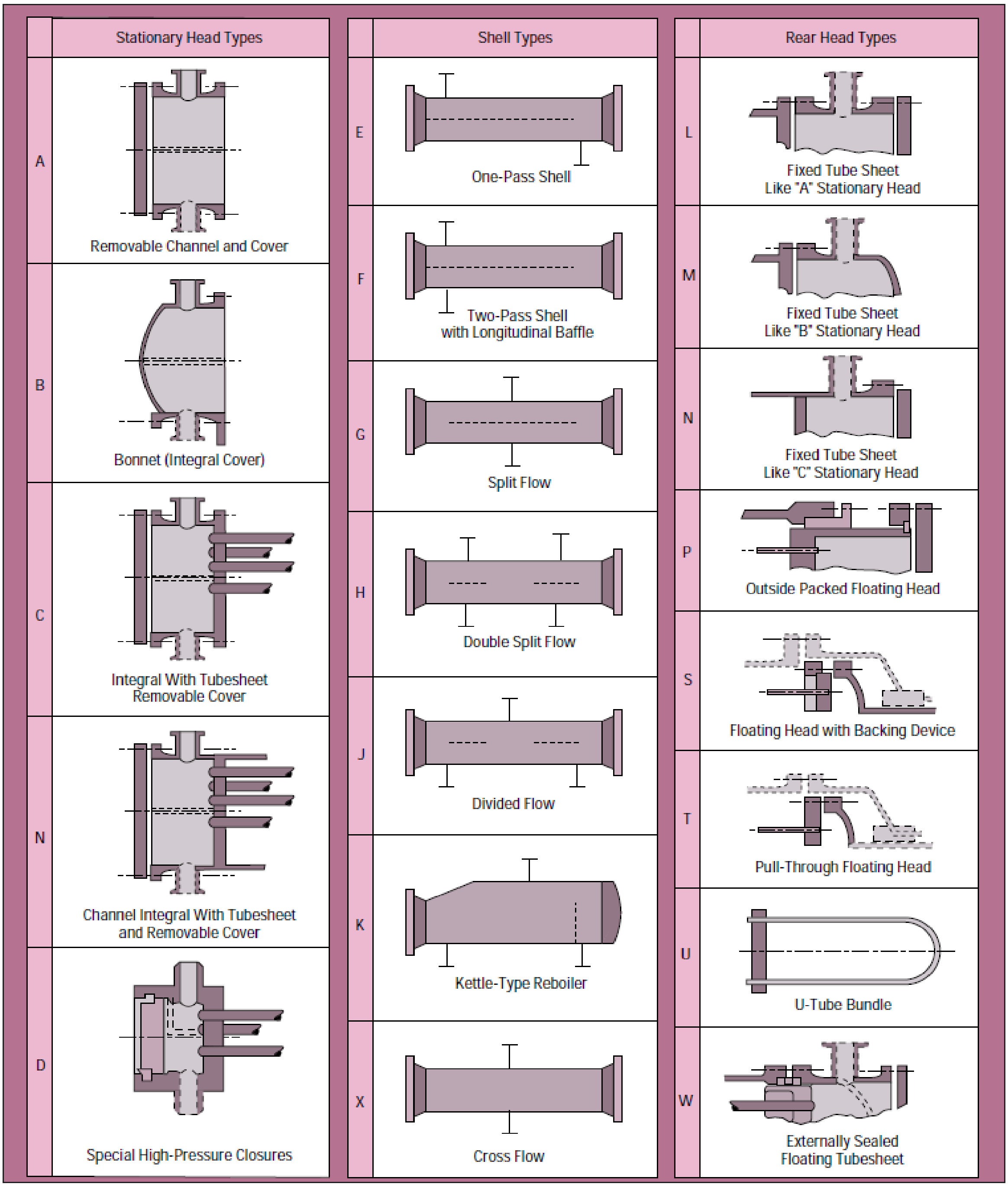


Figure 2.10: TEMA Standard Shell types and front end and rear end head types.

Source: Mukkherjee, R. (1998)

2.4.2 Tubes

Only an E-shell and F-shell are resulting in nominal counterflow. The other types which is consists multiple tube passes needs a temperature profile correction or simply characterized by F. It cannot deliver desired temperature because of temperature cross.

A multiple tube passes are to perform an increment of tube-side fluid velocity and heat transfer coefficient and also minimizing the fouling. Material used for tubes are usually of low carbon steel, low alloy steel, stainless steel, copper, aluminium or titanium. Sizes of tubes diameter depends on purposes. Greater area per volume density is using a small tube diameters but it tend to be limited since its purpose of in-tube cleaning. For larger tube diameters are used in condenser and boiler.

The cost and operation is considerable to determine the tube length. The longer the tubes, the fewer tubes are needed. Besides, it is also have fewer holes to be drilled and shell diameter decreases. Thus, it will result in lower cost.

2.4.3 Tube Layout

Tube layout consists of four patterns which is triangular (30˚), rotated triangular (60˚), square (90˚) and rotated square (45˚). Of all patterns, the most used one is 30˚ where it will result in greatest tube density. The 30˚ and 60˚ layout is consists more tubes than 90˚ and 45˚ layout. In terms of cleaning, the squares are more easier than triangular. The squares required mechanical cleaning for the shellside but for triangular, the chemical cleaning is the solution. So, the squares layouts are the most required. A rotated triangular pattern seldom offers any advantages over a triangular pattern, and its use is consequently not very popular. (Sadik Kakac, 2002). Figure 2.11 presents the patterns of tube layout.

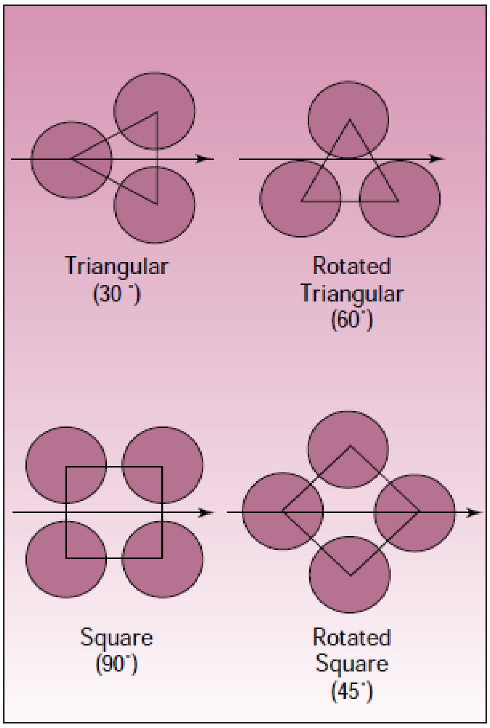


Figure 2.11: Tube layout pattern

Source: Mukherjee, R. (1998)

2.4.4 Baffle Type and Geometry

The functions of baffles are to support the tubes for structural rigidity, to prevent tube vibration and sagging, and also to divert the flow across the bundle to obtain a higher heat transfer coefficient. Baffles represent types as transverse and longitudinal. For transverse baffles, it may classified as plate baffles and rod baffles. The plate baffles are single segmental, double segmental, triple segmental, no-tubes-in-windows segmental, disk and doughnut, and orifice baffles. (Kakac, S. 2002)

The most frequently used baffles are single and double segmental baffles. The most important thing is the baffle spacing has to choose properly. The most recommended baffles spacing is 0.4 and 0.6 of the shell diameter and for the baffle cut is 25% and 35%. Another types of baffles are triple and no-tubes-in-window segmental baffles. They are usually used for low pressure drop applications which are approximately 0.5 and 0.3 of the segmental value. The no-tubes-in-window types have no tubes that supported only by every second baffle and minimizing the tube vibration. Other types, disc and ring or doughnut baffles are composed of alternating rings and inner discs which effects the direction of flow radially across the tube field. While the orifice baffles are the shell-side fluid flows through the clearance between tube outside diameter and baffle-hole diameter. (Kakac, S. 2002)

The rod baffles are constructed by a rod or strip supports. The flow is longitudinal and will result in low pressure drops. This baffle usually for used of vertical condensers and reboilers. The baffle spacing is closed so that no dangerous tube vibration. (Sadik Kakac, 2002) Figure 2.12 presents the three common segmental baffle; single, double and triple segmental. Figure 2.13 presents the no-tubes-in-window baffle and figure 2.14 presents rod baffle.

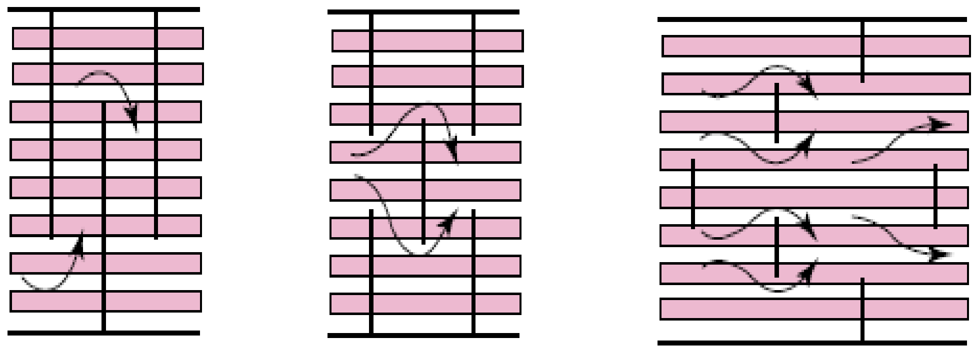


Figure 2.12: Single, double and triple segmental baffle

Source: Mukherjee, R. (1998)

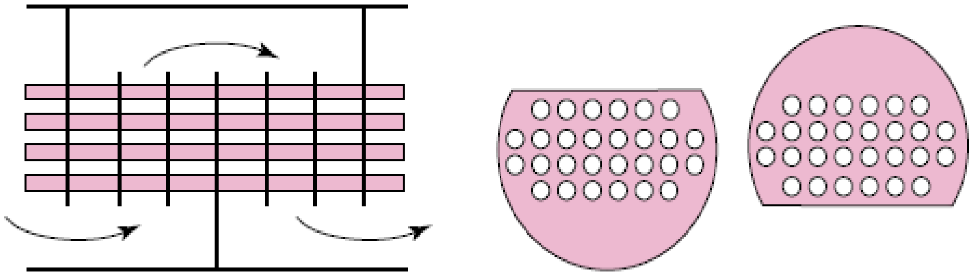


Figure 2.13: No-tubes-in-window segmental baffle

Source: Mukherjee, R. (1998)

