DESIGN OF SMALL HEAT EXCHANGER
(DOUBLE PIPE TYPE)

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BACHELOR OF ENGINEERING

UNIVERSITI MALAYSIA PAHANG

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BORANG PENGESAHAN STATUS TESIS♦

JUDUL: **<u>DESIGN OF SMALL HEAT EXCHANGER (DOUBLE PIPE TYPE)</u>**

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DESIGN OF SMALL HEAT EXCHANGER
(DOUBLE PIPE TYPE)

MOHAMAD SHAFIQ BIN ALIAS

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

DECEMBER 2010

UNIVERSITI MALAYSIA PAHANG
FACULTY OF MECHANICAL ENGINEERING

We certify that the project entitled “Design of Small Heat Exchanger (Double Pipe Type)” is written by Mohamad Shafiq Bin Alias. We have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. We herewith that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering.

Dr. Agung Sudrajad

Examiner   Signature

SUPERVISOR’S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature	:
Name of Supervisor	: Dr. Maisara Mohyeldin Gasim Mohamed
Position	: Lecturer
Date	:

STUDENT’S DECLARATION

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

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Name: Mohamad Shafiq Bin Alias
ID Number: MA07083
Date:

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ABSTRACT

Heat exchanger is one of the important devices in cooling and heating process in factories, buildings, transports and others. The heat exchanger is found in large construction to support cooling process such as fossil fuel power plant. For this research, the small heat exchanger of double pipe type is constructed which wants to make it practicality in daily life such for saving fuel in vehicle. So, in this research, the best design for the small double pipe heat exchanger is choose based on TEMA specification. For this research, the hot air from engine bay is cooling down by using water pipe as the cold water where the temperature inlet and outlet for both fluids are specified. In this research, the properties of materials and its size are considered design process. After choosing the best design, the heat exchanger is fabricated by using sawing, flame-cutting, oxy-acetylene welding and drilling. The experiment is performed under two difference conditions where cold water flow rate is manipulated. From the experiment, the temperature of the hot air is dropped faster when using high flow rate of water with constant flow rate of hot air and the overall heat transfer coefficient is increased when water flow rate is increased.

ABSTRAK

Penukar haba adalah peralatan penting dalam proses penyejukan dan pemanasan di dalam kilang, banguanan, pengangkutan dan lain-lain. Penukar haba dijumpai di dalam pembinaan yang besar untuk menampung proses penyejukan seperti pelantar janakuasa bahan bakar fosil. Untuk kajian ini, penukar haba kecil yang berjenis tiub berkembar dibina dimana mahu membuatkannnya praktikal di dalam kehidupan seharian seperti menjimatkan bahan bakar di dalam kenderaan. Oleh itu, di dalam kajian ini, rekabentuk penukar haba kecil yang berjenis tiub berkembar yang terbaik dipilih berdasarkan spesifikasi TEMA. Untuk kajian ini, udara panas daripada kawasan enjin disejukkan dengan menggunakan air paip sebagai air sejuk dimana suhu keluar dan masuk untuk kedua-dua bendalir ditakrifkan. Di dalam kajian ini, sifat bahan dan saiz adalah diambil kira dalam proses rekabentuk. Selepas memilih rekabentuk yang terbaik, penukar haba difabrikasikan dengan menggunakan gergaji, pemotongan api, kimpalan oksigen-acetylene dan penggerudian. Eksperimen dilakukan di bawah dua keadaan berlainan dimana arus air sejuk dimanipulasikan. Daripada eksperimen, suhu udara panas diturunkan dengan cepat selepas menggunakan arus air yang tinggi dengan arus udara yang tetap.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

A	Area
A_s	Surface area
A_c	Cross section area
A_i	Area of the inner surface of the wall
A_o	Area of the outer surface of the wall
A_s	Area of surface
C_{pc}	Specific heat of cold fluid
$\dot{C}_{ph}$	Specific heat of hot fluid
C_h	Heat capacity rate of hot fluid
C_c	Heat capacity rate of cold fluid
$C_{\min}$	Minimum heat capacity rate
c	Capacity ratio
D	Diameter of tube
D_i	Inner diameter of tube
D_o	Outer diameter of tube
ε	Effectiveness
h_i	Inner fluid convection coefficient
h_o	Outer fluid convection coefficient
L	Length of tube
$\dot{m}$	Mass flow rate
m	Graph gradient

m_c	Mass flow rate of cold fluid
m_h	Mass flow rate of hot fluid
Q	Rate of heat transfer
$Q_{\max}$	Maximum of heat transfer rate
R	Thermal resistance
Re	Reynold number
R_{wall}	Thermal resistance
R_i	Inner fluid thermal resistance
R_o	Outer fluid thermal resistance
R_{total}	Total of thermal resistance
ΔT	Temperature difference
$T_{c,in}$	Inlet temperature of cold fluid
$T_{c,out}$	Outlet temperature of cold fluid
$T_{h,in}$	Inlet temperature of hot fluid
$T_{h,out}$	Outlet temperature of hot fluid
ΔT_{lm}	Log mean temperature difference
U	Overall heat transfer coefficient
U_i	Overall heat transfer coefficient of inside tube
U_o	Overall heat transfer coefficient of outside tube
$\dot{v}$	Volume flow rate
V	Velocity

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LIST OF ABBREVIATIONS

LMTD	Log Mean Temperature Difference
TEMA	The Tubular Exchanger Manufacturers Association

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

The heat exchanger is a device which transferred the heat from hot medium to cold medium without mixed both of medium since both mediums are separated with a solid wall generally. There are many types of heat exchanger that used based on the application. For example, double pipe heat exchanger is used in chemical process like condensing the vapor to the liquid. When to construct this type of heat exchanger, the size of material that want to uses must be considered since it affected the overall heat transfer coefficient. For this type of heat exchanger, the outlet temperature for both hot and cold fluids that produced is estimated by using the best design of this type of heat exchanger.

1.2 PROBLEM STATEMENT

The double pipe heat exchanger is used in industry such as condenser for chemical process and cooling fluid process. This double pipe heat exchanger is designed in a large size for large application in industry. For this research, the small heat exchanger of double pipe type is constructed which wants to make it practicality in daily life such in cooling the hot air from engine bay into intake manifold of car. To make this small double pipe heat exchanger type become practicality, the best design for this small double pipe heat exchanger is choose.

1.3 OBJECTIVES OF RESEARCH

The objectives of this research are as follows:

i. To study about heat transfer analysis in heat exchanger.
ii. To design the heat exchanger based on TEMA specification.

1.4 SCOPES OF RESEARCH

The scopes of this research are as follows:

i. Study on heat transfer for heat exchanger specific to double pipe heat exchanger types.
ii. Construct and simulate calculator for double pipe heat exchanger by using Visual Basic 6.0.
iii. Design the double pipe heat exchanger by using Solidwork.
iv. Fabricated the double pipe heat exchanger by using sawing, flame-cutting, oxy-acetylene welding and drilling process.
v. Analysis the heat exchanger specific to flow rate of hot and cold fluid.

1.5 SIGNIFICANCE OF RESEARCH

The significances of this research are as follows:

i. To determine the best design for double pipe heat exchanger type.
ii. To fabricate the double pipe heat exchanger.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter discussed about definition of heat exchanger, functions of heat exchanger, applications of heat exchanger, criteria for heat exchanger selection, fluid fundamental in heat exchanger, type of heat exchanger, construction of double pipe heat exchanger, flow arrangement in heat exchanger, overall heat transfer coefficient of double pipe heat exchanger, log mean temperature difference (LMTD) method for double pipe heat exchanger, effectiveness-ntu method for double pipe heat exchanger

2.2 DEFINITION OF HEAT EXCHANGER

Heat exchanger is a device, such as an automobile radiator, used to transfer heat from a fluid on one side of a barrier to a fluid on the other side without bringing the fluid into direct contact (Fogiel, 1999). Usually, this barrier is made from metal which has good thermal conductivity in order to transfer heat effectively from one fluid to another fluid. Besides that, heat exchanger can be defined as any of several devices that transfer heat from a hot to a cold fluid. In engineering practical, generally, the hot fluid is needed to cool by the cold fluid. For example, the hot vapor is needed to be cool by water in condenser practical. Moreover, heat exchanger is defined as a device used to exchange heat from one medium to another often through metal walls, usually to extract heat from a medium flowing between two surfaces. In automotive practice, radiator is used as heat exchanger to cool hot water from engine by air surrounding same like intercooler which used as heat exchanger to cool hot air for engine intake manifold by air surrounding. Usually, this device is made from aluminum since it is lightweight and good thermal conductivity.

2.3 FUNCTION OF HEAT EXCHANGER

Heat exchanger is a special equipment type because when heat exchanger is directly fired by a combustion process, it becomes furnace, boiler, heater, tube-still heater and engine. Vice versa, when heat exchanger make a change in phase in one of flowing fluid such as condensation of steam to water, it becomes a chiller, evaporator, sublimator, distillation-coloumn reboiler, still, condenser or cooler-condenser. Heat exchanger may be designed for chemical reactions or energy-generation processes which become an integral part of reaction system such as a nuclear reactor, catalytic reactor or polymer (Fogiel, 1999). Normally, heat exchanger is used only for the transfer and useful elimination or recovery of heat without changed in phase. The fluids on either side of the barrier usually liquids but they can be gasses such as steam, air and hydrocarbon vapour or can be liquid metals such as sodium or mercury. In some application, heat exchanger fluids may used fused salts.

2.4 WHERE CAN FIND HEAT EXCHANGER

2.4.1 VEHICLE

Generally, the vehicle such as car and lorry is used petrol or diesel internal combustion engine where generated high heat and temperature which can affect durability of engine in long term and long journey. Moreover, the metal part of engine such as the crank shaft is quickly overheated and then, makes its life more short. This problem can be overcome by cooling this engine using radiator as a heat exchanger. From Figure 2.1, the hot coolant such as water which comes from the internal combustion of engine is pumped to radiator by water pump. The air from surrounding is exchanged the heat between the hot coolant at the radiator. Then, the hot coolant become cold and entered again to engine. Furthermore, other heat exchanger where used in vehicle is intercooler which designed for force induction engine such as turbocharged engine as shown in Figure 2.2. The hot air from the turbocharger is flowed through the tubes inside the intercooler where the air from surrounding passed through this tubes and fins in the intercooler. At this time, heat is transferred from the tubes and fins to the cool surrounding air which produced cold air in the tubes. Then, this cold air is entered to the air intake of the engine. Based on theory, the cold air is denser and more molecules were carried. As a result, the performance of car is increased.

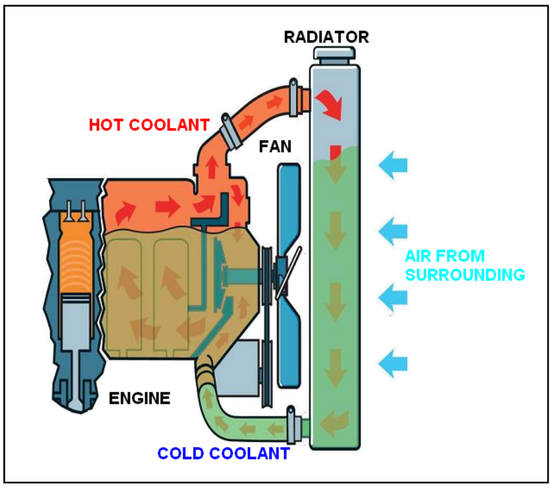


Figure 2.1: Radiator

Source: Walker (1982)

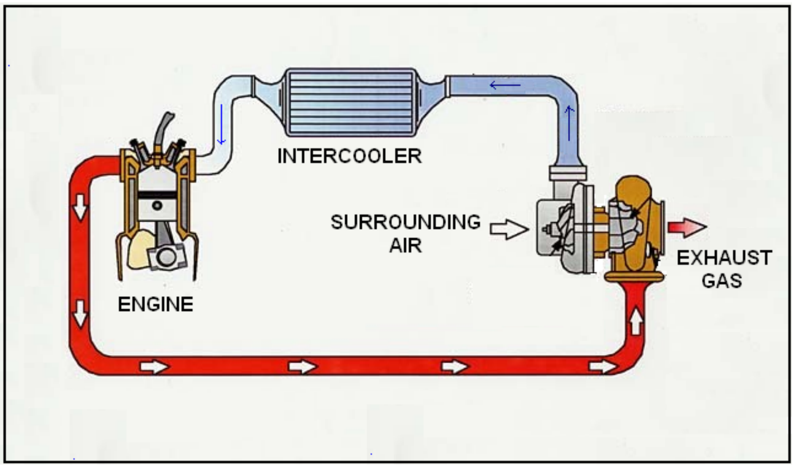


Figure 2.2: Turbocharger engine

Source: Walker (1982)

2.4.2 LABORATORY

Condenser is a device used to cool a vapor to cause it to condense to a liquid. The laboratory condenser has a straight tube which insulated with glass jacket. From Figure 2.3, the hot vapor produced by chemical reaction passes over the tube where thermometer recorded the point vapor temperature. Then, the vapor is flowed in condenser which cooled by cold water and the vapor is condensed to liquid. From heat transfer theory, the hot vapor was transferred heat to cold fluid until the hot vapor was cooled at certain temperature and become the liquid state. Lastly, this liquid as known as distillate is collected in receiver.

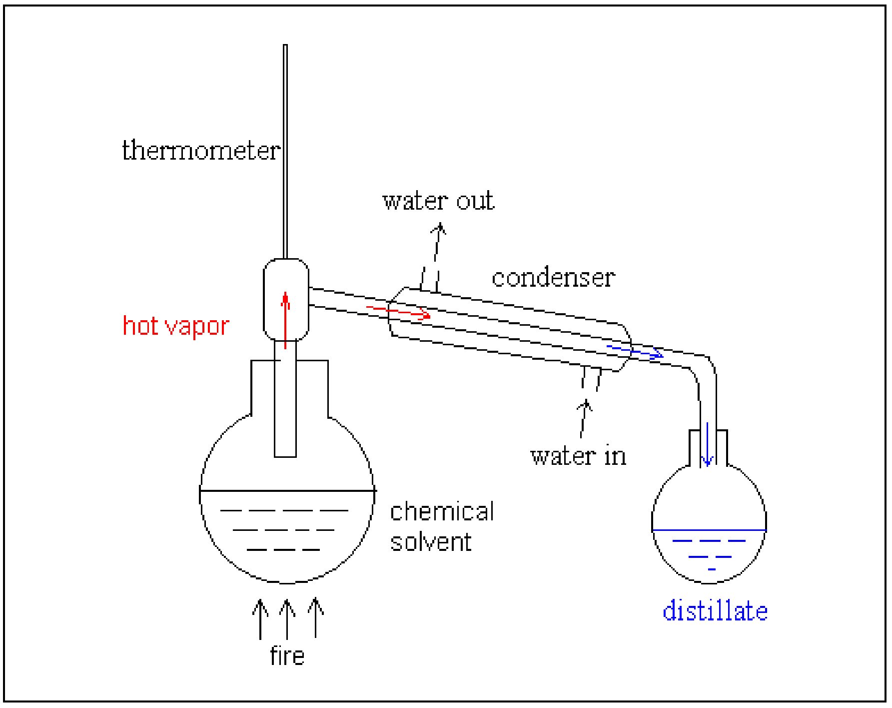


Figure 2.3: Condenser

Source: Walker (1982)

2.4.3 HOUSE

This type of water heater as shown in Figure 2.4 is difference by conventional water heater which used the water is heated in tank. For this type of water heater, it use concept of heat exchanger where the water is instantly heated through the heat coils in the heater. The process is begin with the water entered the heater and the flow sensor is detected the water flow. Then, the computer automatically ignited the burner by using gas as a medium combustion and the burner is blow by fan. At same time, the water is circulated and heated in the heat exchanger at demand temperature. Finally, the hot water is produced.

Beside that, the heat exchanger can be found in house device such as a freezer where fish and vegetables is keep. Freezer is a device where taking the heat from inside the storage place and transferring the heat into the outside or environment. Generally, the freezer contain by compressor, condenser, drier, capillary tube and evaporator coil as shown in Figure 2.5. Firstly, the compressor pressurizes the refrigerant gas and pumped it around the system. After that, the gas is passed through the condenser coil where the heat is rejected to surrounding. Next, the gas passed through the drier to remove the dirt and enter the capillary tube which experience high pressure. Lastly, the cold gas is passed through the evaporator coil where the pressure is dropped and the gas is conducted the heat from storage place which make this place more cooled. This process of freezer system is repeated.