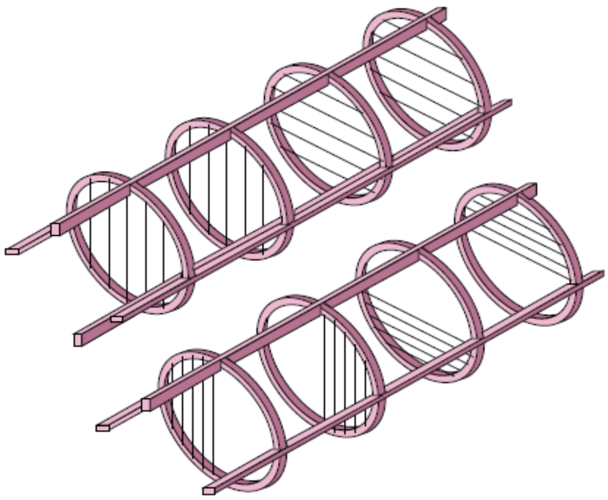


Figure 2.14: Rod baffle

Source: Mukerjee, R. (1998)

CHAPTER 3

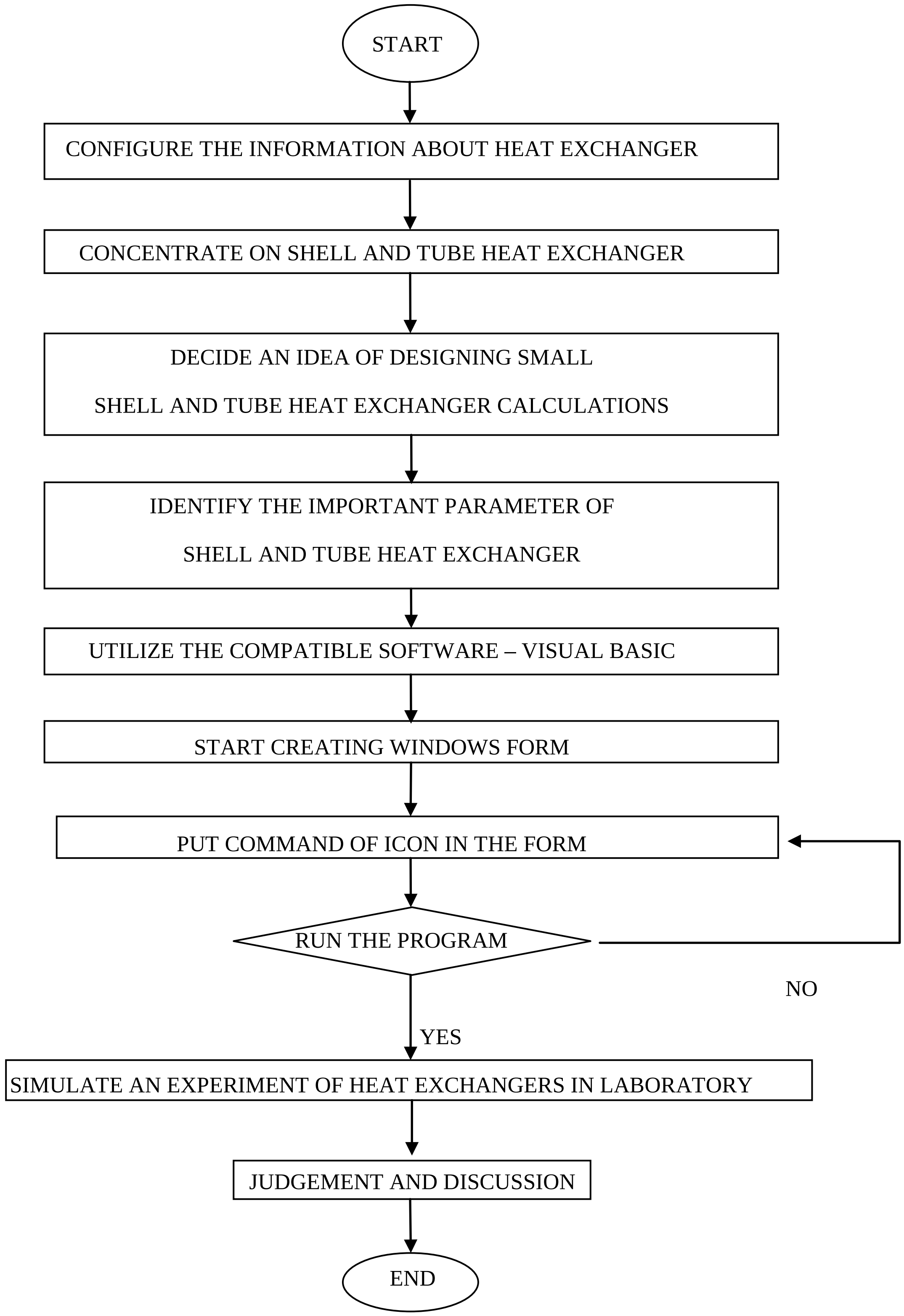
SHELL-AND-TUBE HEAT EXCHANGER PERFORMANCE SIMULATION

3.1 INTRODUCTION

In this chapter, the specific methodology will be discussed. From the literature review part, it already stated the characteristics of many types of heat exchanger. The scope now is to identify the design of shell and tube heat exchanger. From the basic components distinguished before, we can see that the problem that we want solve is choose the best design of small shell and tube heat exchanger. Specifically, it purpose is to know the heat transfer rate by using simplest heat exchanger calculator. In addition, it also gives knowledge of the most basic construction that needed to design shell and tube heat exchanger. After all is done, the next step is to do an experiment of heat transfer rate in laboratory. The purpose is to compare the heat transfer rate by experimental and also theoretical.

In a nut shell, this chapter focusing on the performance simulation of the project inclusive of program flow chart and method of using visual basic step by step.

3.2 PROJECT FLOW



3.3 VISUAL BASIC STEP-BY-STEP

First thing first, a command that will be put in the form must equip with equations. In this project, the ε-NTU method is used. Firstly, the heat transfer surface area is calculated and the equation expressed as:

$$A_s = \pi DLn$$

where A_s= heat transfer surface area (m²)

D = diameter of heat exchanger (m)

L = length of heat exchanger (m)

n = number of tube passes

Equations of the heat capacity rates of cold fluid and hot fluid are:

$$C_h = \dot{m}_h C_{p_h}$$

where C_h= heat capacity rate of hot fluid (kW/˚C)

$\dot{m}_h$ = mass flow rate of hot fluid (kg/s)

C_{p_h} = specific heat of hot fluid (kJ/kg.˚C)

$$C_c = \dot{m}_c C_{p_c}$$

where C_c= heat capacity rate of cold fluid (kW/˚C)

$\dot{m}_c$ = mass flow rate of cold fluid (kg/s)

C_{p_c} = specific heat of cold fluid (kJ/kg.˚C)

From the heat capacity rates, the minimum heat capacity C_{min} is determined by the smallest capacity rate either cold fluid or hot fluid. Thus, the dimensionless capacity ratio, c expressed as:

$$c = \frac{C_{min}}{C_{max}}$$

where c = capacity ratio

C_{min}= minimum heat capacity rate (kW/˚C)

C_{max}= maximum heat capacity rate (kW/˚C)

The effectiveness relations for heat exchanger typically involve the dimensionless group called Number of Transfer Units (NTU).

$$NTU = \frac{UA_s}{C_{min}}$$

where NTU = Number of Transfer Units

U = overall heat transfer coefficient (W/m^2.˚C)

A_s = heat transfer surface area (m^2)

Therefore, the maximum possible heat transfer rate is:

$$\dot{Q}_{max} = C_{min}(T_{h,in} - T_{c,in})$$

where $\dot{Q}_{max}$= maximum possible heat transfer rate (kW)

$T_{h,in}$ = temperature at the inlet of hot fluid (˚C)

$T_{c,in}$ = temperature at the inlet of cold fluid (˚C)

Thus, to find an effectiveness relation of heat exchanger is:

$$\varepsilon = 2\left\{1 + c + \sqrt{1 + c^2}\,\frac{1 + \exp[-NTU\sqrt{1 + c^2}]}{1 - \exp[-NTU\sqrt{1 + c^2}]}\right\}$$

where ε = effectiveness

c = capacity ratio

NTU = Number of Transfer Units

And finally, the actual heat transfer rate is found by equation:

$$\dot{Q} = \varepsilon \dot{Q}_{max}$$

where $\dot{Q}$= actual heat transfer rate (kW)

ε = effectiveness

$\dot{Q}_{max}$= maximum possible heat transfer rate (kW)

After all the equations taking on considerations, the Visual Basic 2005 Express Edition is explore and begin to create an interface. First of all, the Visual Basic is open and choose to create a new project. The form 1 appears in the windows application.

The following figure 3.1 is present a start page of window program.

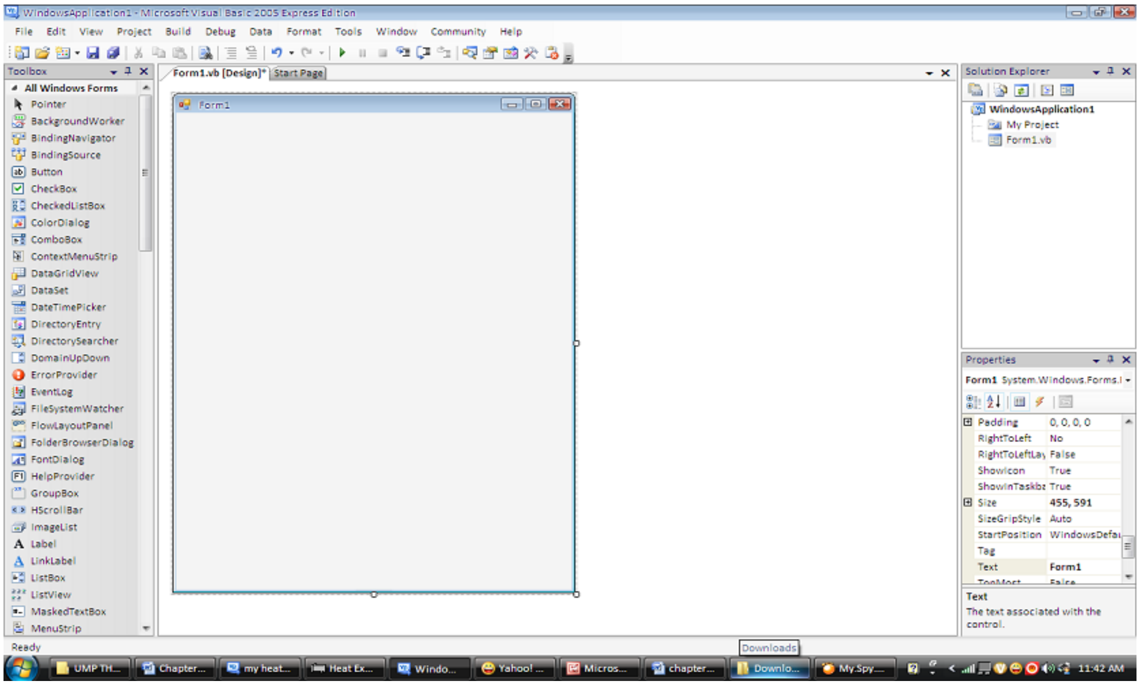


Figure 3.1: A start page

1) Click on tab control in the toolbox and apply to the form as in the figure 3.2.

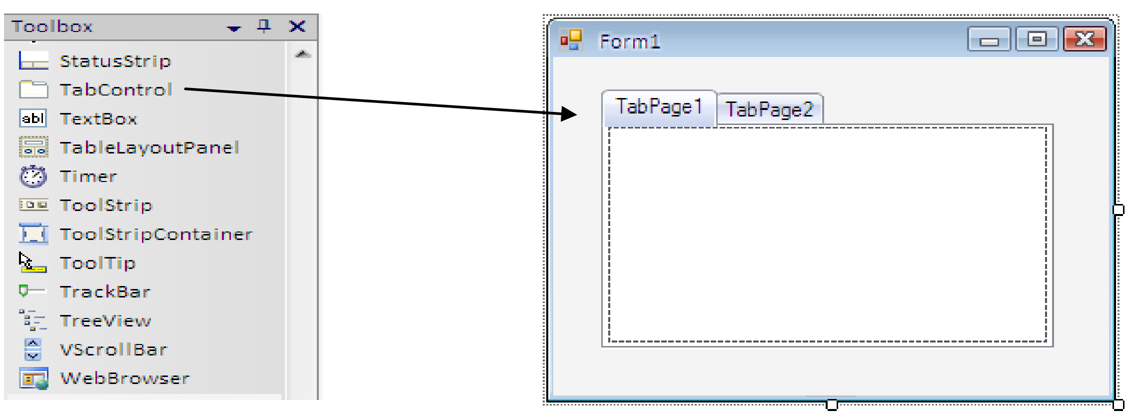


Figure 3.2: Inserting tab control

2) Insert the basic variables of shell and tube heat exchanger by 'labels' and 'textbox'. Figure 3.3 presents the five labels and textboxes.

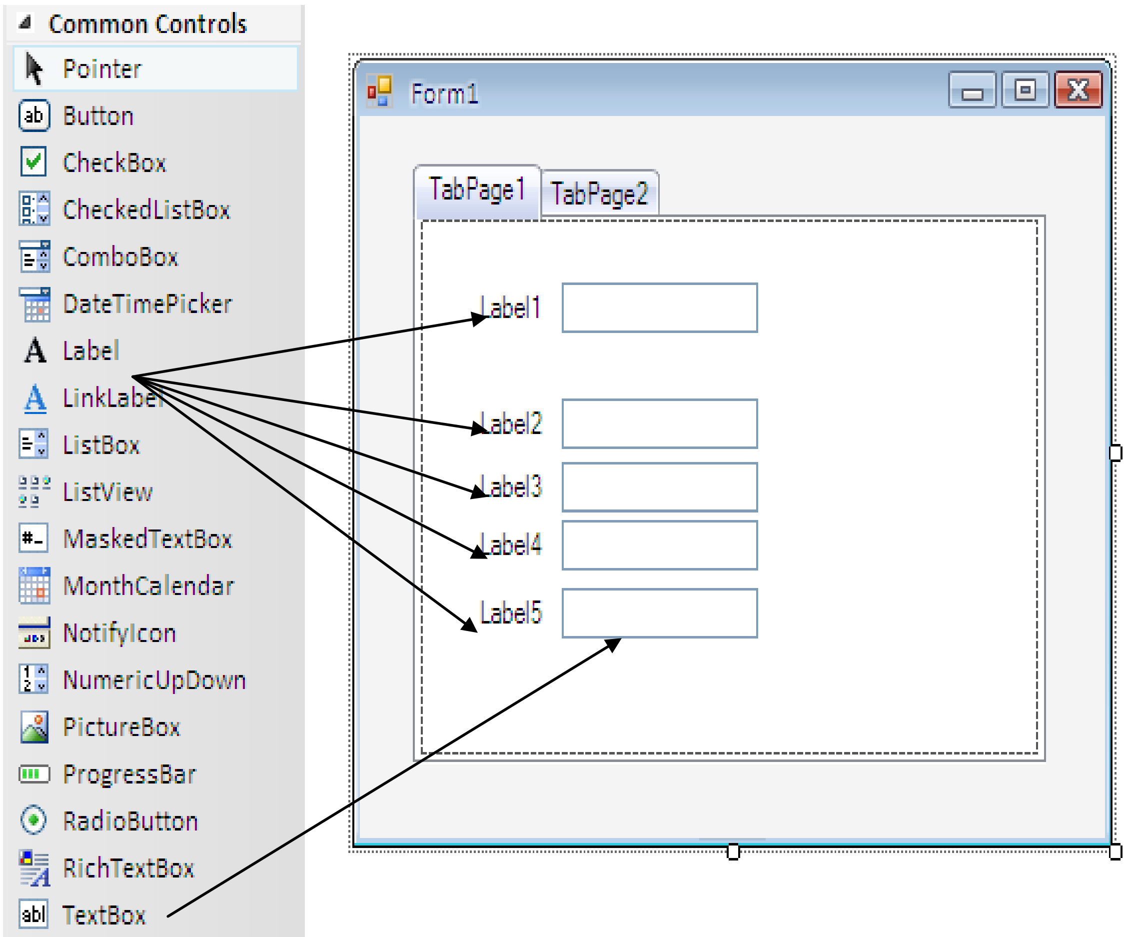


Figure 3.3: Labelling and put textboxes

3) Insert other partition for hot fluid and cold fluid. Figure 3.4 presents the two group box added.

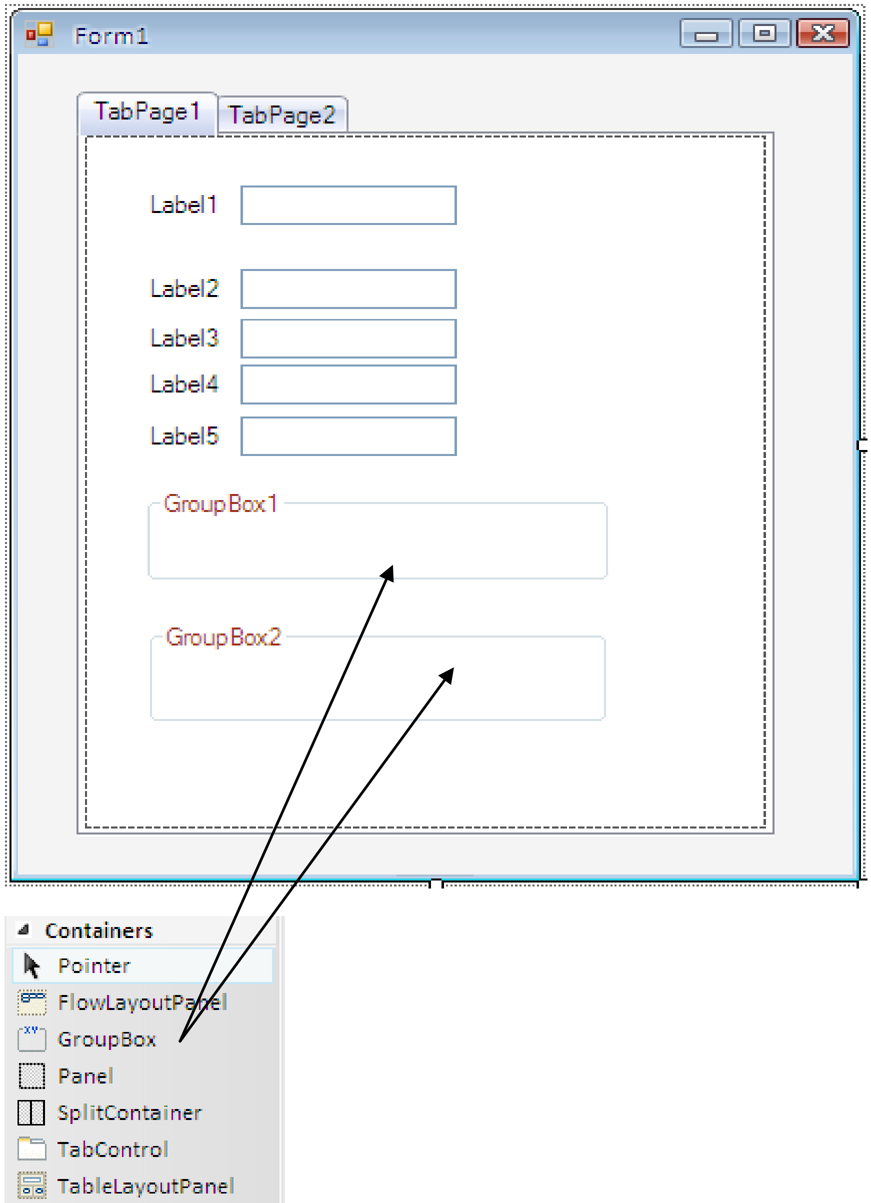


Figure 3.4: Insert group box

4) Insert the other parameters in the partition. Figure 3.5 presents the labels and textboxes added into each groupbox.