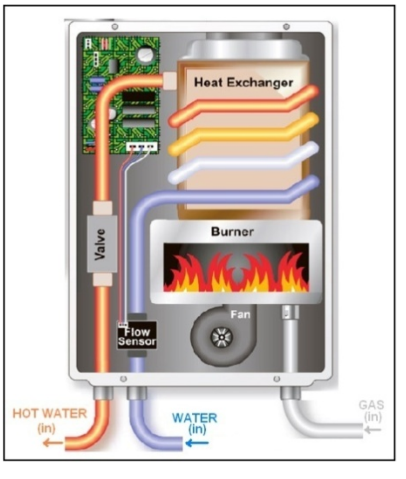


Figure 2.4: Water heater

Source: Walker (1982)

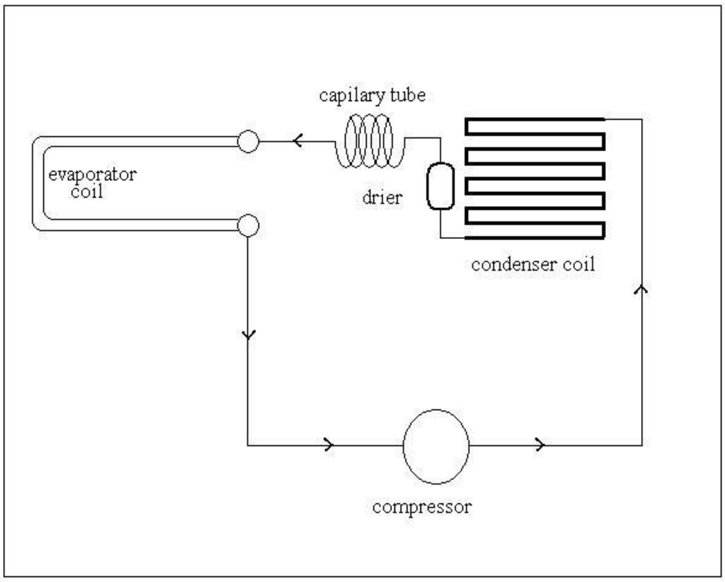


Figure 2.5: Water heater system

Source: Walker (1982)

2.4.4 INDUSTRY

Superheater as shown in Figure 2.6 is a heat exchanger for heating steam above 212°F (100°C) at atmospheric pressure. In water tube boiler, initially, water tube from feedwater drum is heated by hot gas which produced by burning fuel in furnace. Then, this heated water in tube is raised into the steam drum and formed saturated steam. After that, this saturated steam is drawn off at the top of steam drum. Finally, this saturated steam was entered the superheater and produced superheated water.

Moreover, gas engine chiller is used in industry for cooling process such as water. Operation cost for the gas engine chiller is less than the electric chiller since the engine that provides energy for compressor is generated heat. This heat can be using for other purpose. From Figure 2.7, initially, the compressor is generated by the gas engine where applied the pressure to the gas in the system which result reduction in volume and increments in temperature. After that, the hot gas is entered the condenser where the cold water is used to cool the hot refrigerant gas and condensed it to the liquid. Next, the liquid refrigerant is entered the expansion valve where the liquid pressure is reduce which result reduction in the boiling point of refrigerant liquid. Lastly, the refrigerant liquid entered the evaporator where evaporated immediately due to lower pressure and absorbed the heat from the water system which makes the water more cooled.

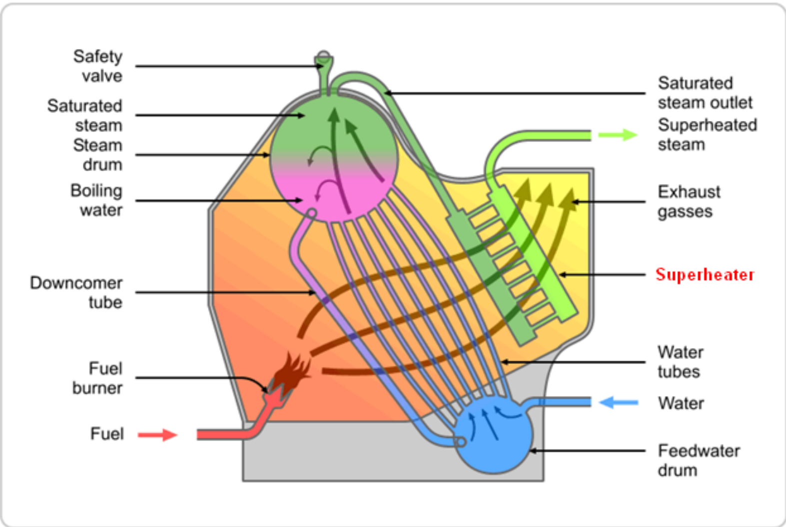


Figure 2.6: Superheater

Source: Walker (1982)

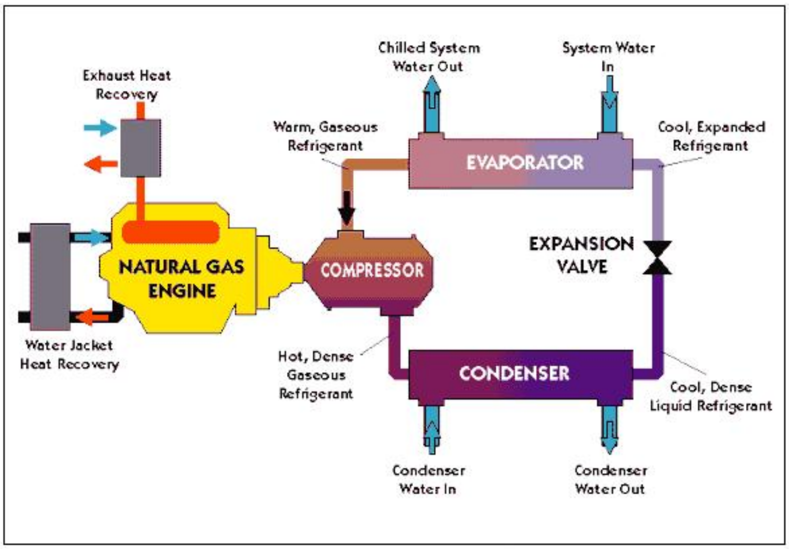


Figure 2.7: Superheater system

Source: Walker (1982)

2.3 CRITERIA FOR HEAT EXCHANGER SELECTION

The selection of heat exchanger from various type of heat exchanger should following some criteria which are:

1) The heat exchanger must be satisfying the process specification.
2) The heat exchanger must withstand the service conditions of the plant environment where it must resisted corrosion and fouling.
3) The heat exchanger must be maintainable which allowed cleaning and replacement of any component.
4) The heat exchanger should be cost effective including installed operating costs, maintenances costs and loss of production which caused by exchanger unavailability.
5) The diameter, length, weight and tube configurations of heat exchanger should followed site requirement, lifting and servicing capabilities or inventory considerations.

2.4 FLOW ARRANGEMENTS OF HEAT EXCHANGER

Heat exchanger can be classified according to the fluid-flow path through the heat exchanger. It can be classified into three categories which are parallel-flow, counter-flow and cross flow. From Figure 2.9, in parallel-flow heat exchanger, the two fluids enter together at one end which flowed through in the same direction and leave together at other end. From Figure 2.10, in counter-flow heat exchanger, the two fluids is flowed in opposite direction. In a single cross flow heat exchanger, one fluid flows through the heat transfer surface at the right angles to the flow path of the other fluid (Fogiel, 1999). In cross flow heat exchanger, it have two arrangements which are the cross flow fluid unmixed and other flowed fluid unmixed as shown in Figure 2.14 or the cross flow fluid mixed and other flowed fluid unmixed as shown in Figure 2.15. In cross flow, it has multi pass cross flow arrangement which can be organized by a basic series arrangement such as U-baffled tube single-pass shell-and-tube heat exchanger as shown in Figure 2.8 (Yunus, 2006). In this type of heat exchanger, one fluid flow through the

U-tube while the other fluid flow downward and upward across the flow path of U-tube which can be classified to cross-counter and cross-parallel flow arrangements.

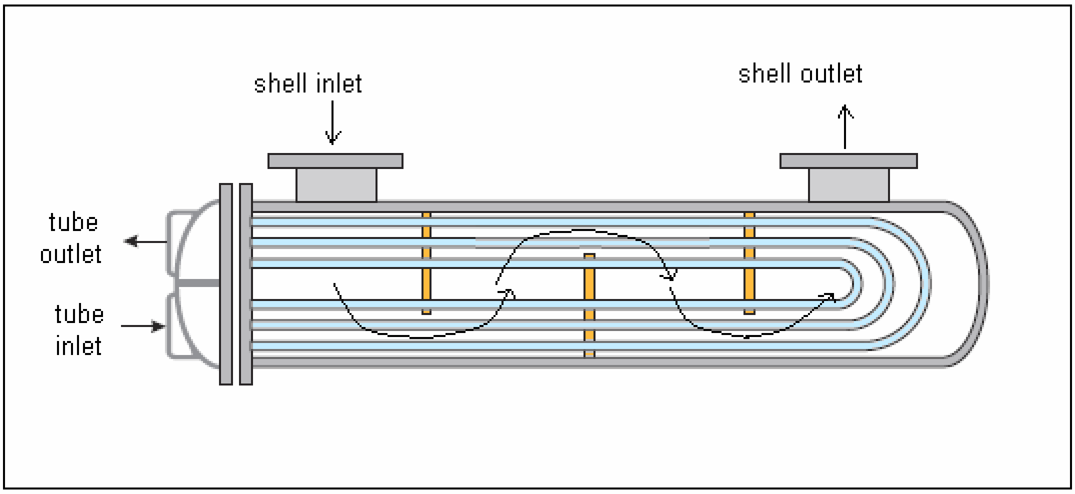


Figure 2.8: Multipass crossflow arrangement

Source: Fogiel (1999)

2.5 FLUID FUNDAMENTALS IN HEAT EXCHANGER

Generally**,** heat exchanger is a device which used to exchange heat from one fluid to another often through metal walls. This heat transfer depended on physical characteristics of the fluids involved including their density, ρ, specific heat, thermal conductivity, k, and dynamic viscosity. For density of fluid, it represented the fluid mass per unit volume. This density can be used to convert a measurement from mass flow rate to volume flow rate and also the velocity of fluid flow as shown in Equation 2.1 and Equation 2.2. This density is important when to determine the overall heat transfer coefficient for heat exchanger. For heat exchanger, the mass flow rate for fluid is constant but the volume flow rate is changes due to temperature and pressure especially for a gas. For specific heat of fluid at constant pressure, it represented the amount of heat required to raise temperature by one degree (Fogiel, 1999). This specific heat related with quantity of transferred heat to the change of temperature of fluid when pass through the heat exchanger. For thermal conductivity, it represented the ability of the fluid to conduct heat. For dynamic viscosity, μ, it represented the fluid resistance to flow. It use for determination the Reynold number of flowed fluid either laminar or turbulent flow as shown in Equation 2.1 to 2.3. The fluid with high dynamic viscosity produces high pressure loss due to the shear resistance along the heat exchanger surface. Moreover, laminar flow heat transfer relies entirely on the thermal conductivity of the fluid to transfer heat from inside a stream to a heat exchanger wall. For turbulent flow, it produces better heat transfer because the fluid is mixed. Laminar flow produces smallest in the pressure loss which increases linearly with flow velocity.

$$\dot{v} = \frac{\dot{m}}{\rho} \tag{2.1}$$

$$V = \frac{\dot{m}}{\rho A_c} \tag{2.2}$$

$$Re = \frac{VD}{\upsilon} \tag{2.3}$$

2.6 TYPE OF HEAT EXCHANGER

2.6.1 DOUBLE PIPE HEAT EXCHANGER

The double-pipe heat exchanger or known as Hairpin heat exchanger is the simplest type of heat exchanger which contained two concentric pipes of different diameter as shown in Figure 2.9 and Figure 2.10. One of fluid in a double-pipe heat exchanger flows through the inner or smaller pipe while the other fluid flows through annular space between the two pipes. Two types of flow arrangement for this type heat exchanger are parallel flow and counter flow. In parallel flow as shown in Figure 2.9 , both the hot and cold fluids are entered the heat exchanger at the same inlet themselves and move in same direction, vice versa in counter flow as shown in Figure 2.10, the hot and cold fluids enter the heat exchanger at the opposite inlet and move in opposite direction (Yunus,2006).

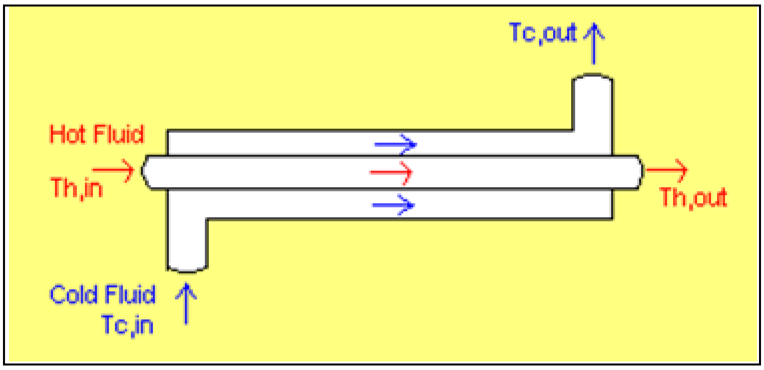


Figure 2.9: Double tube heat exchanger (parallel flow)

Source: Yunus (2006)

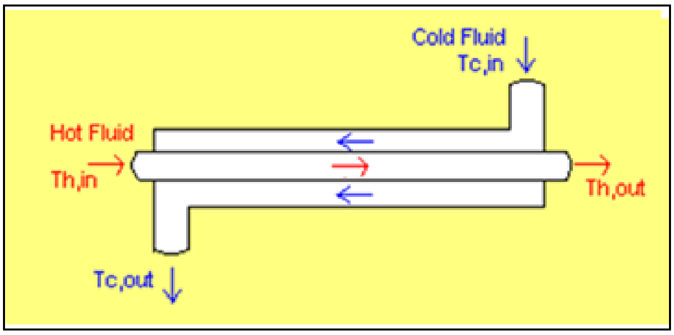


Figure 2.10: Double tube heat exchanger (counter flow)

Source: Yunus (2006)

2.6.2 SHELL AND TUBE HEAT EXCHANGER

Shell and tube heat exchanger is type of heat exchanger which has many of tubes that packed in a shell as shown in Figure 2.12. For this type of heat exchanger, the fluid is flow in the tubes while other fluid is flow in the shell through the tubes where heat is transferred in both tubes and shell. Moreover, the baffles also place in the shell in order to force the fluid in the shell to flow across the tubes (Yunus, 2006). This type of heat exchanger also has headers at both side of end the shell where fluid in the tubes is accumulates before entering and leaving the tubes. This shell and tube heat exchanger is classified according to the number of shell and tube. For example one-shell passes and two-tubes pass heat exchanger as shown in Figure 2.11 and two-shells pass and two-tubes pass heat exchanger as shown in Figure 2.12.

Spiral tube heat exchanger is also classified in shell and tube where the coil assembly fitted in a compact shell to optimize the space and heat transfer efficiency. Every spiral coil assembly has welded tube which jointed together with manifold. The coil assembly is welded to a head and fitted in a compact shell where the gaps between the coil of spiral tube become shell side flow path as shown in Figure 2.13. The spiral shape of tube and shell flow created centrifugal force which increased the heat transfer in counter-flow arrangement.

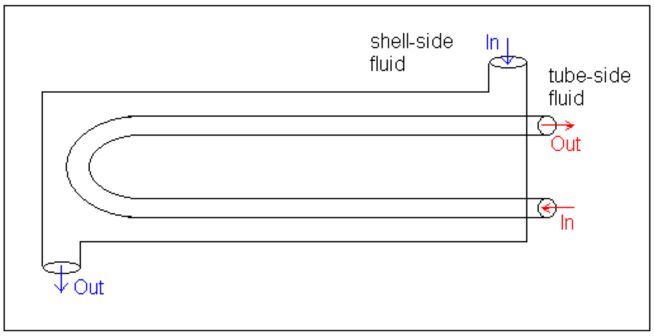


Figure 2.11: One-shell passes and two-tubes pass heat exchanger

Source: Yunus (2006)

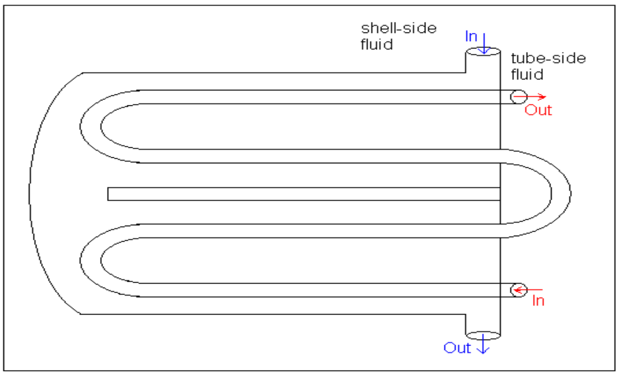


Figure 2.12: Two-shells pass and two-tubes pass heat exchanger

Source: Yunus (2006)

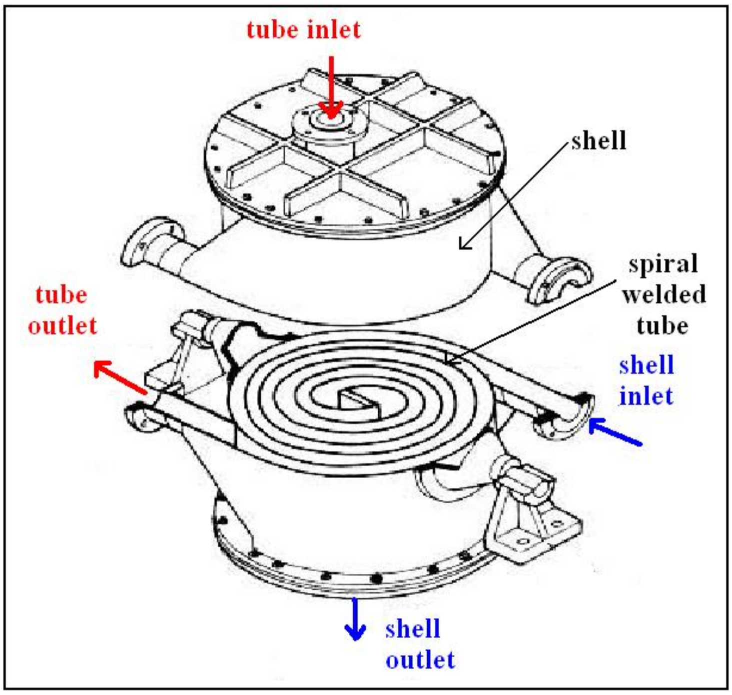


Figure 2.13: Spiral tube heat exchanger

Source: Walker (1982)

2.6.3 COMPACT HEAT EXCHANGER

Compact heat exchanger is type of heat exchanger which have implying surface area density larger than around 200m²/m³ where presented hydraulic area diameters smaller than around 14mm (Kays and London,1984). In this type of heat exchanger, the two fluids are moved perpendicularly with each others which called as cross-flow but not mixed. For cross-flow, these flow configurations have two class. First is unmixed and second is mixed. From Figure 2.14, for unmixed, the fluid is flowed through a tubes between the plates which the flow is prevented to move in transverse direction or parallel to the tubes. From Figure 2.15, the fluid is flowed through the tubes which the flow is free to move in transverse direction. Compact heat exchanger can achieve high heat transfer rates between two fluids in small volume and lightweight of heat exchanger. Moreover, usually, compact heat exchanger is designed gas-to-gas and gas-to-liquid or liquid-to-gas heat exchanger to overcome the low heat transfer coefficient by gas with increased surface area.

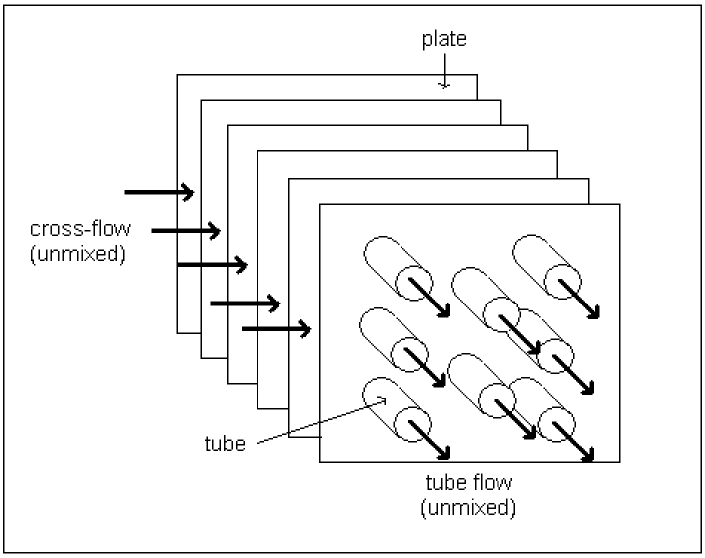


Figure 2.14: Compact heat exchanger (unmixed)

Source: Walker (1982)

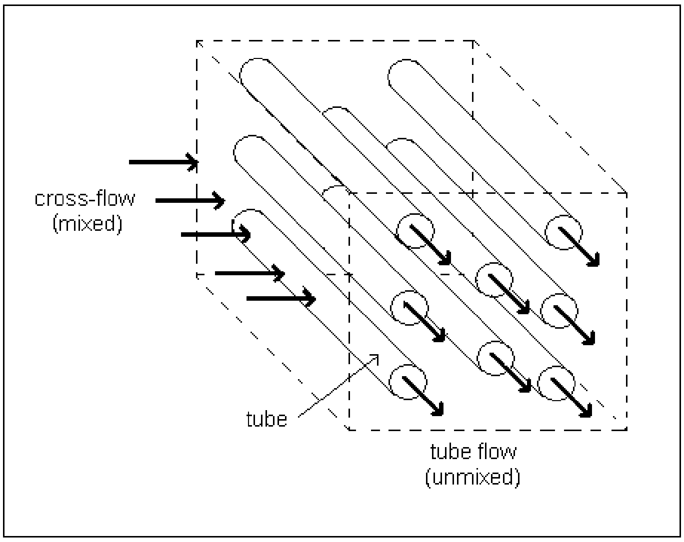


Figure 2.15: Compact heat exchanger (mixed)

Source: Walker (1982)

2.6.4 FLAT PLATE HEAT EXCHANGER

This flat plate heat exchanger as shown in Figure 2.16 is the type of heat exchanger where transfer heat from one medium to other which separate by the plates. This type of heat exchanger consist the separate thin plates that have large surface area and the fluid passages which move the heat easily (Afgan, 1974). The hot and cold fluid flowed in the passages which cold fluid flow is surrounded by hot fluid flow which makes the heat transfer very effective. This liquid-to-liquid of heat exchanger can be used many of plates based on the demand or application that want to use.

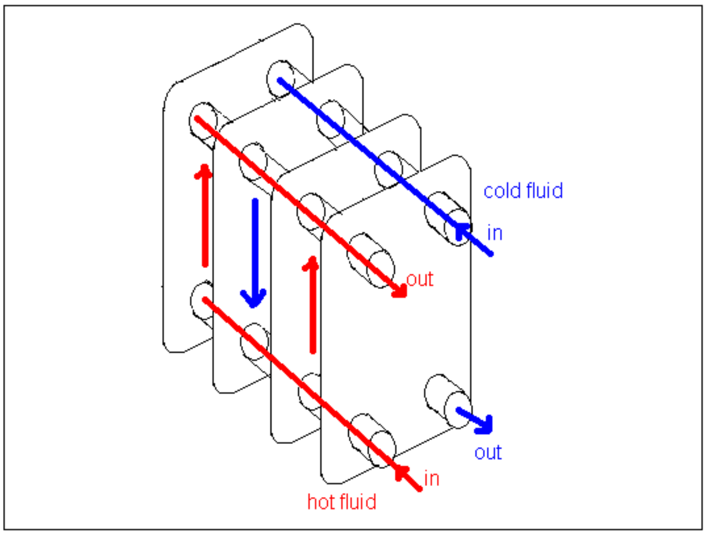


Figure 2.16: Flat plate heat exchanger

Source: Afgan (1974)

2.7 COSTRUCTION OF DOUBLE-PIPE HEAT EXCHANGER

Generally, double-pipe heat exchanger or known as hairpin heat exchanger is made with concentric inner and outer pipe where one pipe is placed in other tube with specified size in inner diameter, D, outer diameter, D and length, L. These sizes are influence in the overall heat transfer coefficient for the heat exchanger as shown in Equation 2.4 to Equation 2.9. Cold and hot fluids are flowed either in the inner pipe or gap between outer and inner pipe as shown in Figure 2.17. From Figure 2.17, the inner pipe is connected with U-tube while the outer tube is connected with the outer tube is connected with direct tube. The structure of this heat exchanger is simple compared to other type of heat exchanger but heat transferred is large. Moreover, this type of heat exchanger is easy to clean since it is easy to assemble or disassemble.

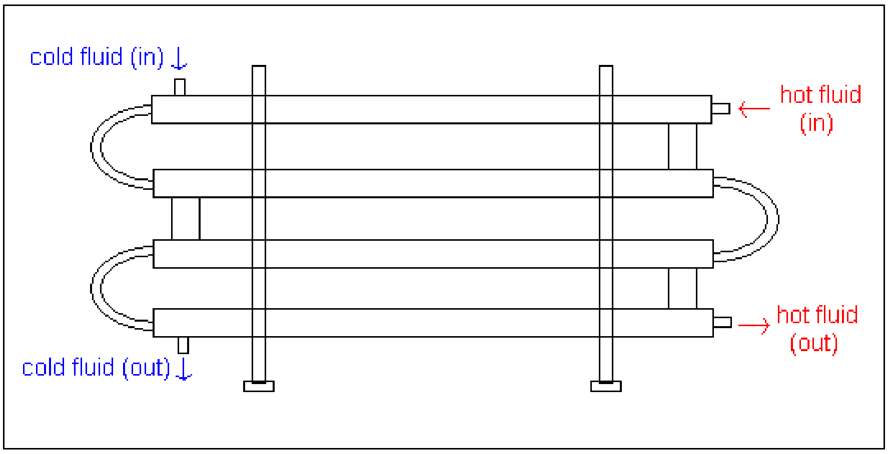


Figure 2.17: Hairpin heat exchanger

Source: Schlunder (1982)

2.8 OVERALL HEAT TRANSFER COEFFICIENT OF DOUBLE PIPE HEAT EXCHANGER

The double tube heat exchanger have two flowing fluid which separated by solid wall. From Figure 2.18, initially, the heat is transferred from the hot fluid to the wall by convection through the wall, then through the wall by conduction and lastly from the wall to the cold fluid by convection (Yunus, 2006). For double pipe heat exchanger, the total thermal resistance can be shown in Equation 2.4. From Equation 2.7, we get the overall heat transfer coefficient become as Equation 2.8 by cancelling ΔT. For double pipe heat exchanger which small thickness of the tubes and the thermal conductivity of the material tube is high, the thermal tube is negligible where $(R_{wall} \approx 0)$ and the inner and outer surfaces of the tube are almost same where $A_i \approx A_o \approx A_s$. So, the overall heat transfer coefficient become as Equation 2.9.

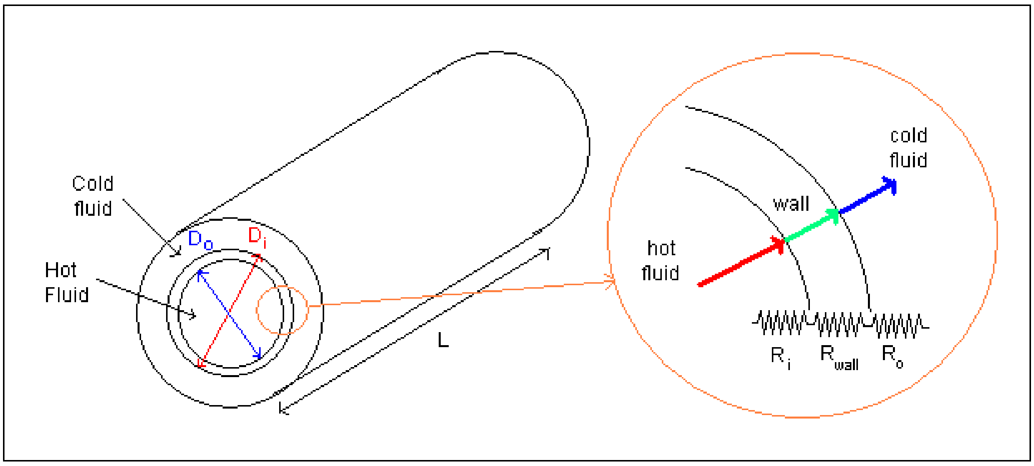


Figure 2.18: Heat transfer of double pipe heat exchanger

Source: Yunus (2006)

$$R_{total} = R_i + R_{wall} + R_o = \frac{1}{h_i A_i} + \frac{\ln\left(\frac{D_o}{D_i}\right)}{2\pi kL} + \frac{1}{h_o A_o} \tag{2.4}$$

$$A_i = \pi D_i L \tag{2.5}$$

$$A_o = \pi D_o L \tag{2.6}$$

$$Q = \frac{\Delta T}{R} = UA\Delta T = U_i A_i \Delta T = U_o A_o \Delta T \tag{2.7}$$

$$\frac{1}{UA_s} = \frac{1}{U_i A_i} = \frac{1}{U_o A_o} = \frac{1}{h_i A_i} = R = \frac{1}{h_i A_i} + R_{wall} + \frac{1}{h_o A_o} \tag{2.8}$$

$$\frac{1}{U} \approx \frac{1}{h_i} + \frac{1}{h_o} \tag{2.9}$$

2.9 LOG MEAN TEMPERATURE DIFFERENCE (LMTD) METHOD FOR DOUBLE PIPE HEAT EXCHANGER

Generally, double heat exchanger is used in industry as a cooling or heater device such as condenser. This heat exchanger is very large and required some method or way to designed it. So, this LMTD method can assist for this design process since this method is easy to use when make analysis. This method is suitable for determining the size of a heat exchanger since the inlet and outlet temperature and mass flow rates for both flowed fluid is known (Yunus, 2006). The procedure for these methods are as followed:

1) The type of heat exchanger is selected which suitable for application.

2) Inlet and outlet temperature and heat transfer rate are calculated by using Eq. (2.10).

$$Q = m_c C_{pc} (T_{c,out} - T_{c,in}) = m_h C_{ph} (T_{h,in} - T_{h,out}) \tag{2.10}$$

3) The log mean temperature difference is calculated by Eq. (2.11), (2.12), (2.13) for parallel flow and Eq. (2.14) and (2.15) for counter flow.

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 \Delta T_2)} \tag{2.11}$$

$$\Delta T_1 = T_{h,in} - T_{c,in} \tag{2.12}$$

$$\Delta T_2 = T_{h,out} - T_{c,out} \tag{2.13}$$

$$\Delta T_1 = T_{h,in} - T_{c,out} \tag{2.14}$$

$$\Delta T_2 = T_{h,out} - T_{c,in} \tag{2.15}$$

4) The value of the overall heat transfer coefficient is calculated by Eq. (2.16) to Eq. (2.17).

$$A_s = \frac{Q}{U\Delta T_{lm}} \tag{2.16}$$

$$A_s = \pi DL \tag{2.17}$$

5) The heat transfer surface area is calculated by Eq. (2.16) and either long or diameter of tube is founded by Eq. (2.17).

2.10 EFFECTIVENESS-NTU METHOD FOR DOUBLE PIPE HEAT EXCHANGER

This method is suitable for this type of heat exchanger since the size of tube, inlet temperature and mass flow rates for both flowed fluid is known (Yunus, 2006). The procedure for these methods are as followed:

1) The heat capacity rates for hot and cold fluid are calculated by using Eq. (2.18) and (2.19).

$$C_h = m_h C_{ph} \tag{2.18}$$

$$C_c = m_c C_{pc} \tag{2.19}$$

2) The minimum heat capacity rates is determined by using Eq. (2.20) and constant, c is calculated by using Eq. (2.21).

$$C_{\min} = \min(C_h, C_c) \tag{2.20}$$

$$c = \frac{C_{\min}}{C_{\max}} \tag{2.21}$$

3) The maximum heat transfer rate is calculated by using Eq. (2.22).

$$Q_{\max} = C_{\min}(T_{h,in} - T_{c,in}) \tag{2.22}$$

4) The heat transfer surface area is calculated by using Eq. (2.23).

$$A_s = \pi DL \tag{2.23}$$

5) The value of the overall heat transfer coefficient is calculated by using Eq. (2.4) to Eq. (2.9) as shown in chapter 2.9.

6) The value of NTU is founded by using Eq. (2.24).

$$NTU = \frac{UA_s}{C_{\min}} \tag{2.24}$$

7) The effectiveness of heat exchanger is calculated by using Eq. (2.25) for parallel and Eq. (2.26) for counter flow.

$$\varepsilon = \frac{1 - \exp[-NTU(1+c)]}{1+c} \tag{2.25}$$

$$\varepsilon = \frac{1 - \exp[-NTU(1+c)]}{1 - c\exp[-NTU(1+c)]} \tag{2.26}$$

8) The actual rate of heat transfer is calculated by using Eq. (2.27).

$$Q = \varepsilon Q_{\max} \tag{2.27}$$

9) The outlet temperature for cold and hot flowed fluid is determined by using Eq. (2.28) and (2.29).

$$T_{c,out} = T_{c,in} + \frac{Q}{C_c} \tag{2.28}$$

$$T_{h,out} = T_{h,in} - \frac{Q}{C_h} \tag{2.29}$$

CHAPTER 3

SIMULATION

3.1 INTRODUCTION

For this research, the problems statement is identified which related with design of heat exchanger specific to double pipe type. In this research, the current technology that relate with design of double pipe heat exchanger is investigated such as intercooler. The problem which wants to solve is choose the best design of small double pipe heat exchanger. So, topic that related with heat transfer process in heat exchanger is concentrated. For this case, the main consideration for designed the double pipe heat exchanger type is studied. After that, literature review is prepared about the topic related. Next, we have prepared calculator by using Visual Basic 6.0 with choose and arranged suitable equation of heat transfer. Then, the inlet and outlet temperature of both fluids are specified together with the flow rate and the material for the heat exchanger is choose based on the physical properties and size. After that, all the parameters are keyed in calculator. From the result, the best design is choose and the heat exchanger design is draw by Solidwork. The flow of project is shown in Figure 3.1.