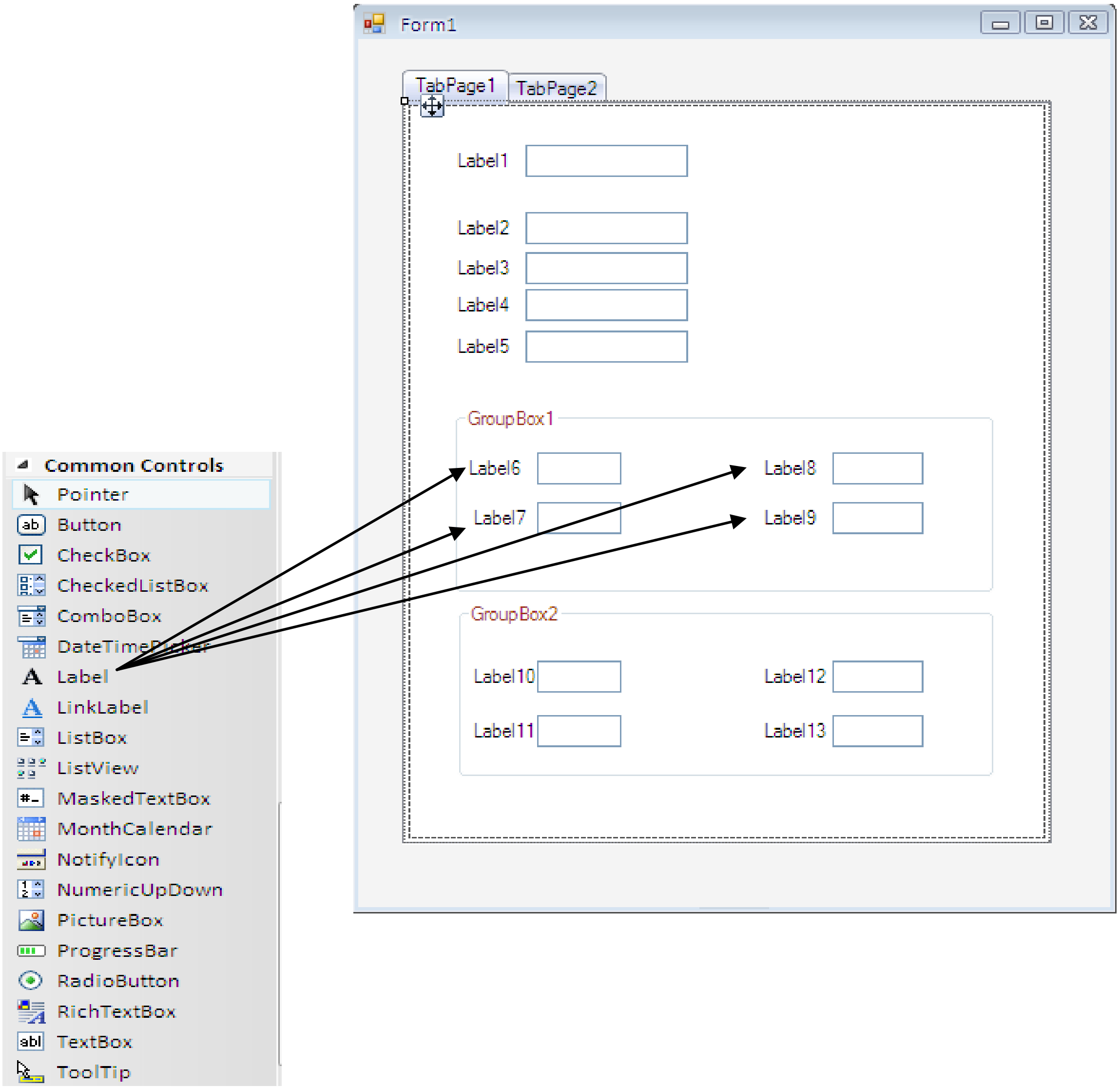


Figure 3.5: Insert labels and textboxes in groupbox

5) The units added to each textboxes as labels. Figure 3.6 presents the labels added as an units.

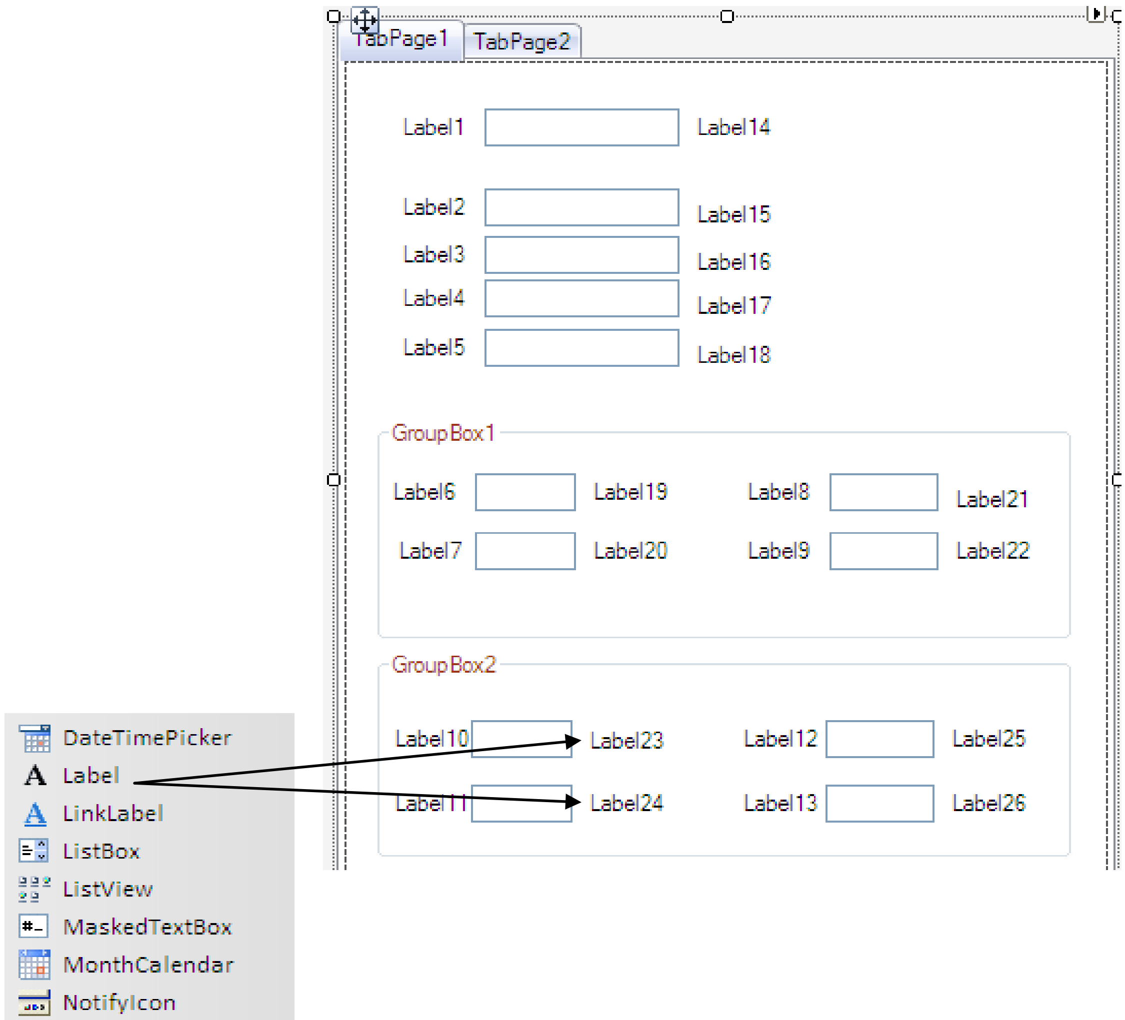


Figure 3.6: Insert units label

6) Done for Tab Page 1 then each parameters are rename. Next, add the 'OK' button. Figure 3.7 presents the OK button added.