3.2 FLOW OF PROJECT

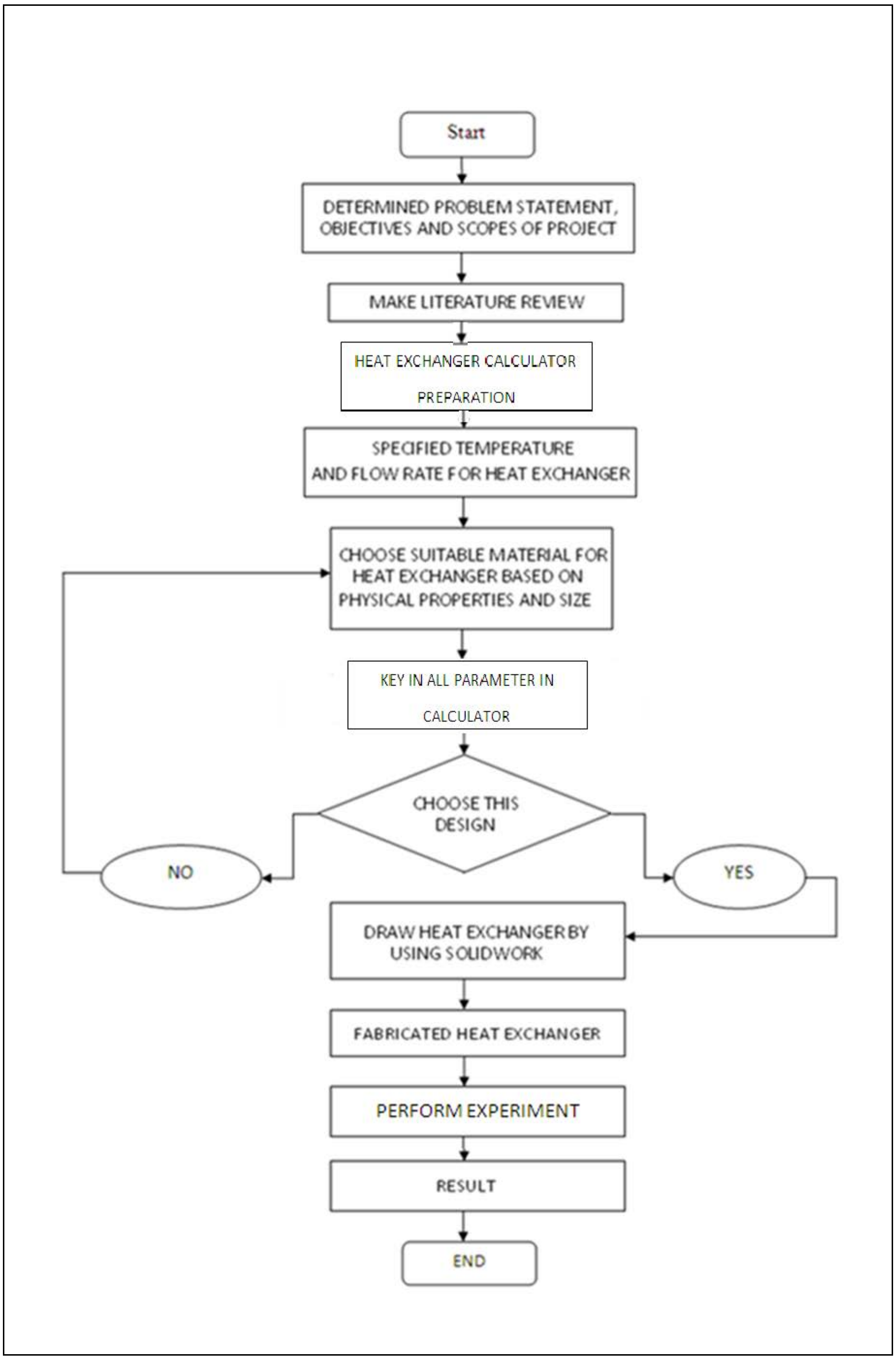


Figure 3.1: Project Flow

3.3 HEAT EXCHANGER CALCULATOR

From literature review, for heat exchanger, the analysis can be doing in two methods either Log Mean Temperature Difference (LMTD) method or Effectiveness-NTU method. For this design process, LMTD method is choosing for the basic construction of calculator for double pipe heat exchanger together with simple equation. The arrangement and choosing of the equations are shown below. After that, all the equations are transfer to Visual Basic 6.0 for calculator preparation as shown in Figure 3.3.

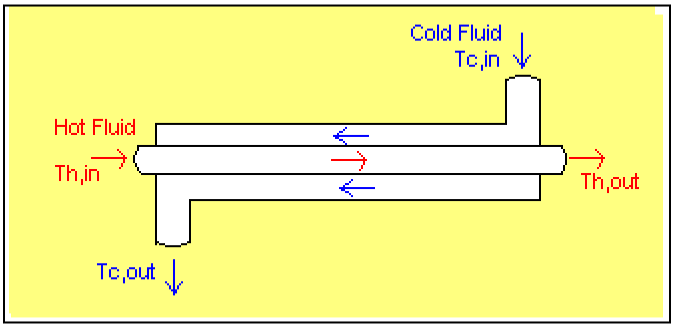


Figure 3.2: Double pipe heat exchanger (counter-flow)

Source: Yunus (2006)

For inner tube,

$$D_h = D_i \quad (3.1)$$

$$V = \frac{m_h}{\rho A_c} \quad (3.2)$$

$$Re = \frac{v D_h}{\upsilon} \quad (3.3)$$

$$Nu = 0.023 Re^{0.8} Pr^{0.4} \quad (3.4)$$

$$h_i = \frac{k}{D_h} Nu \tag{3.5}$$

For outer tube,

$$D_h = D_o - D_i \tag{3.7}$$

$$V = \frac{m_c}{\rho A_c} \tag{3.8}$$

$$Re = \frac{v D_h}{\upsilon} \tag{3.9}$$

$$Nu = 0.023 Re^{0.8} Pr^{0.4} \tag{3.10}$$

$$h_o = \frac{k}{D_h} Nu \tag{3.11}$$

For overall heat transfer coefficient,

$$U = 1/(\frac{1}{h_i} + \frac{1}{h_o}) \tag{3.12}$$

Using LMTD method for 2nd calculator,

$$Q = m_c C_{pc}(T_{c,out} - T_{c,in}) = m_h C_{ph}(T_{h,in} - T_{h,out}) \tag{3.13}$$

$$T_{c,out} = T_{c,in} + \frac{Q}{m_c C_{pc}} \tag{3.14}$$

$$\Delta T_1 = T_{h,in} - T_{c,out} \tag{3.15}$$

$$\Delta T_2 = T_{h,out} - T_{c,in} \tag{3.16}$$

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 \Delta T_2)} \tag{3.17}$$

$$A_s = \frac{Q}{U \Delta T_{lm}} \tag{3.18}$$

$$L = \frac{A_s}{\pi D} \tag{3.19}$$

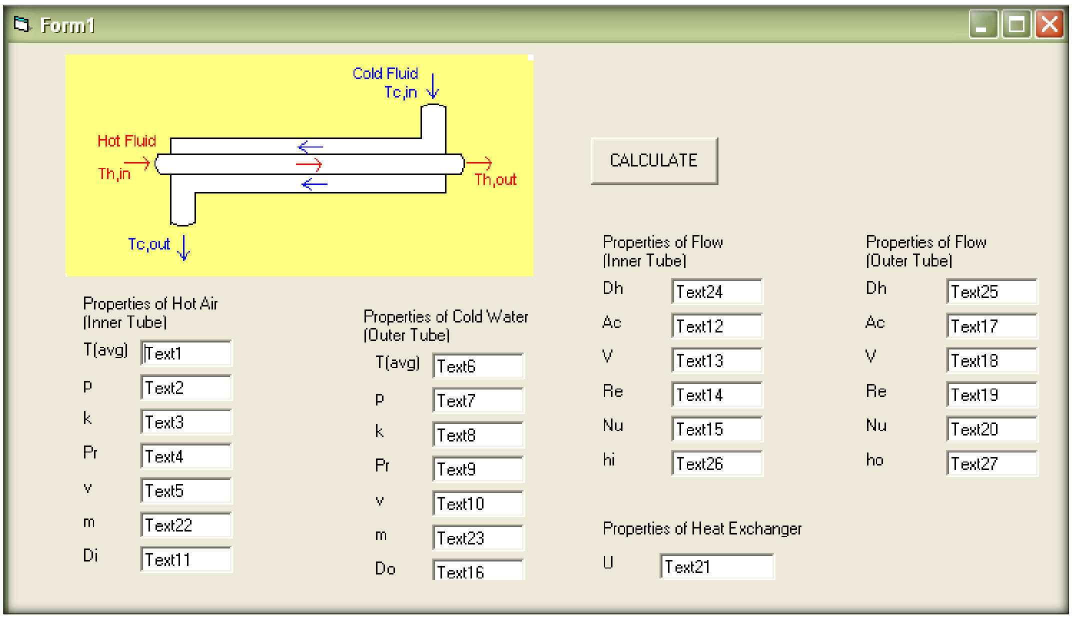


Figure 3.3: Heat Exchanger Double Pipe Calculator 1

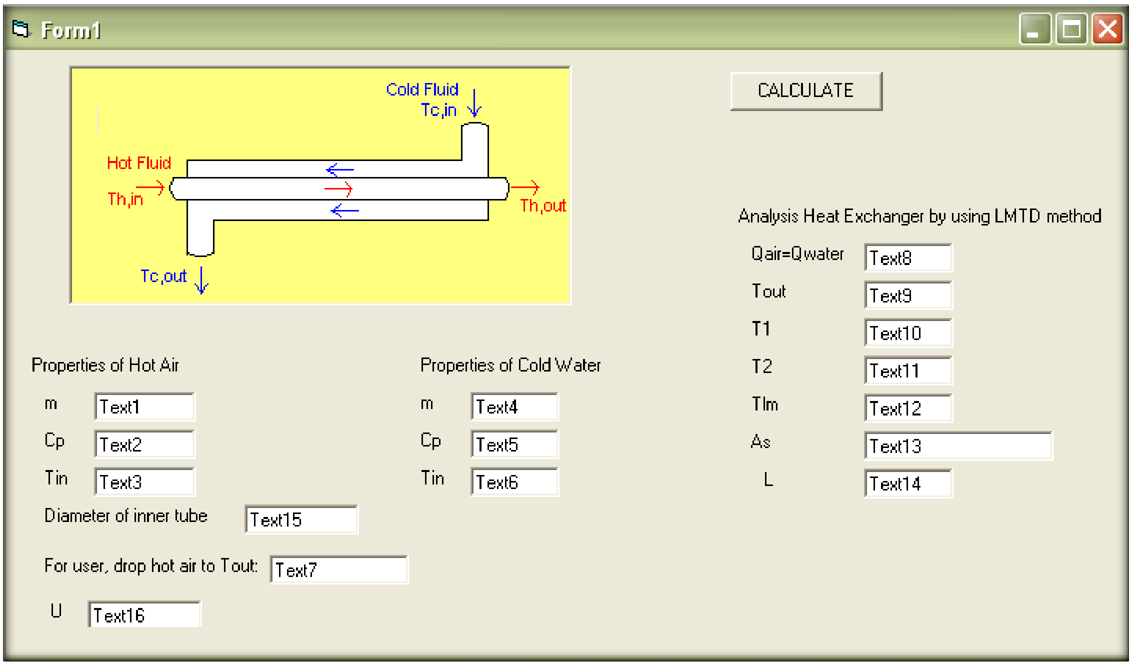


Figure 3.4: Heat Exchanger Double Pipe Calculator 2

3.4 SPECIFIED TEMPERATURE AND FLOW RATE OF HEAT EXCHANGER

For this project, the hot air from car engine bay where absorbed by the filter as shown in Figure 3.5 want to cooling down by using the water. For the average hot air temperature, $T_{h,avg}$ where measured from operation of the car around 15 minute is 50°C. While for the average cold water temperature, $T_{c,avg}$ where measured from the normal temperature of water pipe is 30°C. For the hot air, the mass flow rate, m_h is 0.222 kg/s. While, for the mass flow rate of cold water, m_c is 0.249 kg/s.

Figure 3.5: Car engine bay

3.5 CHOOSE THE MATERIAL FOR HEAT EXCHANGER

To compare and identify engineering materials, it is important to understand the meaning of their common properties such as heat properties. Heat conductivity is the ability of a material to conduct heat. Metals are good conductors of heat and non-metals are poor conductor of heat. From figure 3.3, inner tube of heat exchanger are required the best of metals for conducting since it has high thermal conductivity. For outer tube of the heat exchanger, it is required the poor conductor of heat such as wood or plastic but for the construction of heat exchanger, we should used metal that has low thermal conductivity since it can resisted high pressure. From Table A.1 in Appendix A and the market survey, the best material for this double tube heat exchanger is the commercial bronze copper since this type of copper is using for construction of air-condition. This type of copper has 52W/m.K of thermal conductivity. This copper tube is suitable for inner tube to exchange the heat between cold water and hot air. While for outer tube, the suitable material is AISI 304 Stainless Steel since this type of metal is using for exhaust car piping and can resisted high pressure of water. This type of Stainless Steel has 14.9 W/m.K of thermal conductivity.

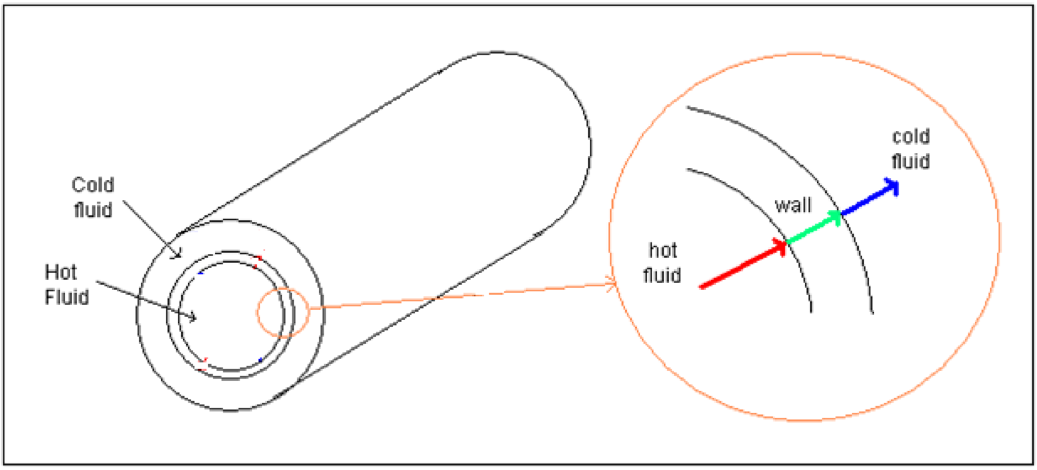


Figure 3.6: Double tube heat exchanger

Source: Yunus (2006)

3.6 SIMULATED HEAT EXCHANGER DESIGN WITH MICROSOFT VISUAL BASIC 6.0

After get the mass flow rate and average temperature for hot air and cold water, we key in all parameter of hot air and cold water in Microsoft Visual Basic 6.0 calculator and we get the result as shown in Table 3.2 by using parameter below:

$T_{h,avg}$ = 50°C $T_{c,avg}$ = 30°C

m_h = 0.222 kg/s m_c = 0.249kg/s

$T_{h,in}$ = 70°C $T_{h,out}$ = 35°C $T_{c,in}$ = 30°C

Table 3.1: Design of heat exchanger

Design	Inlet diameter of inner tube, Di (m)	Outer diamete r of outer tube, Do (m)	Overall heat transfer coefficient , U (W/m.K)	Total length of heat exchanger , L (m)
1	0.025	0.050	485.790	0.800
2	0.050	0.076	186.237	0.930
3	0.064	0.076	146.992	0.920
4	0.076	0.089	108.997	1.045

3.7 CHOOSE THE DESIGN

After calculated the all parameter such as the overall heat transfer coefficient and the length of heat exchanger based diameter of inner tube and outer tube, from Table 3.2, the design is choose from the tube that has short length since the heat exchanger is required more compact since Hairpin heat exchanger style is used. From the result, Design 1 is the best where 0.800m of total length with the inlet diameter of inner tube is 0.025m and the outer tube diameter of outer tube is 0.050m.

3. 8 THE HEAT EXCHANGER DESGN BASED ON TEMA SPECIFICATION

After choose the best design based on all the parameter, the heat exchanger is drawing by using Solidwork based on TEMA specification such in Figure 3.7, Figure 3.8 and Figure 3.9. For this project, the double tube heat exchanger drawing is based on Hairpin heat exchanger such in Figure 3.6. since it is more compacted. Hairpin heat exchangers are characterized by a construction form which imparts a U-shaped appearance to the heat exchanger. In its classical sense, the term double pipe refers to a heat exchanger consisting of a pipe within a pipe, usually of a straight-leg construction with no bends. However, due to the need for removable bundle construction and the ability to handle differential thermal expansion while avoiding the use of expansion joints (often the weak point of the exchanger), the current U-shaped configuration has become the standard in the industry. A further departure from the classical definition comes when more than one pipe or tube is used to make a tube bundle, complete with tube sheets and tube supports similar to the TEMA style exchanger. From Figure 3.7, type E is choosing for the tube. From Figure 3.8, for the end of the heat exchanger, type A and B are choosing. From 3.9, for connection of tube to tube, type U is choosing. From the parameters that given in Design, the final result is produced as shown in Figure 3.1 and for the dimension involved is shown Appendices B.2.