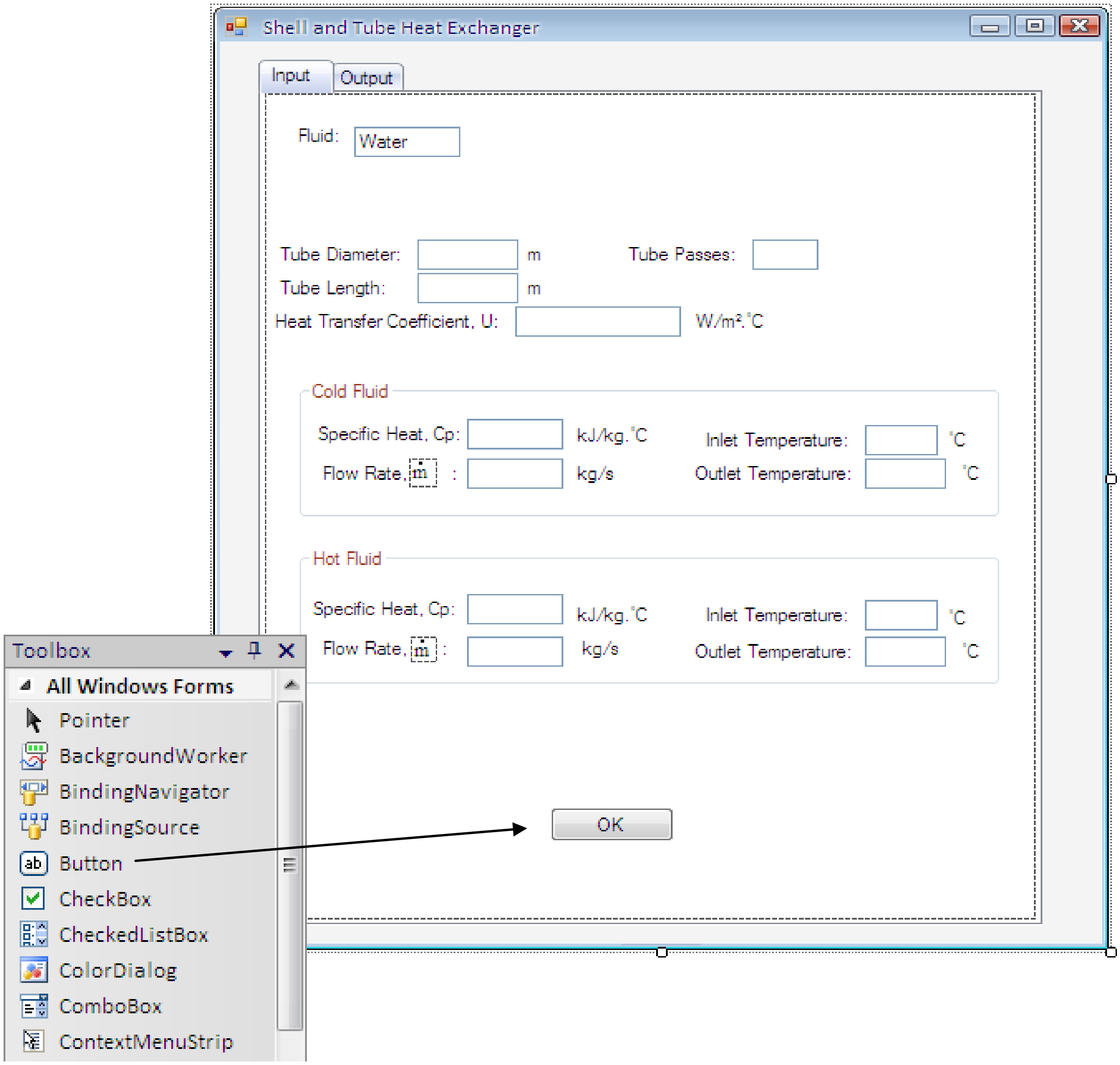


Figure 3.7: Use a button

7) Next step is inserting the coding by clicking ‘OK’ button twice.

```
'Declare x and y variables
  Dim Dia, Lg, n, p As String

  'Define Area'
  Dia = TextBox32.Text
  Lg = TextBox31.Text
  n = TextBox21.Text
  p = "3.142"
  TextBox38.Text = Dia * Lg * p * n

  'Define Cc'
  Dim mc, Cpc As Double
  mc = TextBox25.Text
  Cpc = TextBox23.Text
  TextBox40.Text = mc * Cpc

  'Define Ch'
  Dim mh, Cph As Double
  mh = TextBox28.Text
  Cph = TextBox29.Text
  TextBox39.Text = mh * Cph

  'Define c'
  TextBox35.Text = (mh * Cph) / (mc * Cpc)



  'Define NTU'
  Dim u, Ar, c As Double
  Ar = TextBox38.Text
  c = TextBox35.Text
  u = TextBox30.Text
  TextBox37.Text = (u * Ar) / c

  'Define Q*max'
  Dim Thin, Tcin, Tin As Double
  Thin = TextBox27.Text
  Tcin = TextBox24.Text
  Tin = Thin - Tcin
  TextBox34.Text = mh * Cph * Tin

  'Define efficiency e'
  Dim a, b, d, f, g, h, i, j, k, l, Nt As Double
  Nt = TextBox37.Text
  a = c ^ 2
  b = 1 + a
  d = b ^ (1 / 2)
  f = -Nt * d
  g = 10 ^ f
  h = 1 + g
  i = 1 - g
```

```
        j = h / i
        k = d * j
        l = 1 + c + k
        TextBox36.Text = 2 * l

        'Define Q*'
        Dim ef, Qm As Double
        ef = TextBox36.Text
        Qm = TextBox34.Text
        TextBox33.Text = ef * Qm

    End Sub
```

8) Then, the Tab Page 2 is created by inserting the same previous procedure. Figure 3.8 presents the labels and textboxes added for tab page 2.

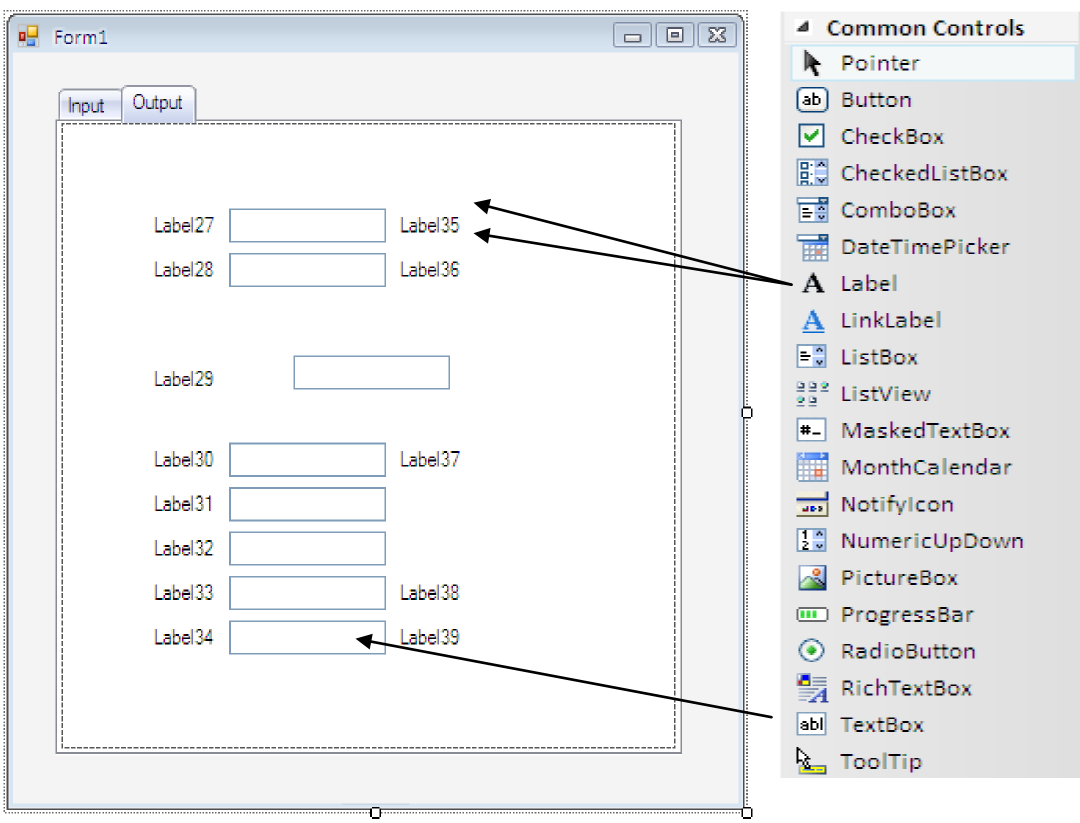


Figure 3.8: Repeating of the previous steps for tab page 2

9) At Tab Page 2, all the parameters are rename. Figure 3.9 shows all the labels and textboxes rename.

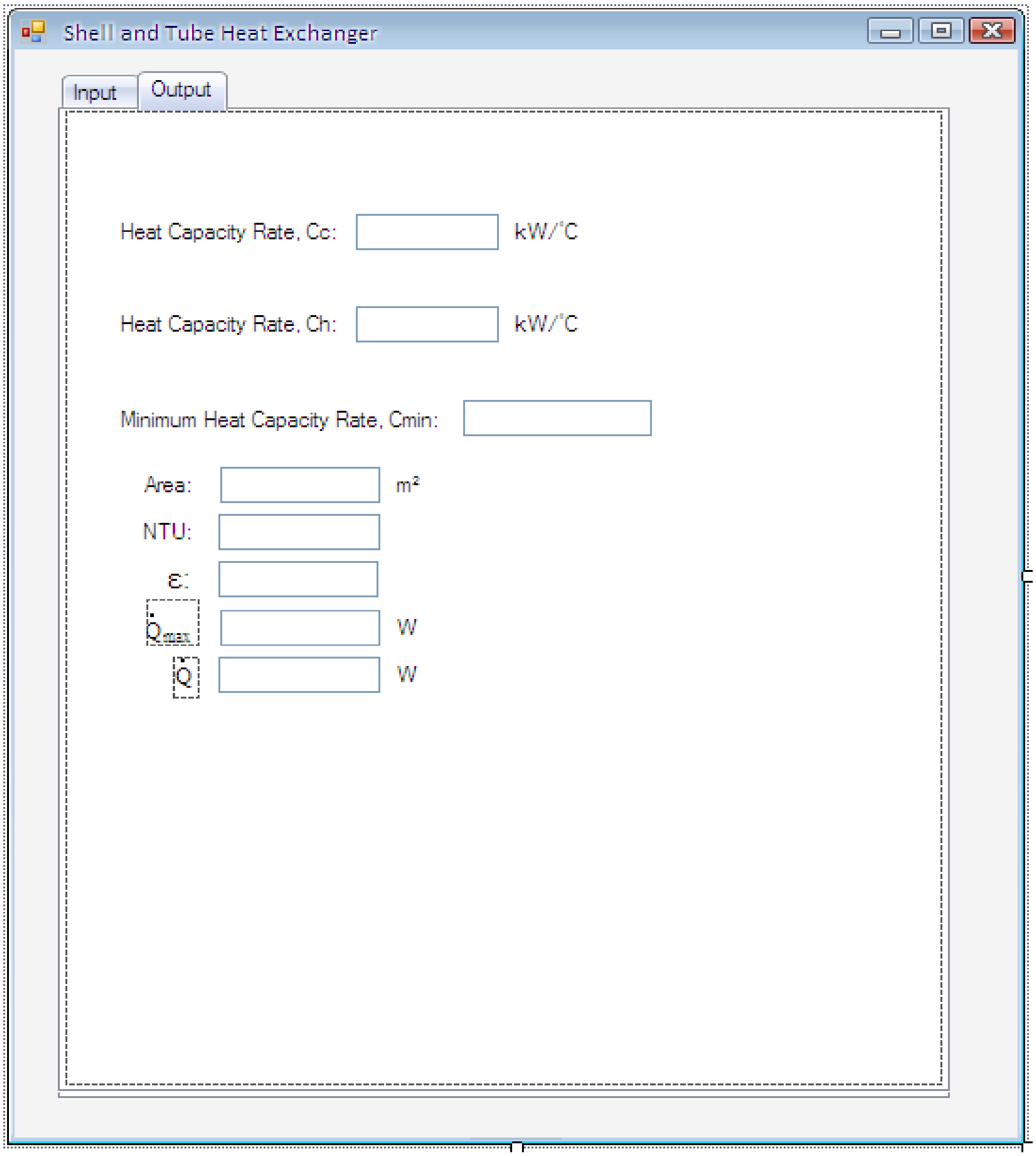


Figure 3.9: Renaming the parameters

10) The program now can be safely run without errors. To look for the output, just click 'OK' button and click output tab. Figure 3.10 presents the example of outputs at tab page 1.