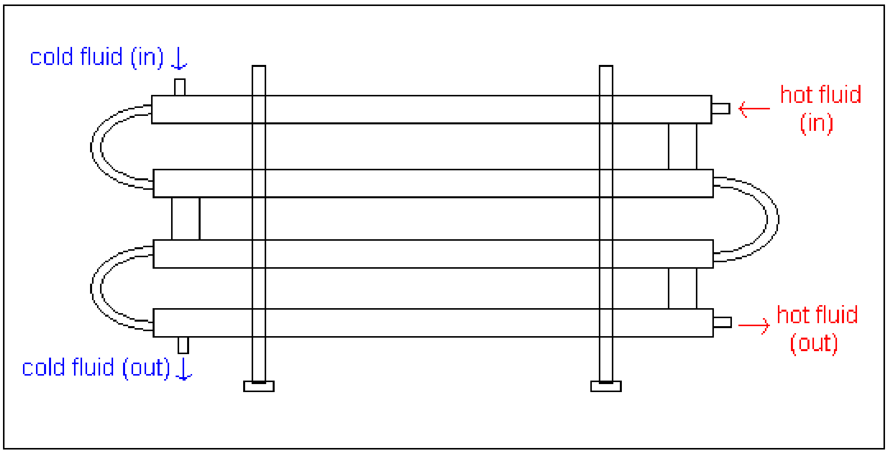


Figure 3.7: Hairpin heat exchanger

Source: Schlunder (1982)

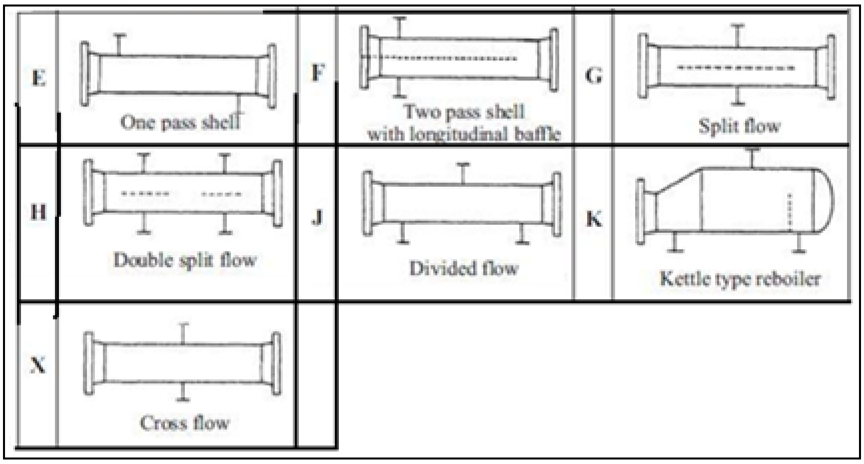


Figure 3.8: Shell Type

Source: Schlunder (1982)

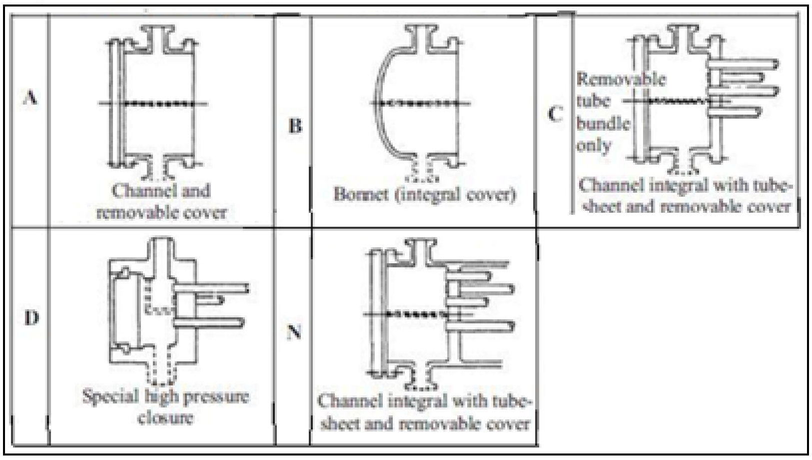


Figure 3.9: Front End Stationary Head Type

Source: Schlunder (1982)

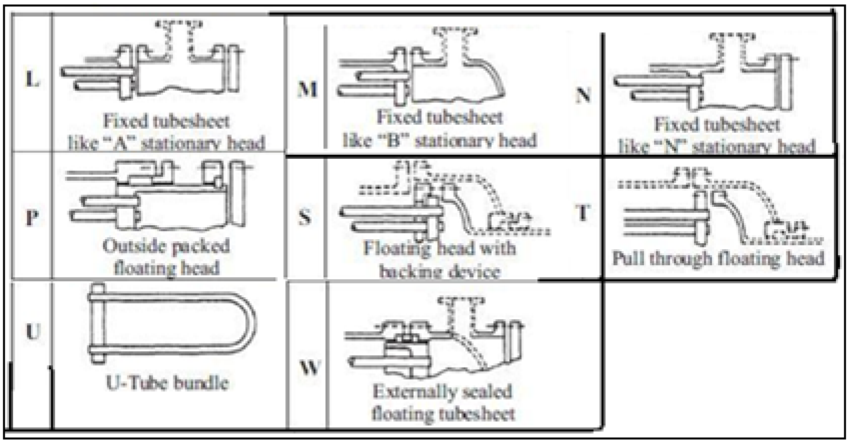


Figure 3.10: Rear End Head Type

Source: Schlunder (1982)

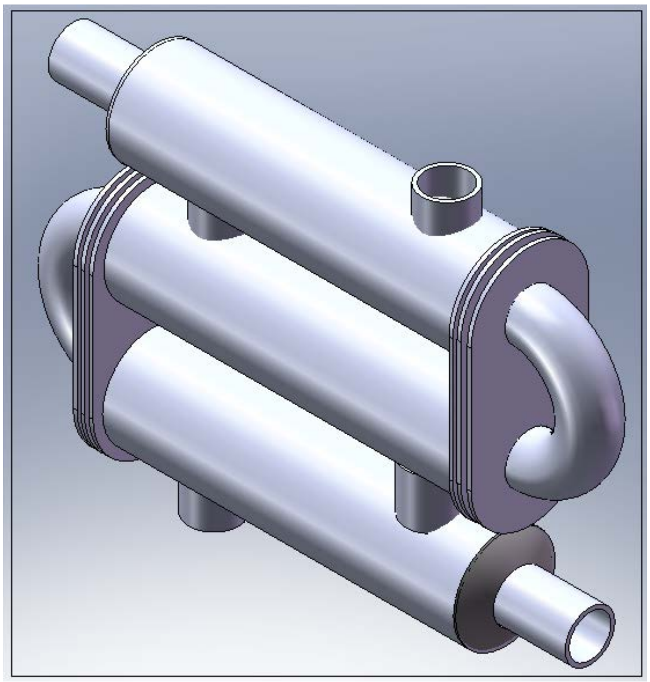


Figure 3.11: Heat exchanger drawing

CHAPTER 4

FABRICATION

4.1 INTRODUCTION

In this chapter, the heat exchanger is fabricated by following methods that state clearly in this chapter based on Solidwork drawing as shown in Figure B.2 in Appendix B. The fabrication of heat exchanger is involved measurement process where the parameters involve in the design should be precise in order to achieve best cooling process. For this fabrication, the fabrication process is performed part by part which started with part of Shell, Front End Stationary Head and Rear End Head.

4.2 SAWING THE TUBE METAL

To cutting the material for the heat exchanger tube, we required sawing process to cut the material according the length of tube, L. For sawing process, we can use hacksaw as shown in figure 3.10 which use manually by hand or power hacksaw as shown in Figure 3.11 which generated by machine. To use the hacksaw for cutting the tube of heat exchanger, we should follow this instruction:

i. The teeth of the blade should face the direction of cut and the blade should be correctly tension.
ii. The rate of sawing should not exceed 50 to 60 strokes per minute.
iii. Always start a new cut with new blade.

While for power hacksaw for fast cutting the tube of heat exchanger, we should follow this instruction:

i. A coolant should always be used to keep the blade cool and to flush away the chips.

ii. The work piece should be securely fastened in the machine vice before cutting (Roger, 2008).

Figure 4.1: Hacksaw

Source: Roger (2008)

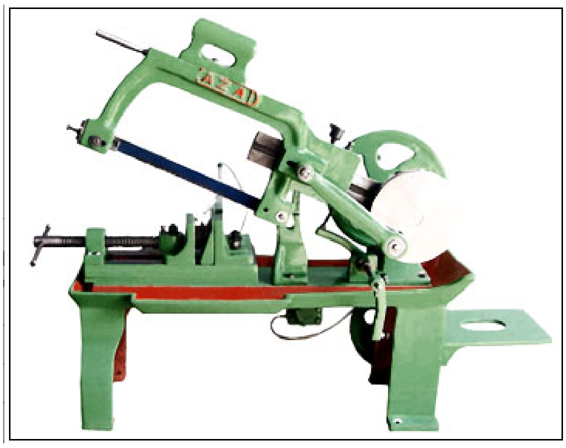


Figure 4.2: Power Hacksaw

Source: Roger (2008)

4.3 FLAME-CUTTING THE PLATE METAL

Since we cannot use to drill the big diameter of hole of plate, we can use flame-cutting as shown in Figure 3.12. It can be used for cutting plain carbon steel since the process depends upon a chemical reaction between the hot steel and a stream of high pressure oxygen (Roger, 2008). Despite its appearance a set of flame-cutting equipment is not same as welding equipment although it looks similar. It provides a ring of flames to preheat the metal being cut to 870-900°C. When the metal reaches this ignition temperature, a powerful jet of pure oxygen is released into the centre of the preheated area. The oxidizing reaction help to heat up the metal being cut and the process become continuous.

Figure 4.3: Flame cutting equipment

Source: Roger (2008)

4.4 OXY-ACETYLENE WELDING

To join the tube and other part, we are required the welding process. The type of welding that suitable with stainless steel and copper tube is oxy-acetylene welding as shown in Figure 3.13 since the oxy-fuel flame provides the heat required at high enough temperature to melt most engineering materials in common use (Roger, 2008).

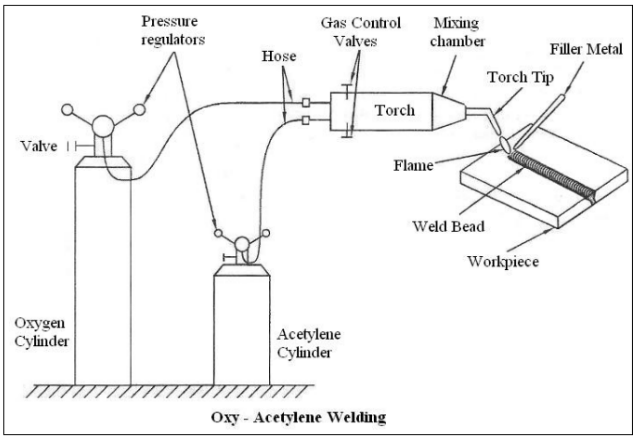


Figure 4.4: Oxy-acetylene welding

Source: Roger (2008)

4.5 DRILLING SHEET METAL

For rear end of the plate heat exchanger, we required to make the hole on the steel plate. So we can use portable electric machine to drill the small hole for bolt and nut. Besides that, we can use the bench drilling machine as shown in Figure 3.14 to saving our time. It is capable of accepting drills up to 0.5 inch diameter (Roger, 2008).

Figure 4.5: The Bench Drilling Machine

Source: Roger (2008)

4.6 SHELL PART

From Figure 4.1, we start fabricated the heat exchanger with sawing 0.0604 m diameter of the stainless pipe by 1m for 3 units and the copper tube by 1m for 1 unit and 1.15m for 2 unit as shown in Figure 4.2 and drill the hole with 0.02m in each side . Next, we use flame cutting to make 0.0504 m diameter of hole on 4 steel plate and drill 16 holes with 0.005 m diameter as shown in Figure 4.3 and filling it. Then, we are used oxy-acetylene welding to join the stainless pipe, copper tube, 0.02m diameter of metal pipe with the plate as shown in Figure 4.4 and 4.5.

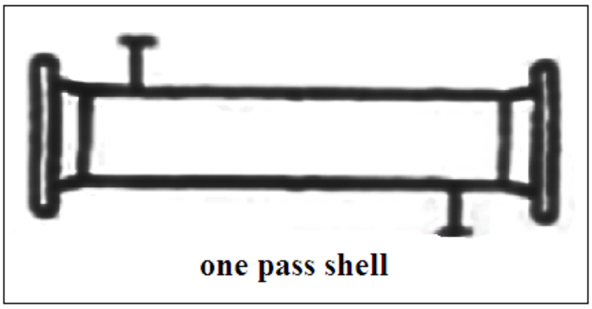


Figure 4.6: Shell (TEMA)

Source: Schlunder (1982)

Figure 4.7: Sawing on stainless steel pipe

Source: Roger (2008)

Figure 4.8: Flame cutting result

Figure 4.9: Welding on steel plate and stainless steel pipe

Figure 4.10: Welding on stainless steel pipe and small steel pipe

4.7 REAR END HEAD PART

From Figure 4.6, we use oxy-acetylene welding with copper rod to join two of the copper junction tube with the steel plate as shown in Figure 4.7.

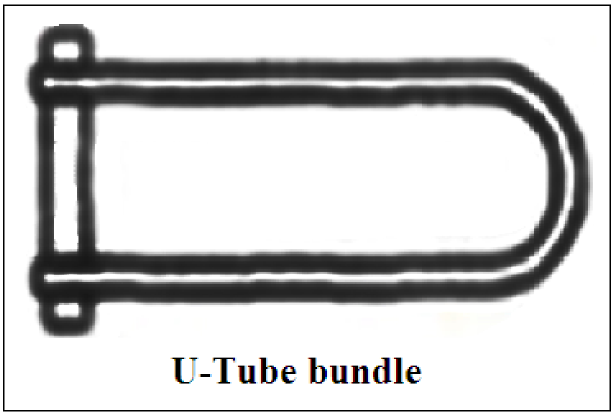


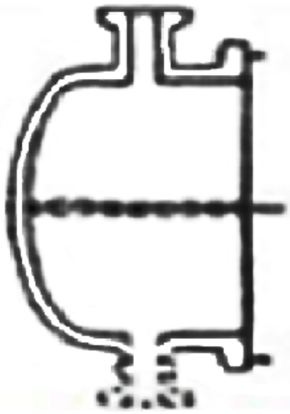
Figure 4.11: Rear end head (TEMA)

Source: Schlunder (1982)

Figure 4.12: Rear end head part

4.8 FRONT END STATIONARY HEAD

From Figure 4.8, we use we use oxy-acetylene welding with copper rod to join the small chamber steel with the end of stainless steel pipe as shown in Figure 4.9.



Bonnet (integral cover)

Figure 4.13: Front End Stationary Head

Source: Schlunder (1982)

Figure 4.14: Rear end head welding

4.9 ASSEMBLY THE PARTS

After all of the parts are finished for fabrication process, we want to assemble all the part by using bolt and nut as shown in Figure 4.10.

Figure 4.15: Heat exchanger assembly

4.10 AIR/WATER TEST FOR HEAT EXCHANGER

After assembly of heat exchanger is finished, we want to check lacking of the heat exchanger by using the air and water as shown in Figure 4.11. This process is important for both fluid flows in the copper tube and stainless steel pipe in order to make sure the both fluid is out through the lacking.

Figure 4.16: Heat exchanger air/water test

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 INTRODUCTION

For this chapter, the experiment is conducted to test the design of double tube heat exchanger. The design is tested by using hot air gun to produce hot air where need to be cooling down by cold water. The all parameter that involved in this design including the inlet and outlet temperature of hot air and cold water and also the mass flow rate of both fluids are analyzed. From the experiment, we make comparison the results based on their parameter that is manipulated.

5.2 EXPERIMENT OF HEAT EXCHANGER

After fabrication processes of heat exchanger are finished, the experiment has conducted to analyze the design of heat exchanger. The experiment is conducted based on this procedure:

1) All of apparatus including heat exchanger, hair dryer, thermometers and piping system are set up as shown in Figure 3.15.
2) The valve of pipe is fully opened and the flow rate of water is measured by using 1 liter container over the time.
3) Speed 1 of the hair dryer is turn ON and the flow rate of air is measured.
4) The thermometers are reading based on time and the inlet and outlet temperature are fill in Table 5.3.
5) Step 1 to 4 are repeated by using small flow rate of water and high flow rate of air by using speed 2 of hair dryer.