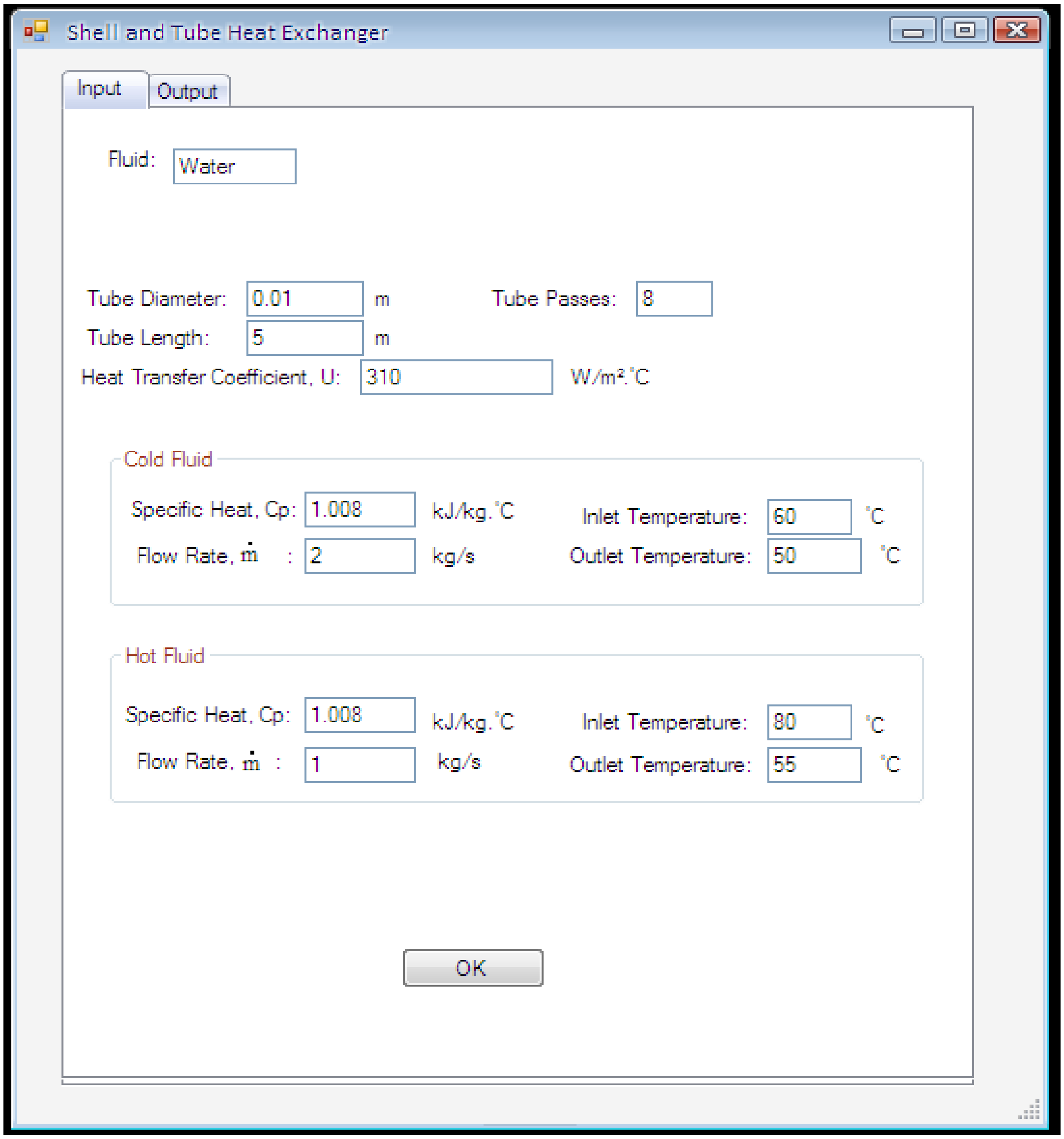


Figure 3.10: Tab page 1

11) For the desired outputs, just click the output button and it appears as in figure 3.11.

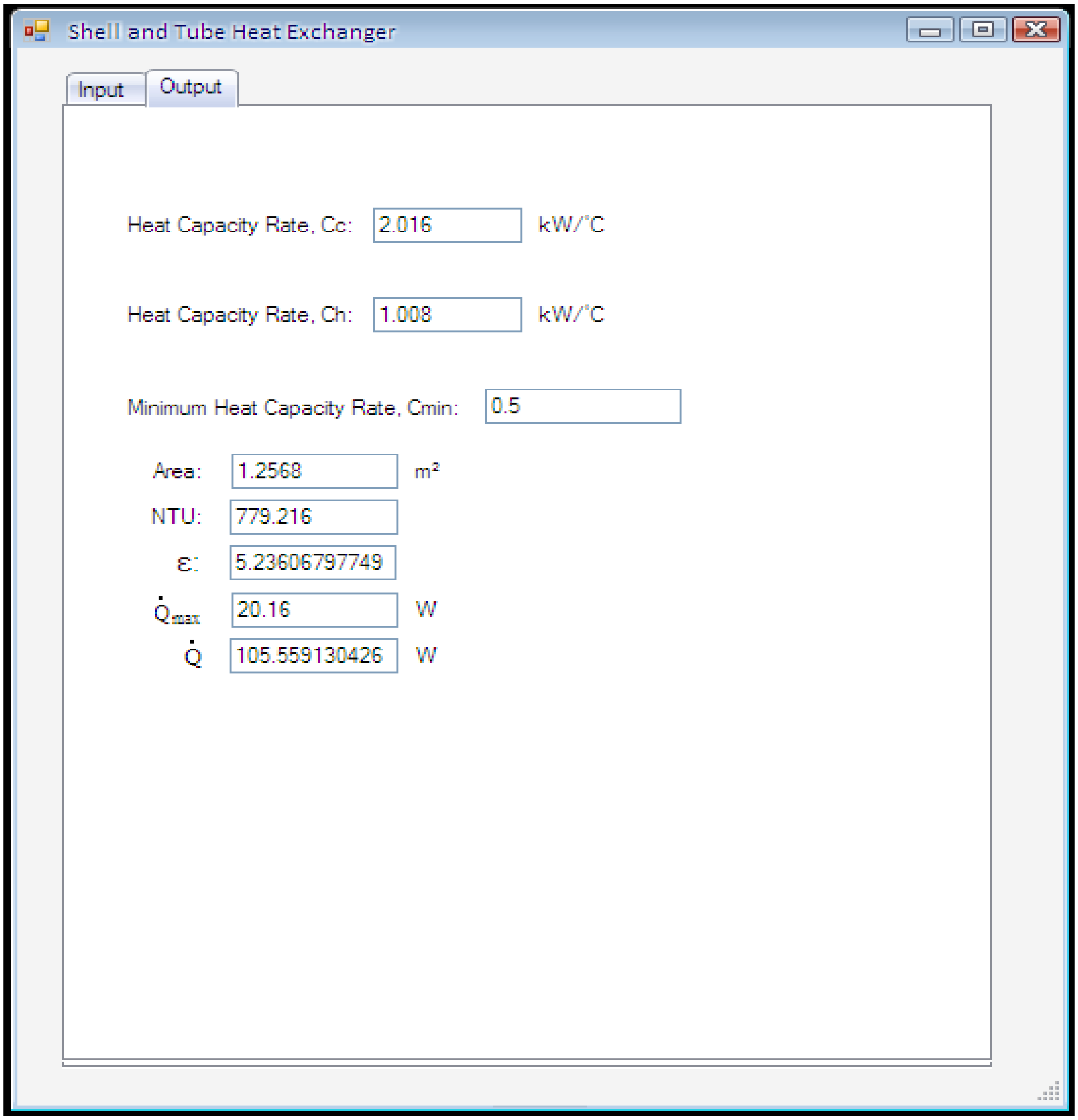


Figure 3.11: Tab page 2

CHAPTER 4

DESIGN AND MANUFACTURING A SMALL SHELL-AND-TUBE HEAT EXCHANGER

4.1 INTRODUCTION

This chapter will discuss about the fabrication process in making the shell-and-tube heat exchanger. Based to the scopes discussed earlier, the experimental strategy is carried out. The fabrication will focused on the data parameter, basic concept of designing, list of material and lastly the process of fabrication.

4.2 DATA PARAMETER

The data that is going to be collected are as followed:

- water flow
- water inlet temperature
- water outlet temperature

4.3 BASIC CONCEPT

The basic concept is which in designing the heat exchanger by roughly on sketching and also using certain software to create a 3-dimension drawing. The software used in this project is Solidworks.

4.3.1 Rough Sketching

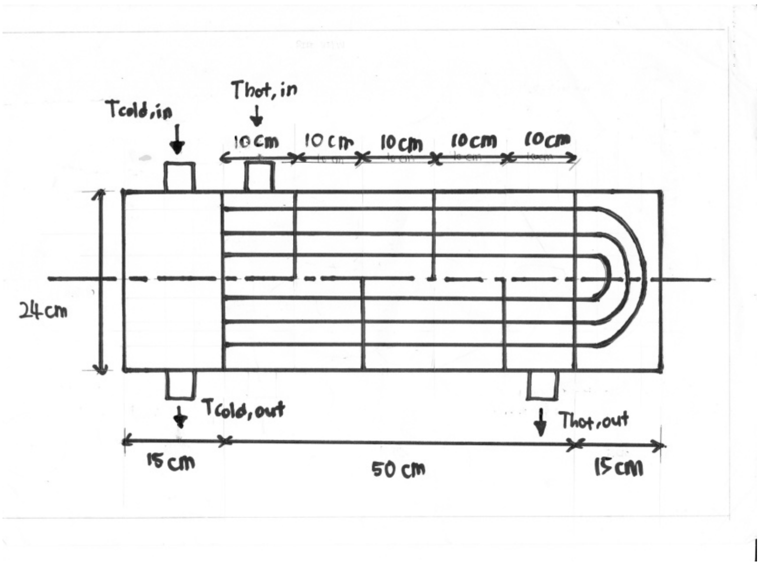


Figure 4.1: Rough drawing

4.3.2 Solidworks Drawing

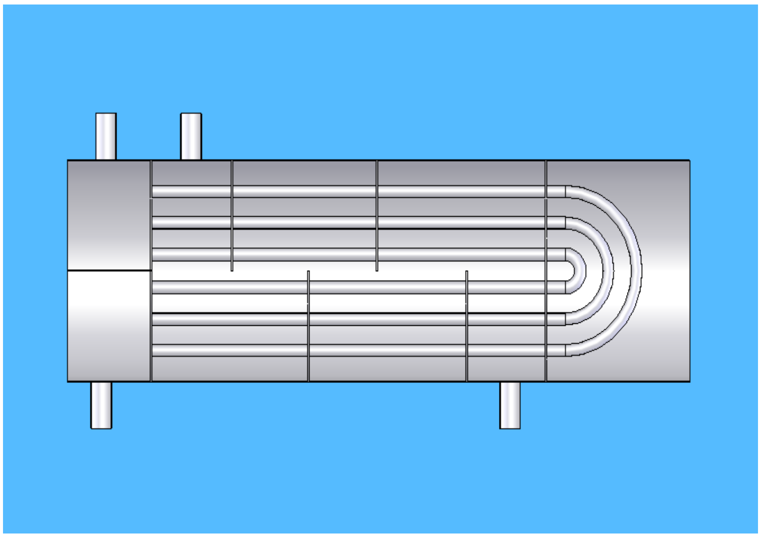


Figure 4.2: Design of shell-and-tube heat exchanger in Solidworks

4.4 LIST OF MATERIAL

4.4.1 Raw Material

In order to make shell-and-tube heat exchanger, material that can be used to make a shell such as zinc, aluminium, copper or steel. In this project, zinc is preferable because it is light in weight and cheap. For the tubes, the most suitable and proper material is copper. In fact, in most applications usually used copper instead of brass and bronze. In terms of properties, copper conduct electricity and heat better than bronze and brass. Figure 4.3 presents the zinc sheet while figure 4.4 presents the copper tube of size 1/2".

Figure 4.3: Zinc sheet

Figure 4.4: Copper tube 1/2"

4.4.2 List of Material

To make this project happen, another component has added to complete the experiment setting. Instead of using the main raw material as above to make a shell, another parts and component are put into consideration too. The parts needed are as shown in the table below.

Table 2.1: Market Price

No	Parts	Price	Quantity	Amount
1	Fittings			
	-45˚ elbow	RM1.00	5	RM5.00
	-nipple	RM0.50	4	RM2.00
	-PT elbow	RM0.60	4	RM2.40
2	Ball valve	RM4.00	2	RM8.00
3	PVC pipe	RM0.30/ft	10ft	RM3.00
4	Heater coil	RM20.00	1	RM20.00
5	Water pump	RM29.00	1	RM29.00
6	Thermometer	RM20.00	4	RM80.00
			Total amount =	RM149.40

4.5 FABRICATION PROCESS

As the first step to begin, the raw materials have to be measured precisely and divide into many pieces. For the zinc sheet, it is used for the shell, and tubesheets. For the copper, they are divided depending on how many holes at the tubesheets and the baffles.

4.5.1 Shearing process

The process of shearing is applied for zinc sheet to divide into making shell and tubesheets. In this case, the tubesheets needed is two while for the baffles it needs 4 sheets. The shell is then going through the next process. Figure 4.5 presents the hydraulic shearing machine in workshop while figure 4.6 presents the common shear.

Figure 4.5: Hydraulic shearing machine

Figure 4.6: Shear

4.5.2 Welding process

The welding used in this project is only focusing on MIG-type welding (gas metal arc welding). When compared with arc welding, the MIG welding process is faster, easier, and requires little cleanup of welds. This makes MIG welding cost effective for production welding in fabrication shops. It will joint the zinc sheet to perform it into cylinder shape. Figure 4.7 presents the welded zinc sheet.

Figure 4.7: Welded zinc

4.5.3 Drilling process

Next step is drilling process. The drill will make a hole needed for the tubesheets and baffles. In this case, the hand drill with hole saw cutting tool is the most suitable and easy to handle. Figure 4.8 presents the hand drill while figure 4.9 presents the drilling process.

Figure 4.8: Hand drill

Figure 4.9: Drilling process

4.5.4 Cutting process

The cutting process is referred to the copper tube. This material is cut by its cutter. It is way more easier than using others like handsaw. Figure 4.10 shows the cutter tool.

Figure 4.10: Cutter

4.5.5 Assembly

After all the process stated done, the main part of the heat exchanger is assembled. They must be assemble in their position to make sure the copper tube fit into the hole. Figure 4.11 presents the fitted copper rod into baffles.

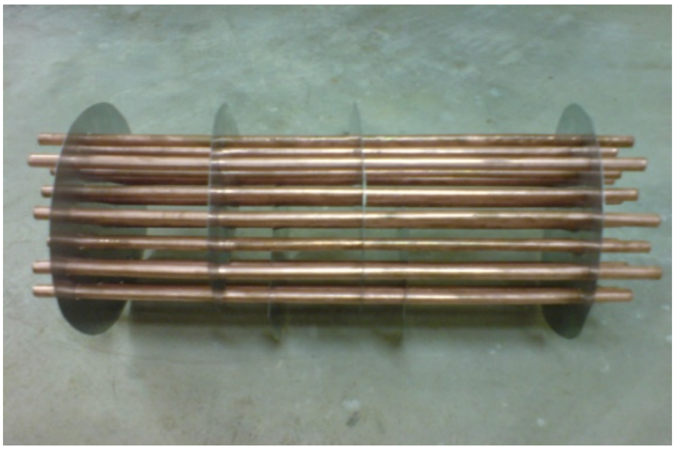


Figure 4.11: Fitting copper rod into baffles

4.6 ASSEMBLY OF FABRICATION

According to the previous processes, the last process which is assembling is the most important process. This is because one mistake committed, it may ruin others since there are lots of copper tubes to fit in.

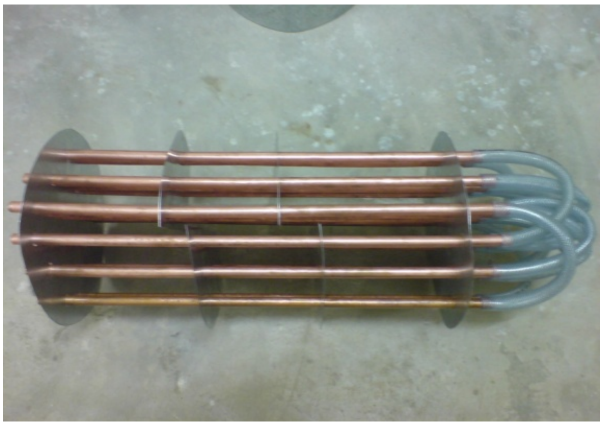


Figure 4.12: Fitted copper tubes

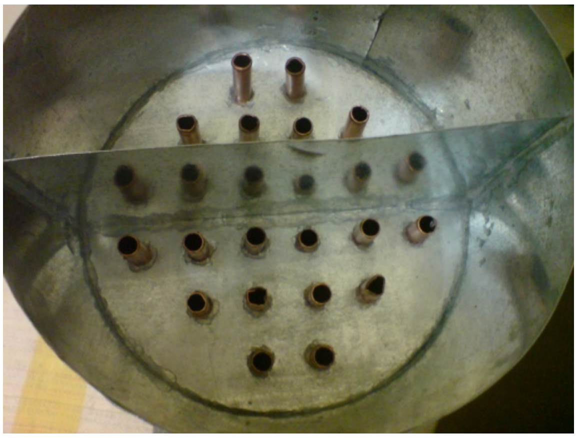


Figure 4.13: Front view of the assembly of shellside and tubeside without endcap

Figure 4.14: Digital thermometer applied to each inlet and outlet.

Figure 4.15: Complete assembly.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 INTRODUCTION

The important objective in this chapter is to discuss about the problem and consideration while handling the fabrication process and the final result of small shell-and-tube heat exchanger. To make sure the process is running smooth, the temperature must be constant so that the result will tally and reducing errors.

5.2 EXPERIMENTAL RESULTS

As stated earlier, the data that have to collect were the water flow and the temperature on both inlet and outlet at the tubeside and shellside. The calculations were put down into a table.

The temperature involved:

$T_{c,in} = 28$ ˚C

$T_{c,out} = 40$ ˚C

$T_{h,in} = 70$ ˚C

$T_{h,out} = 50$ ˚C

Table 5.1: Estimated result for five different flow rate for both cold and hot fluid.