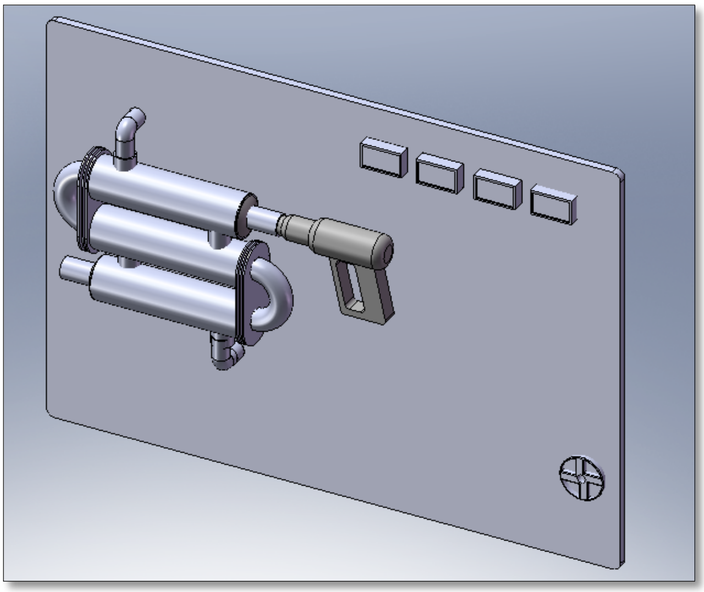


Figure 5.1: Apparatus configuration

5.3 EXPERIMENT RESULT

The results are shown in Table 5.1 and Table 5.2. From the result, the small difference between outlet and inlet temperature for cold water is increase just around 0.5°C but the big difference in inlet and outlet temperature for hot air which drop around 30°C at time of 65 minute. For comparison between Table 5.1 and 5.2, when high flow rate of water is used from 0.00008(m^3/s) to 0.00025(m^3/s) with constant air flow rate 0.0013(m^3/s), the outlet hot air is drop fast. For example, at time of 30 minute, hot air drop from 49.1°C to 33.8°C where 15.3°C for initially flow rate of water and hot air drop from 49.4°C to 33.5°C where 15.9°C after increase the flow rate of water.

Table 5.1: Flow rate and temperature reading (1)

Hot air flow	V_h =0.0013(m³/s)		m_h =0.0014(kg/s)	
Cold water flow	V_c =0.00008(m³/s)		m_c =0.07968(kg/s)	
Time (s)	$T_{h,in}$ (°C)	$T_{h,out}$ (°C)	$T_{c,in}$ (°C)	$T_{c,out}$ (°C)
5	30.9	29.6	29.9	29.4
10	36.3	30.8	29.9	29.5
15	39.4	31.2	29.8	29.6
20	41.7	32.4	29.8	29.7
25	45.5	32.5	29.8	29.7
30	49.1	33.8	29.7	29.8
35	53.5	34.6	29.8	29.8
40	56.2	34.4	29.7	29.8
45	57.4	34.5	29.7	29.8
50	59.3	35.4	29.4	29.6
55	60.2	35.6	29.0	29.1
60	61.7	35.5	29.4	29.6
65	67.7	36.9	29.0	29.1

Table 5.2: Flow rate and temperature reading (2)

Hot air flow	V_h =0.0013(m³/s)		m_h =0.0014(kg/s)	
Cold water flow	V_c =0.00025(m³/s)		m_c =0.249(kg/s)	
Time (s)	$T_{h,in}$ (°C)	$T_{h,out}$ (°C)	$T_{c,in}$ (°C)	$T_{c,out}$ (°C)
5	31.3	29.3	29.3	29.5
10	33.9	30.9	29.4	29.6
15	36.2	31.9	29.6	29.5
20	40.5	32.0	29.7	29.3
25	46.4	32.3	29.9	29.2
30	49.4	33.5	29.9	29.3
35	51.0	34.0	29.8	29.3
40	53.1	34.2	29.5	29.3
45	55.2	34.4	29.7	29.3
50	57.2	35.5	29.5	29.4
55	59.5	35.5	29.5	29.5
60	60.3	35.6	29.5	29.6
65	61.7	35.5	29.4	29.6

5.4 EXPERIMENT ANALYSIS

For heat exchanger, the analysis is used Log Mean Temperature Difference (LMTD) where the all equation which involved is rearranged. The arrangement and choosing of the equations are shown below. After that, Table 5.4 and Table 5.4 are constructed to find heat transfer rate, Q and Log Mean Temperature Difference, ΔT_{lm} by using Equation 5.2 to 5.5. After get the result, heat transfer rate, Q and Log Mean Temperature Difference, ΔT_{lm} is plotted as shown in Figure 5.2 and 5.3. From the graph as shown in Figure 5.2 and 5.3, the gradient of graph is found to get the overall transfer coefficient as shown in Table 5.5. From the result which shown in Table 5.5, the overall transfer coefficient is increased from 7.404 U(W/m².°C) to 7.484 U(W/m².°C) when water flow rate, m_c is increased as shown in Equation 5.8 to 5.10.

$$A_s = \pi DL \tag{5.1}$$

$$Q = m_h C_{ph} (T_{h,in} - T_{h,out}) \tag{5.2}$$

$$\Delta T_1 = T_{h,in} - T_{c,out} \tag{5.3}$$

$$\Delta T_2 = T_{h,out} - T_{c,in} \tag{5.4}$$

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 \Delta T_2)} \tag{5.5}$$

$$\frac{Q}{\Delta T_{lm}} = m(graph - gradient) \tag{5.7}$$

$$U = \frac{1}{A_s} \frac{Q}{\Delta T_{lm}} \tag{5.8}$$

$$U = \frac{1}{A_s} \frac{m_c C_{pc} (T_{c,out} - T_{c,in})}{\Delta T_{lm}} \tag{5.9}$$

$$U \ \alpha \ m_c \tag{5.10}$$

Table 5.3: Analysis of heat exchanger (1)

Hot air flow	V_h=0.0013(m³/s) m_h=0.0014(kg/s)				
Cold water flow	V_c=0.00008(m³/s) m_c=0.07968(kg/s)				
Time (s)	$T_{h,in}-T_{h,out}$ (°C)	$Q(w)$	ΔT_1(°C)	ΔT_2(°C)	ΔT_{lm}(°C)
5	1.3	1.832	1.5	-0.3	0
10	5.5	7.754	6.8	0.9	2.917
15	8.2	11.560	9.8	1.4	4.137
20	9.3	13.111	12	2.6	6.146
25	13	18.327	15.8	2.7	7.415
30	15.3	21.570	19.3	4.1	9.812
35	18.9	26.645	23.7	4.8	11.836
40	21.8	30.734	26.4	4.7	12.574
45	22.9	32.284	27.6	4.8	13.035
50	23.9	33.694	29.7	6.0	14.818
55	24.6	34.681	31.1	6.6	15.805
60	26.2	36.937	32.1	6.1	15.657
65	30.8	43.422	38.6	7.9	19.352

Table 5.4: Analysis of heat exchanger (2)

Hot air flow	V_h =0.0013(m³/s) m_h =0.0014(kg/s)				
Cold water flow	V_c =0.00025 (m³/s) m_c =0.249 (kg/s)				
Time (s)	$T_{h,in} - T_{h,out}$ (°C)	$Q(w)$	ΔT_1 (°C)	ΔT_2 (°C)	ΔT_{lm} (°C)
5	2	2.820	1.8	0	0
10	3	4.229	4.3	1.5	2.659
15	4.3	6.062	6.7	2.3	4.115
20	8.5	11.983	11.2	2.3	5.622
25	14.1	19.878	17.2	2.4	7.515
30	15.9	22.416	20.1	3.6	9.594
35	17	23.967	21.7	4.2	10.656
40	18.9	26.645	23.8	4.7	11.775
45	20.8	29.324	25.9	4.7	12.422
50	21.7	30.593	27.8	6.0	14.218
55	24.0	33.835	30.0	6.0	14.912
60	24.7	34.822	30.7	6.1	15.223
65	26.2	36.937	32.1	6.1	15.657

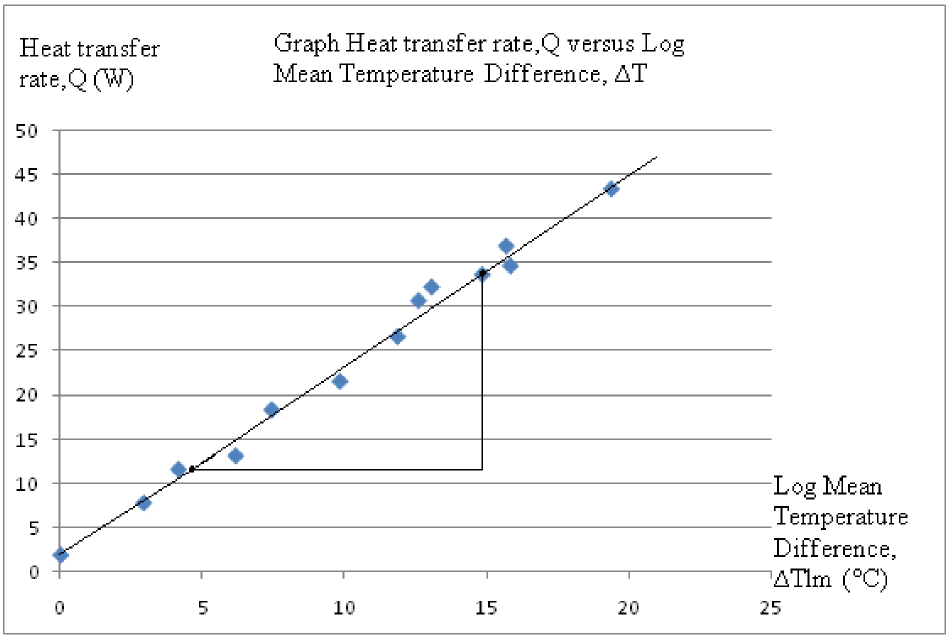


Figure 5.2: Graph heat transfer rate versus Log Mean Temperature Difference (1)

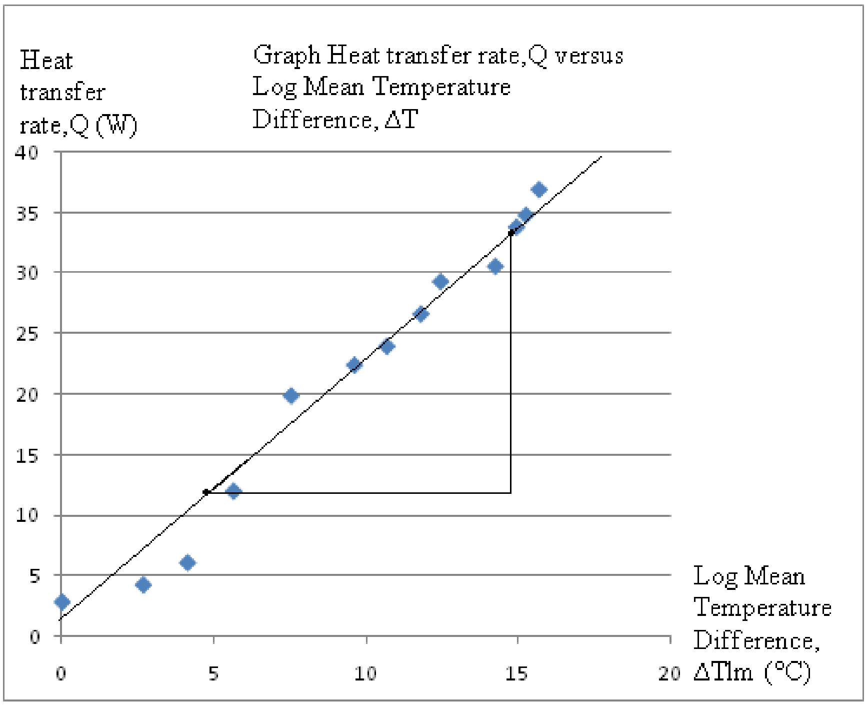


Figure 5.3: Graph heat transfer rate versus Log Mean Temperature Difference (2)

Table 5.5: Result of the overall transfer coefficient

Cold water flow rate, m_c (kg/s)	0.07968	
A_s (m²)	$\frac{Q}{\Delta T_{lm}} = m$(W/°C) $(graph - gradient)$	U(W/m².°C)
0.0628	0.465	7.404
Cold water flow rate, m_c (kg/s)	0.249	
A_s (m²)	$\frac{Q}{\Delta T_{lm}} = m$(W/°C) $(graph - gradient)$	U(W/m².°C)
0.0628	0.470	7.484

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.2 CONCLUSIONS

From the research, the objectives is achieve where study about heat transfer analysis in heat exchanger and to design the heat exchanger based on TEMA specification. Based on this research, when size of inlet and outer tube of double pipe heat exchanger is minimum, it is produced large overall heat transfer coefficient while when size of inlet and outer tube of double pipe heat exchanger is minimum, it is produced small in length of heat exchanger and suitable for compact heat exchanger. Moreover, when thermal conductivity of inlet tube of heat exchanger is maximized, it can produce high heat transfer between both fluids. Beside that, when cold fluid flow rate is maximum, it is produced fast drop in of hot fluid. Lastly, TEMA specification can produce the best design of double tube heat exchanger design.

6.3 RECOMMENDATIONS

The recommendations to improve this study are:

i. Study again about double tube heat exchanger design by using recycled of cold fluid since we are maintained the inlet of cold fluid temperature.
ii. Use small radiator in water to air heat exchanger for move application such a vehicle since the cold fluid is recycled.

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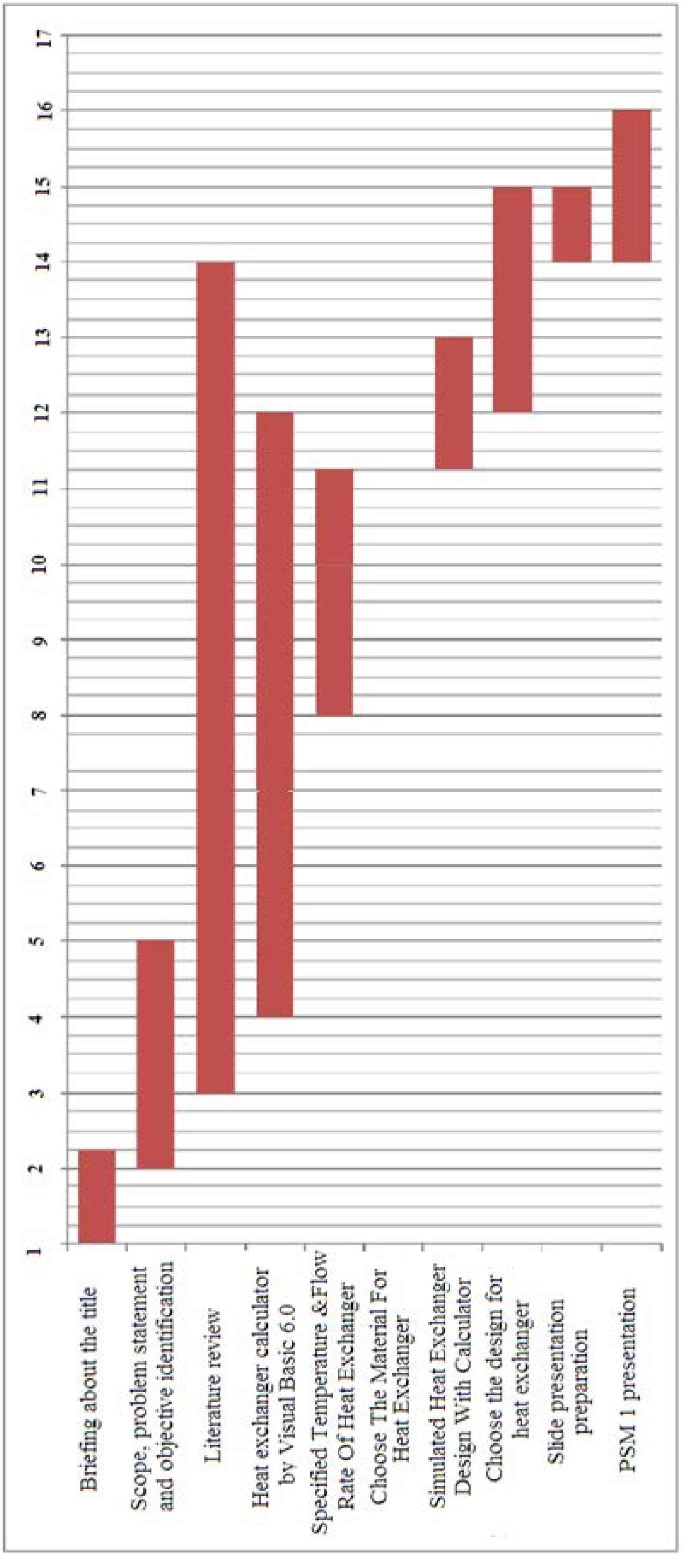
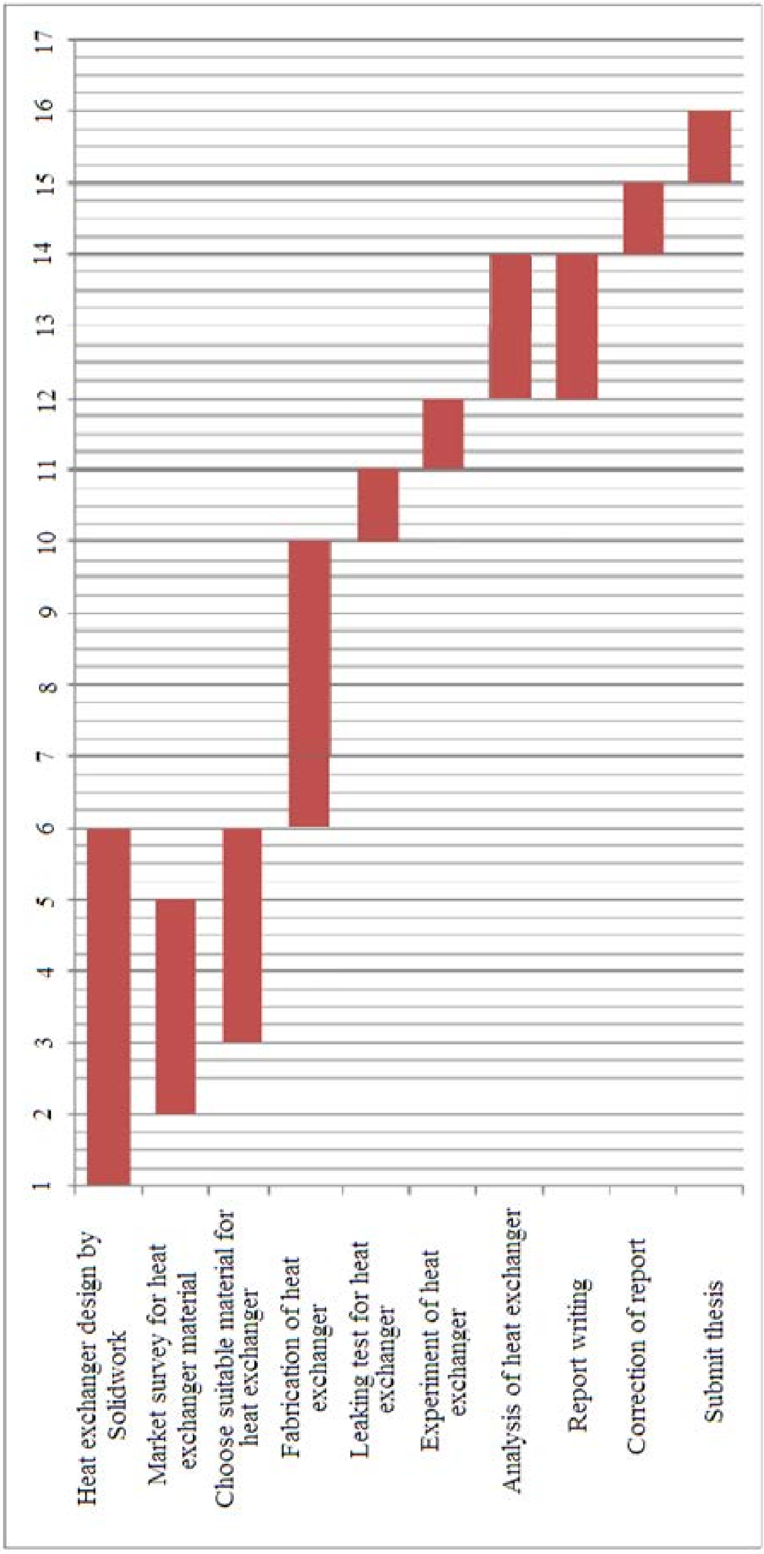
APPENDIX A

Gantt Chart PSM 1



APPENDIX B

Gantt Chart PSM 2



APPENDIX C

Properties of solid metal

Properties of solid metals

Composition	Melting Point, K	Properties at 300 K: ρ kg/m³	c_p J/kg · K	k W/m · K	$\alpha \times 10^6$ m²/s	Properties at Various Temperatures (K), k(W/m · K)/c_p(J/kg · K): 100	200	400	600	800	1000
Aluminum:											
Pure	933	2702	903	237	97.1	302	237	240	231	218	
						482	798	949	1033	1146	
Alloy 2024-T6 (4.5% Cu, 1.5% Mg, 0.6% Mn)	775	2770	875	177	73.0	65	163	186	186		
						473	787	925	1042		
Alloy 195, Cast (4.5% Cu)		2790	883	168	68.2			174	185		
Beryllium	1550	1850	1825	200	59.2	990	301	161	126	106	90.8
						203	1114	2191	2604	2823	3018
Bismuth	545	9780	122	7.86	6.59	16.5	9.69	7.04			
						112	120	127			
Boron	2573	2500	1107	27.0	9.76	190	55.5	16.8	10.6	9.60	9.85
						128	600	1463	1892	2160	2338
Cadmium	594	8650	231	96.8	48.4	203	99.3	94.7			
						198	222	242			
Chromium	2118	7160	449	93.7	29.1	159	111	90.9	80.7	71.3	65.4
						192	384	484	542	581	616
Cobalt	1769	8862	421	99.2	26.6	167	122	85.4	67.4	58.2	52.1
						236	379	450	503	550	628
Copper:											
Pure	1358	8933	385	401	117	482	413	393	379	366	352
						252	356	397	417	433	451
Commercial bronze (90% Cu, 10% Al)	1293	8800	420	52	14		42	52	59		
							785	160	545		
Phosphor gear bronze (89% Cu, 11% Sn)	1104	8780	355	54	17		41	65	74		
							—	—	—		
Cartridge brass (70% Cu, 30% Zn)	1188	8530	380	110	33.9	75	95	137	149		
							360	395	425		
Constantan (55% Cu, 45% Ni)	1493	8920	384	23	6.71	17	19				
						237	362				
Germanium	1211	5360	322	59.9	34.7	232	96.8	43.2	27.3	19.8	17.4
						190	290	337	348	357	375
Gold	1336	19,300	129	317	127	327	323	311	298	284	270
						109	124	131	135	140	145
Iridium	2720	22,500	130	147	50.3	172	153	144	138	132	126
						90	122	133	138	144	153
Iron:											
Pure	1810	7870	447	80.2	23.1	134	94.0	69.5	54.7	43.3	32.8
						216	384	490	574	680	975
Armco (99.75% pure)		7870	447	72.7	20.7	95.6	80.6	65.7	53.1	42.2	32.3
						215	384	490	574	680	975
Carbon steels:											
Plain carbon (Mn ≤ 1% Si ≤ 0.1%)		7854	434	60.5	17.7			56.7	48.0	39.2	30.0
								487	559	685	1169
AISI 1010		7832	434	63.9	18.8			58.7	48.8	39.2	31.3
							487	559	685	1168	
Carbon–silicon (Mn ≤ 1% 0.1% < Si ≤ 0.6%)		7817	446	51.9	14.9			49.8	44.0	37.4	29.3
								501	582	699	971

Properties of solid metals *(Continued)*

Composition	Melting Point, K	Properties at 300 K: ρ kg/m^3	c_p J/kg · K	k W/m · K	$\alpha \times 10^6$ m^2/s	Properties at Various Temperatures (K), k(W/m · K)/c_p(J/kg · K): 100	200	400	600	800	1000
Carbon–manganese–silicon (1% < Mn < 1.65% 0.1% < Si < 0.6%)		8131	434	41.0	11.6			42.2 487	39.7 559	35.0 685	27.6 1090
Chromium (low) steels:											
$\frac{1}{2}$ Cr–$\frac{1}{4}$ Mo–Si (0.18% C, 0.65% Cr, 0.23% Mo, 0.6% Si)		7822	444	37.7	10.9			38.2 492	36.7 575	33.3 688	26.9 969
1 Cr–$\frac{1}{2}$ Mo (0.16% C, 1% Cr, 0.54% Mo, 0.39% Si)		7858	442	42.3	12.2			42.0 492	39.1 575	34.5 688	27.4 969
1 Cr–V (0.2% C, 1.02% Cr, 0.15% V)		7836	443	48.9	14.1			46.8 492	42.1 575	36.3 688	28.2 969
Stainless steels:											
AISI 302		8055	480	15.1	3.91			17.3 512	20.0 559	22.8 585	25.4 606
AISI 304	1670	7900	477	14.9	3.95	9.2 272	12.6 402	16.6 515	19.8 557	22.6 582	25.4 611
AISI 316		8238	468	13.4	3.48			15.2 504	18.3 550	21.3 576	24.2 602
AISI 347		7978	480	14.2	3.71			15.8 513	18.9 559	21.9 585	24.7 606
Lead	601	11,340	129	35.3	24.1	39.7 118	36.7 125	34.0 132	31.4 142		
Magnesium	923	1740	1024	156	87.6	169 649	159 934	153 1074	149 1170	146 1267	
Molybdenum	2894	10,240	251	138	53.7	179 141	143 224	134 261	126 275	118 285	112 295
Nickel:											
Pure	1728	8900	444	90.7	23.0	164 232	107 383	80.2 485	65.6 592	67.6 530	71.8 562
Nichrome (80% Ni, 20% Cr)	1672	8400	420	12	3.4			14 480	16 525	21 545	
Inconel X-750 (73% Ni, 15% Cr, 6.7% Fe)	1665	8510	439	11.7	3.1	8.7 —	10.3 372	13.5 473	17.0 510	20.5 546	24.0 626
Niobium	2741	8570	265	53.7	23.6	55.2 188	52.6 249	55.2 274	58.2 283	61.3 292	64.4 301
Palladium	1827	12,020	244	71.8	24.5	76.5 168	71.6 227	73.6 251	79.7 261	86.9 271	94.2 281
Platinum:											
Pure	2045	21,450	133	71.6	25.1	77.5 100	72.6 125	71.8 136	73.2 141	75.6 146	78.7 152
Alloy 60Pt–40Rh (60% Pt, 40% Rh)	1800	16,630	162	47	17.4			52 —	59 —	65 —	69 —
Rhenium	3453	21,100	136	47.9	16.7	58.9 97	51.0 127	46.1 139	44.2 145	44.1 151	44.6 156
Rhodium	2236	12,450	243	150	49.6	186 147	154 220	146 253	136 274	127 293	121 311

Properties of solid metals *(Concluded)*

Composition	Melting Point, K	*Properties at 300 K* ρ kg/m^3	c_p J/kg · K	k W/m · K	$\alpha \times 10^6$ m^2/s	*Properties at Various Temperatures* (K), k(W/m · K)/c_p(J/kg · K) 100	200	400	600	800	1000
Silicon	1685	2330	712	148	89.2	884 259	264 556	98.9 790	61.9 867	42.4 913	31.2 946
Silver	1235	10,500	235	429	174	444 187	430 225	425 239	412 250	396 262	379 277
Tantalum	3269	16,600	140	57.5	24.7	59.2 110	57.5 133	57.8 144	58.6 146	59.4 149	60.2 152
Thorium	2023	11,700	118	54.0	39.1	59.8 99	54.6 112	54.5 124	55.8 134	56.9 145	56.9 156
Tin	505	7310	227	66.6	40.1	85.2 188	73.3 215	62.2 243			
Titanium	1953	4500	522	21.9	9.32	30.5 300	24.5 465	20.4 551	19.4 591	19.7 633	20.7 675
Tungsten	3660	19,300	132	174	68.3	208 87	186 122	159 137	137 142	125 146	118 148
Uranium	1406	19,070	116	27.6	12.5	21.7 94	25.1 108	29.6 125	34.0 146	38.8 176	43.9 180
Vanadium	2192	6100	489	30.7	10.3	35.8 258	31.3 430	31.3 515	33.3 540	35.7 563	38.2 597
Zinc	693	7140	389	116	41.8	117 297	118 367	111 402	103 436		
Zirconium	2125	6570	278	22.7	12.4	33.2 205	25.2 264	21.6 300	20.7 332	21.6 342	23.7 362

From Frank P. Incropera and David P. DeWitt, *Fundamentals of Heat and Mass Transfer, 3rd ed.*, 1990. This material is used by permission of John Wiley & Sons, Inc.

APPENDIX D

Properties of solid nonmetal

Properties of solid nonmetals

Composition	Melting Point, K	ρ kg/m³	c_p J/kg · K	k W/m · K	$\alpha \times 10^6$ m²/s	100	200	400	600	800	1000
		Properties at 300 K				*Properties at Various Temperatures (K), k (W/m · K)/c_p(J/kg · K)*					
Aluminum oxide, sapphire	2323	3970	765	46	15.1	450 —	82 —	32.4 940	18.9 1110	13.0 1180	10.5 1225
Aluminum oxide, polycrystalline	2323	3970	765	36.0	11.9	133 —	55 —	26.4 940	15.8 1110	10.4 1180	7.85 1225
Beryllium oxide	2725	3000	1030	272	88.0			196 1350	111 1690	70 1865	47 1975
Boron	2573	2500	1105	27.6	9.99	190 —	52.5 —	18.7 1490	11.3 1880	8.1 2135	6.3 2350
Boron fiber epoxy (30% vol.) composite	590	2080									
k, ∥ to fibers				2.29		2.10	2.23	2.28			
k, ⊥ to fibers				0.59		0.37	0.49	0.60			
c_p			1122			364	757	1431			
Carbon											
Amorphous	1500	1950	—	1.60	—	0.67 —	1.18 —	1.89 —	21.9 —	2.37 —	2.53 —
Diamond, type IIa insulator	—	3500	509	2300		10,000 21	4000 194	1540 853			
Graphite, pyrolytic	2273	2210									
k, ∥ to layers				1950		4970	3230	1390	892	667	534
k, ⊥ to layers				5.70		16.8	9.23	4.09	2.68	2.01	1.60
c_p			709			136	411	992	1406	1650	1793
Graphite fiber epoxy (25% vol.) composite	450	1400									
k, heat flow ∥ to fibers				11.1		5.7	8.7	13.0			
k, heat flow ⊥ to fibers				0.87	0.46	0.68	1.1				
c_p			935			337	642	1216			
Pyroceram, Corning 9606	1623	2600	808	3.98	1.89	5.25 —	4.78 —	3.64 908	3.28 1038	3.08 1122	2.96 1197
Silicon carbide	3100	3160	675	490	230			— 880	— 1050	— 1135	87 1195
Silicon dioxide, crystalline (quartz)	1883	2650									
k, ∥ to c-axis				10.4		39	16.4	7.6	5.0	4.2	
k, ⊥ to c-axis				6.21		20.8	9.5	4.70	3.4	3.1	
c_p			745			—	—	885	1075	1250	
Silicon dioxide, polycrystalline (fused silica)	1883	2220	745	1.38	0.834	0.69 —	1.14 —	1.51 905	1.75 1040	2.17 1105	2.87 1155
Silicon nitride	2173	2400	691	16.0	9.65	— —	— 578	13.9 778	11.3 937	9.88 1063	8.76 1155
Sulfur	392	2070	708	0.206	0.141	0.165 403	0.185 606				
Thorium dioxide	3573	9110	235	13	6.1			10.2 255	6.6 274	4.7 285	3.68 295
Titanium dioxide, polycrystalline	2133	4157	710	8.4	2.8			7.01 805	5.02 880	8.94 910	3.46 930