Valve % open for hot fluid	**Valve % open for cold fluid**	**Maximum Possible Heat Transfer Rate $\dot{Q}_{max}$(kW)**	**Heat Transfer Rate, $\dot{Q}$ (kW)**	**Effectiveness, ε**
50	50	35.87	28.80	0.803
60	60	45.63	39.33	0.862
65	65	59.89	53.74	0.897
75	75	79.66	73.53	0.923
100	100	85.21	81.03	0.951

Table 5.2: Estimated result for five different flow rate of cold fluid.

Valve % open for hot fluid	**Valve % open for cold fluid**	**Maximum Possible Heat Transfer Rate $\dot{Q}_{max}$(kW)**	**Heat Transfer Rate, $\dot{Q}$ (kW)**	**Effectiveness, ε**
100	50	46.51	40.09	0.862
100	60	59.75	52.46	0.878
100	65	67.53	63.82	0.945
100	75	73.81	70.78	0.959
100	100	88.69	87.54	0.987

Table 5.3: Estimated result for five different flow rate of hot fluid.

Valve % open for hot fluid	**Valve % open for cold fluid**	**Maximum Possible Heat Transfer Rate $\dot{Q}_{max}$(kW)**	**Heat Transfer Rate, $\dot{Q}$ (kW)**	**Effectiveness, ε**
50	100	49.27	40.01	0.812
60	100	62.11	53.54	0.862
65	100	67.50	60.01	0.889
75	100	75.50	70.14	0.929
100	100	86.59	82.43	0.952

The opening valve is representing the mass flow rate. The mass flow rate are obtained by an equation

$$\dot{Q} = \dot{m} C_p \Delta T$$

where $\dot{Q}$ = Heat transfer rate (kW)

m = Mass flow rate (kg/s)

C_p= Specific heat (kJ/kg.˚C)

ΔT= Temperature difference (˚C)

$$81.03 = \dot{m} \times 4.18 \times 15$$

$$\dot{m} = 1.2\ kg/s$$

Figure 5.1: Graph of Heat Transfer Rate, $\dot{Q}$ (kW) versus Valve Open For Hot and Cold Fluid (%).

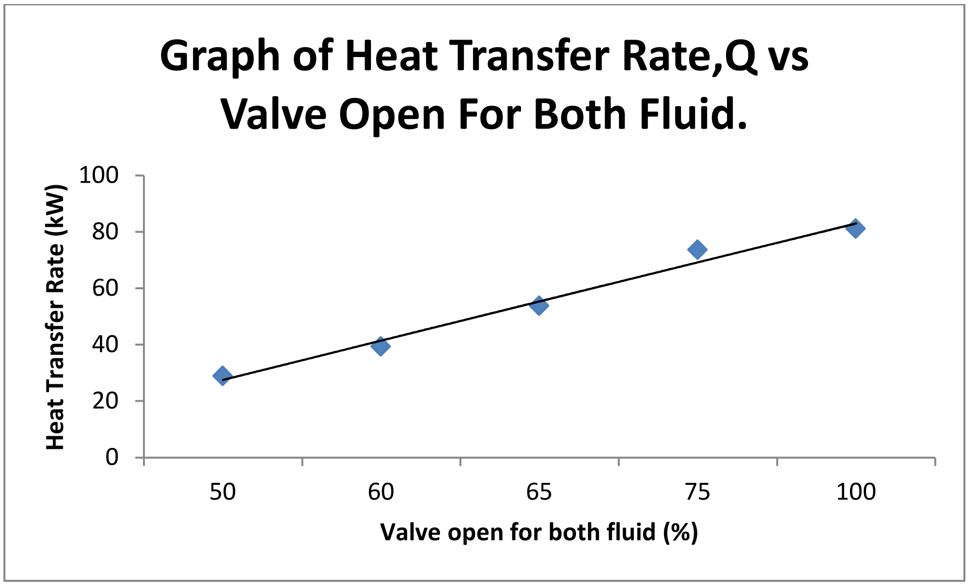


Figure 5.2: Graph of Heat Transfer Rate, $\dot{Q}$ (kW) versus Valve Open For Cold Fluid (%).

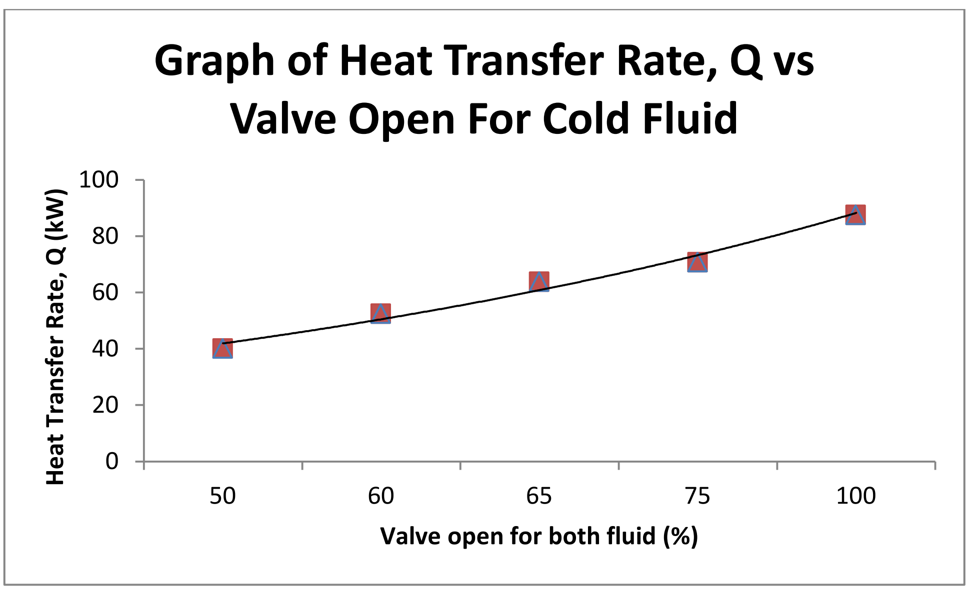
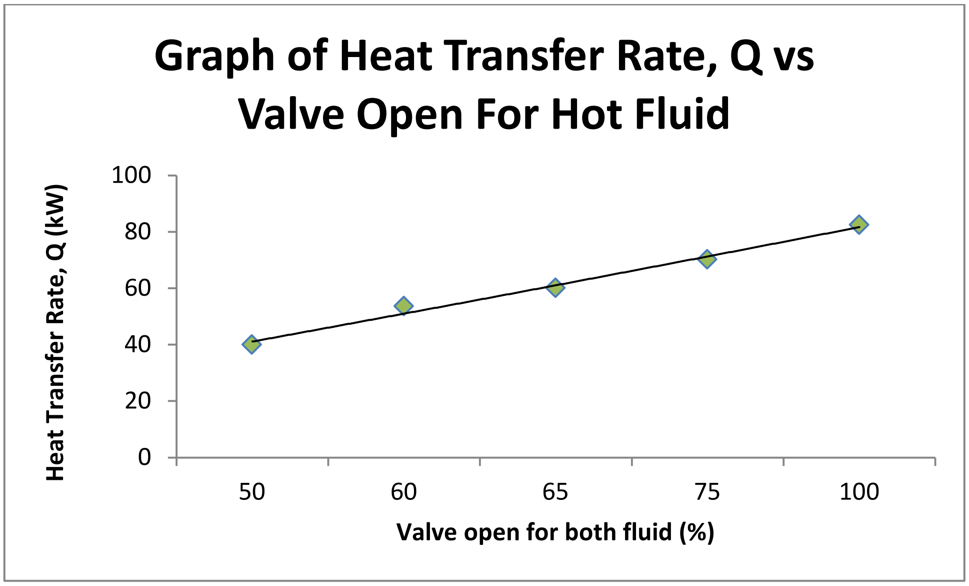


Figure 5.3: Graph of Heat Transfer Rate, $\dot{Q}$ (kW) versus Valve Open For Hot Fluid (%).



5.3 DISCUSSION

Based on the results obtained, the heat transfer rate raise as the mass flow rate increasing. The mass flow rates in this experiment are represented by the percentage of the opening valve attached at the inlet of hot and cold water. Besides, the heat transfer coefficient also increased with a rise of mass flow rate. Both are said to be directly proportional to the flow.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.2 CONCLUSION

The objectives of this research are such to study the properties of shell and tube heat exchanger. Besides, there is a software built to make it easier for researcher to find the best specifications of shell and tube heat exchanger. To operate this heat exchanger, the design must be following the specifications and the rules of designing. After fabricating, the experiments were held and focusing on the results where it will give the answer to the right and suitable of this kind of heat exchanger.

What had achieved in this project was very important for the future. Instead of gaining knowledge in this field, it will also market one self in the industries since there are experiences working with this project.

The experiment was held with an attachment of a thermometer digital first at the inlet and at the outlet for both the shellside and tubeside. The hot fluid flow at the inlet of shellside and go through 4 baffles fitted with the copper rods then cycle back. Together, the cold fluid enters the copper rod and drain. The opening valve was set and the temperature controlled.

Based on the results, the heat transfer rate increased when the mass flow rate increases. Note that the mass flow rates are depending on the percentage of valve opening. That would mean that the heat transfer rates are having a linear relationship with the flow opening through valve. Since the valves are in both cold side and hot side of water flowing, so the heat transfer rate of the tubeside are equal to the heat transfer rate at shellside also. To conclude, the simulation of heat exchanger in the software is compatible with the design as the result is same. The design for both simulation and fabrication are succeed.

6.3 RECOMMENDATIONS

Through all the researched done, the shell and tube heat exchanger are recommended to operate at 75% flow opening for sufficient heat transfer and in terms of economic efficiency. Not too high and not too low in heat transfer rate. Besides, it is compatible with the small design.

Besides, the experiment is recommended to run with a thermostat at the boiling part. This is because when the water get into the shellside, it will cycle back to the tank after exit the outlet. The hot water received in the tank will getting more hotter to enter the shellside again. With the attachment of thermostat, it will control and maintain the temperature that will go up the shellside.

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