APPENDIX E

Properties of saturated water

Properties of saturated water

Temp. T, °C	Saturation Pressure P_{sat}, kPa	Density ρ, kg/m³ Liquid	Density ρ, kg/m³ Vapor	Enthalpy of Vaporization h_{fg}, kJ/kg	Specific Heat c_p, J/kg · K Liquid	Specific Heat c_p, J/kg · K Vapor	Thermal Conductivity k, W/m · K Liquid	Thermal Conductivity k, W/m · K Vapor	Dynamic Viscosity μ, kg/m · s Liquid	Dynamic Viscosity μ, kg/m · s Vapor	Prandtl Number Pr Liquid	Prandtl Number Pr Vapor	Volume Expansion Coefficient β, 1/K Liquid
0.01	0.6113	999.8	0.0048	2501	4217	1854	0.561	0.0171	1.792×10^{-3}	0.922×10^{-5}	13.5	1.00	-0.068×10^{-3}
5	0.8721	999.9	0.0068	2490	4205	1857	0.571	0.0173	1.519×10^{-3}	0.934×10^{-5}	11.2	1.00	0.015×10^{-3}
10	1.2276	999.7	0.0094	2478	4194	1862	0.580	0.0176	1.307×10^{-3}	0.946×10^{-5}	9.45	1.00	0.733×10^{-3}
15	1.7051	999.1	0.0128	2466	4185	1863	0.589	0.0179	1.138×10^{-3}	0.959×10^{-5}	8.09	1.00	0.138×10^{-3}
20	2.339	998.0	0.0173	2454	4182	1867	0.598	0.0182	1.002×10^{-3}	0.973×10^{-5}	7.01	1.00	0.195×10^{-3}
25	3.169	997.0	0.0231	2442	4180	1870	0.607	0.0186	0.891×10^{-3}	0.987×10^{-5}	6.14	1.00	0.247×10^{-3}
30	4.246	996.0	0.0304	2431	4178	1875	0.615	0.0189	0.798×10^{-3}	1.001×10^{-5}	5.42	1.00	0.294×10^{-3}
35	5.628	994.0	0.0397	2419	4178	1880	0.623	0.0192	0.720×10^{-3}	1.016×10^{-5}	4.83	1.00	0.337×10^{-3}
40	7.384	992.1	0.0512	2407	4179	1885	0.631	0.0196	0.653×10^{-3}	1.031×10^{-5}	4.32	1.00	0.377×10^{-3}
45	9.593	990.1	0.0655	2395	4180	1892	0.637	0.0200	0.596×10^{-3}	1.046×10^{-5}	3.91	1.00	0.415×10^{-3}
50	12.35	988.1	0.0831	2383	4181	1900	0.644	0.0204	0.547×10^{-3}	1.062×10^{-5}	3.55	1.00	0.451×10^{-3}
55	15.76	985.2	0.1045	2371	4183	1908	0.649	0.0208	0.504×10^{-3}	1.077×10^{-5}	3.25	1.00	0.484×10^{-3}
60	19.94	983.3	0.1304	2359	4185	1916	0.654	0.0212	0.467×10^{-3}	1.093×10^{-5}	2.99	1.00	0.517×10^{-3}
65	25.03	980.4	0.1614	2346	4187	1926	0.659	0.0216	0.433×10^{-3}	1.110×10^{-5}	2.75	1.00	0.548×10^{-3}
70	31.19	977.5	0.1983	2334	4190	1936	0.663	0.0221	0.404×10^{-3}	1.126×10^{-5}	2.55	1.00	0.578×10^{-3}
75	38.58	974.7	0.2421	2321	4193	1948	0.667	0.0225	0.378×10^{-3}	1.142×10^{-5}	2.38	1.00	0.607×10^{-3}
80	47.39	971.8	0.2935	2309	4197	1962	0.670	0.0230	0.355×10^{-3}	1.159×10^{-5}	2.22	1.00	0.653×10^{-3}
85	57.83	968.1	0.3536	2296	4201	1977	0.673	0.0235	0.333×10^{-3}	1.176×10^{-5}	2.08	1.00	0.670×10^{-3}
90	70.14	965.3	0.4235	2283	4206	1993	0.675	0.0240	0.315×10^{-3}	1.193×10^{-5}	1.96	1.00	0.702×10^{-3}
95	84.55	961.5	0.5045	2270	4212	2010	0.677	0.0246	0.297×10^{-3}	1.210×10^{-5}	1.85	1.00	0.716×10^{-3}
100	101.33	957.9	0.5978	2257	4217	2029	0.679	0.0251	0.282×10^{-3}	1.227×10^{-5}	1.75	1.00	0.750×10^{-3}
110	143.27	950.6	0.8263	2230	4229	2071	0.682	0.0262	0.255×10^{-3}	1.261×10^{-5}	1.58	1.00	0.798×10^{-3}
120	198.53	943.4	1.121	2203	4244	2120	0.683	0.0275	0.232×10^{-3}	1.296×10^{-5}	1.44	1.00	0.858×10^{-3}
130	270.1	934.6	1.496	2174	4263	2177	0.684	0.0288	0.213×10^{-3}	1.330×10^{-5}	1.33	1.01	0.913×10^{-3}
140	361.3	921.7	1.965	2145	4286	2244	0.683	0.0301	0.197×10^{-3}	1.365×10^{-5}	1.24	1.02	0.970×10^{-3}
150	475.8	916.6	2.546	2114	4311	2314	0.682	0.0316	0.183×10^{-3}	1.399×10^{-5}	1.16	1.02	1.025×10^{-3}
160	617.8	907.4	3.256	2083	4340	2420	0.680	0.0331	0.170×10^{-3}	1.434×10^{-5}	1.09	1.05	1.145×10^{-3}
170	791.7	897.7	4.119	2050	4370	2490	0.677	0.0347	0.160×10^{-3}	1.468×10^{-5}	1.03	1.05	1.178×10^{-3}
180	1,002.1	887.3	5.153	2015	4410	2590	0.673	0.0364	0.150×10^{-3}	1.502×10^{-5}	0.983	1.07	1.210×10^{-3}
190	1,254.4	876.4	6.388	1979	4460	2710	0.669	0.0382	0.142×10^{-3}	1.537×10^{-5}	0.947	1.09	1.280×10^{-3}
200	1,553.8	864.3	7.852	1941	4500	2840	0.663	0.0401	0.134×10^{-3}	1.571×10^{-5}	0.910	1.11	1.350×10^{-3}
220	2,318	840.3	11.60	1859	4610	3110	0.650	0.0442	0.122×10^{-3}	1.641×10^{-5}	0.865	1.15	1.520×10^{-3}
240	3,344	813.7	16.73	1767	4760	3520	0.632	0.0487	0.111×10^{-3}	1.712×10^{-5}	0.836	1.24	1.720×10^{-3}
260	4,688	783.7	23.69	1663	4970	4070	0.609	0.0540	0.102×10^{-3}	1.788×10^{-5}	0.832	1.35	2.000×10^{-3}
280	6,412	750.8	33.15	1544	5280	4835	0.581	0.0605	0.094×10^{-3}	1.870×10^{-5}	0.854	1.49	2.380×10^{-3}
300	8,581	713.8	46.15	1405	5750	5980	0.548	0.0695	0.086×10^{-3}	1.965×10^{-5}	0.902	1.69	2.950×10^{-3}
320	11,274	667.1	64.57	1239	6540	7900	0.509	0.0836	0.078×10^{-3}	2.084×10^{-5}	1.00	1.97	
340	14,586	610.5	92.62	1028	8240	11,870	0.469	0.110	0.070×10^{-3}	2.255×10^{-5}	1.23	2.43	
360	18,651	528.3	144.0	720	14,690	25,800	0.427	0.178	0.060×10^{-3}	2.571×10^{-5}	2.06	3.73	
374.14	22,090	317.0	317.0	0	—	—	—	—	0.043×10^{-3}	4.313×10^{-5}			

Note 1: Kinematic viscosity ν and thermal diffusivity α can be calculated from their definitions, $\nu = \mu/\rho$ and $\alpha = k/\rho c_p = \nu/\text{Pr}$. The temperatures 0.01°C, 100°C, and 374.14°C are the triple-, boiling-, and critical-point temperatures of water, respectively. The properties listed above (except the vapor density) can be used at any pressure with negligible error except at temperatures near the critical-point value.

Note 2: The unit kJ/kg · °C for specific heat is equivalent to kJ/kg · K, and the unit W/m · °C for thermal conductivity is equivalent to W/m · K.

Source: Viscosity and thermal conductivity data are from J. V. Sengers and J. T. R. Watson, *Journal of Physical and Chemical Reference Data* 15 (1986), pp. 1291–1322. Other data are obtained from various sources or calculated.

APPENDIX F

Properties of air at 1 atm pressure

Properties of air at 1 atm pressure

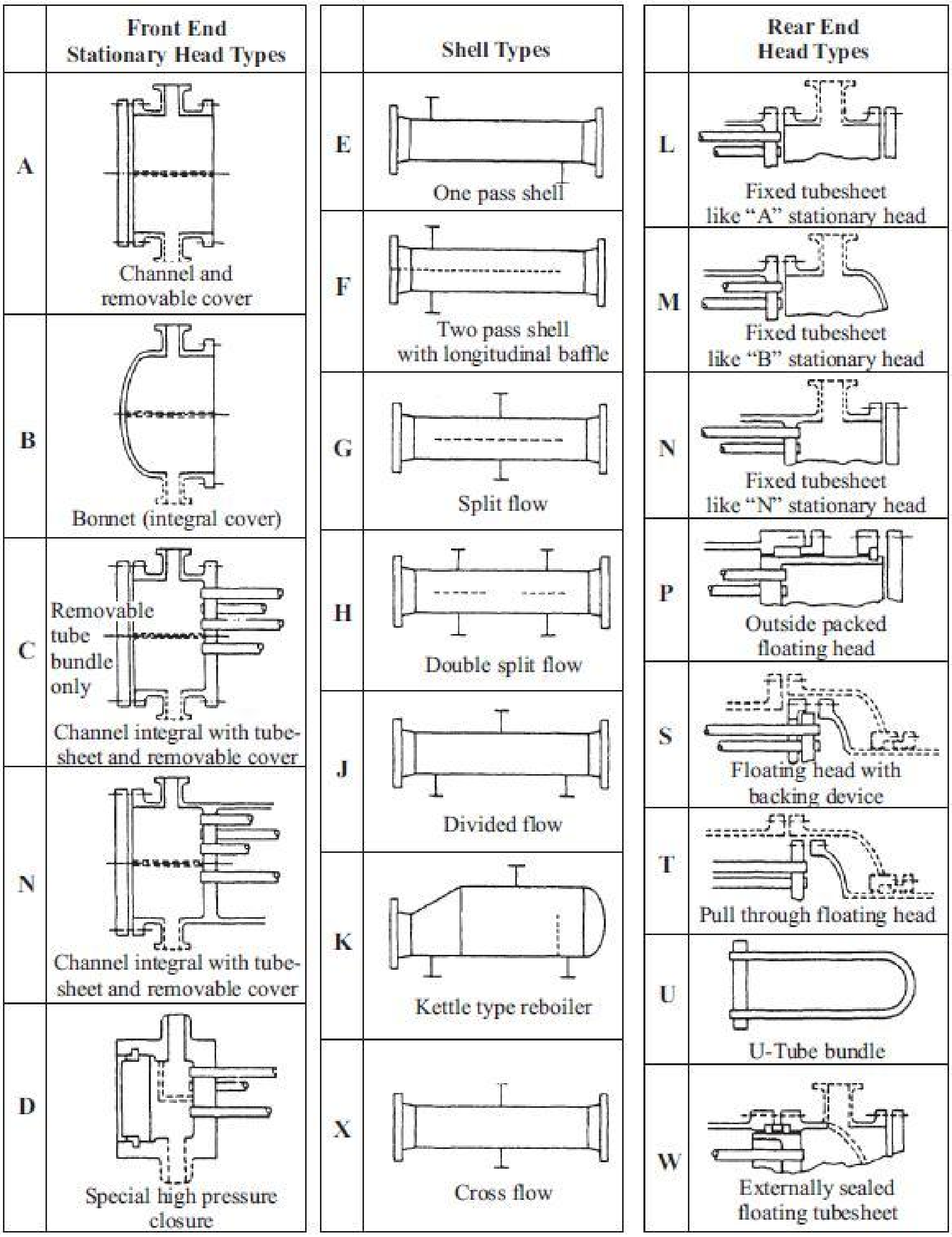
Temp. T, °C	Density ρ, kg/m³	Specific Heat c_p, J/kg · K	Thermal Conductivity k, W/m · K	Thermal Diffusivity α, m²/s²	Dynamic Viscosity μ, kg/m · s	Kinematic Viscosity ν, m²/s	Prandtl Number Pr
−150	2.866	983	0.01171	4.158×10^{-6}	8.636×10^{-6}	3.013×10^{-6}	0.7246
−100	2.038	966	0.01582	8.036×10^{-6}	1.189×10^{-5}	5.837×10^{-6}	0.7263
−50	1.582	999	0.01979	1.252×10^{-5}	1.474×10^{-5}	9.319×10^{-6}	0.7440
−40	1.514	1002	0.02057	1.356×10^{-5}	1.527×10^{-5}	1.008×10^{-5}	0.7436
−30	1.451	1004	0.02134	1.465×10^{-5}	1.579×10^{-5}	1.087×10^{-5}	0.7425
−20	1.394	1005	0.02211	1.578×10^{-5}	1.630×10^{-5}	1.169×10^{-5}	0.7408
−10	1.341	1006	0.02288	1.696×10^{-5}	1.680×10^{-5}	1.252×10^{-5}	0.7387
0	1.292	1006	0.02364	1.818×10^{-5}	1.729×10^{-5}	1.338×10^{-5}	0.7362
5	1.269	1006	0.02401	1.880×10^{-5}	1.754×10^{-5}	1.382×10^{-5}	0.7350
10	1.246	1006	0.02439	1.944×10^{-5}	1.778×10^{-5}	1.426×10^{-5}	0.7336
15	1.225	1007	0.02476	2.009×10^{-5}	1.802×10^{-5}	1.470×10^{-5}	0.7323
20	1.204	1007	0.02514	2.074×10^{-5}	1.825×10^{-5}	1.516×10^{-5}	0.7309
25	1.184	1007	0.02551	2.141×10^{-5}	1.849×10^{-5}	1.562×10^{-5}	0.7296
30	1.164	1007	0.02588	2.208×10^{-5}	1.872×10^{-5}	1.608×10^{-5}	0.7282
35	1.145	1007	0.02625	2.277×10^{-5}	1.895×10^{-5}	1.655×10^{-5}	0.7268
40	1.127	1007	0.02662	2.346×10^{-5}	1.918×10^{-5}	1.702×10^{-5}	0.7255
45	1.109	1007	0.02699	2.416×10^{-5}	1.941×10^{-5}	1.750×10^{-5}	0.7241
50	1.092	1007	0.02735	2.487×10^{-5}	1.963×10^{-5}	1.798×10^{-5}	0.7228
60	1.059	1007	0.02808	2.632×10^{-5}	2.008×10^{-5}	1.896×10^{-5}	0.7202
70	1.028	1007	0.02881	2.780×10^{-5}	2.052×10^{-5}	1.995×10^{-5}	0.7177
80	0.9994	1008	0.02953	2.931×10^{-5}	2.096×10^{-5}	2.097×10^{-5}	0.7154
90	0.9718	1008	0.03024	3.086×10^{-5}	2.139×10^{-5}	2.201×10^{-5}	0.7132
100	0.9458	1009	0.03095	3.243×10^{-5}	2.181×10^{-5}	2.306×10^{-5}	0.7111
120	0.8977	1011	0.03235	3.565×10^{-5}	2.264×10^{-5}	2.522×10^{-5}	0.7073
140	0.8542	1013	0.03374	3.898×10^{-5}	2.345×10^{-5}	2.745×10^{-5}	0.7041
160	0.8148	1016	0.03511	4.241×10^{-5}	2.420×10^{-5}	2.975×10^{-5}	0.7014
180	0.7788	1019	0.03646	4.593×10^{-5}	2.504×10^{-5}	3.212×10^{-5}	0.6992
200	0.7459	1023	0.03779	4.954×10^{-5}	2.577×10^{-5}	3.455×10^{-5}	0.6974
250	0.6746	1033	0.04104	5.890×10^{-5}	2.760×10^{-5}	4.091×10^{-5}	0.6946
300	0.6158	1044	0.04418	6.871×10^{-5}	2.934×10^{-5}	4.765×10^{-5}	0.6935
350	0.5664	1056	0.04721	7.892×10^{-5}	3.101×10^{-5}	5.475×10^{-5}	0.6937
400	0.5243	1069	0.05015	8.951×10^{-5}	3.261×10^{-5}	6.219×10^{-5}	0.6948
450	0.4880	1081	0.05298	1.004×10^{-4}	3.415×10^{-5}	6.997×10^{-5}	0.6965
500	0.4565	1093	0.05572	1.117×10^{-4}	3.563×10^{-5}	7.806×10^{-5}	0.6986
600	0.4042	1115	0.06093	1.352×10^{-4}	3.846×10^{-5}	9.515×10^{-5}	0.7037
700	0.3627	1135	0.06581	1.598×10^{-4}	4.111×10^{-5}	1.133×10^{-4}	0.7092
800	0.3289	1153	0.07037	1.855×10^{-4}	4.362×10^{-5}	1.326×10^{-4}	0.7149
900	0.3008	1169	0.07465	2.122×10^{-4}	4.600×10^{-5}	1.529×10^{-4}	0.7206
1000	0.2772	1184	0.07868	2.398×10^{-4}	4.826×10^{-5}	1.741×10^{-4}	0.7260
1500	0.1990	1234	0.09599	3.908×10^{-4}	5.817×10^{-5}	2.922×10^{-4}	0.7478
2000	0.1553	1264	0.11113	5.664×10^{-4}	6.630×10^{-5}	4.270×10^{-4}	0.7539

Note: For ideal gases, the properties c_p, k, μ, and Pr are independent of pressure. The properties ρ, ν, and α at a pressure P (in atm) other than 1 atm are determined by multiplying the values of ρ at the given temperature by P and by dividing ν and α by P.

Source: Data generated from the EES software developed by S. A. Klein and F. L. Alvarado. Original sources: Keenan, Chao, Keyes, Gas Tables, Wiley, 198; and Thermophysical Properties of Matter. Vol. 3: Thermal Conductivity, Y. S. Touloukian, P. E. Liley, S. C. Saxena, Vol. 11: Viscosity, Y. S. Touloukian, S. C. Saxena, and P. Hestermans, IFI/Plenun, NY, 1970, ISBN 0-306067020-8.

APPENDIX G

TEMA Specification for Tubular Heat Exchanger



APPENDIX H

Solidwork Drawing of Double Pipe Heat Exchanger