STUDY ON HEAT EXCHANGER FOR STEAM GENERATOR FROM WASTE HEAT

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

STUDY ON HEAT EXCHANGER FOR STEAM GENERATOR FROM WASTE HEAT

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A report submitted in fulfilment of the requirement for the degree of Bachelor of Mechanical Engineering (Thermal & Fluid)

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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DECLARATION

I declare that this project report entitled "Study on Heat Exchanger for Steam Generator from waste heat" is the result of my own work except as cited in the references.

Signature : ....

Name of Supervisor : ....

Date : ....

PENGAKUAN

Saya akui laporan ini yang bertajuk “Kajian penukar haba untuk penjana stim dari haba sisa” adalah hasil kerja saya sendiri kecuali yang dipetik daripada sumber rujukan.

Tandatangan :...................................

Nama :...................................

Tarikh :...................................

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Thermal & Fluid).

Signature :.................................

Supervisor's Name :.................................

Date :.................................

PENGESAHAN PENYELIA

Saya akui bahawa telah membaca laporan ini dan pada pandangan saya laporan ini adalah memadai dari segi skop dan kualiti untuk tujuan penganugerahan Ijazah Sarjana Muda Kejuruteraan Mekanikal (Thermal & Bendalir)

Tandatangan :..................................

Nama Penyelia :..................................

Tarikh :..................................

DEDICATION

To my beloved mother and father.

DEDIKASI

Khas buat

Ayah dan Ibu tersayang.

ABSTRACT

In this modern era, motor vehicles are rapidly increase which cause global warming by expelling carbon dioxide gas, carbon monoxide gas and etc. In order to overcome this phenomenon, new motor vehicle technology should be introduced. So that, the purpose of the research is to determine the optimal performance of heat exchanger as steam generator for waste heat recovery. Eventually, current motor vehicle's engine energy flow from fuel to internal combustion engine and produce thermal energy. The thermal energy will be transfer to exhaust system. Without realize, a lot of wasted energy has been lost when engine start running and the efficiency of the engine has been decrease. Thus, a mechanical invention system which is heat exchanger are used to convert waste heat energy to heat recovery energy. The heat exchanger plays a significant role by absorb the heat produce by the engine exhaust system and convert the liquid into steam. So that, the recovery energy is the high temperature that expelled from exhaust system. As a result, the energy source help to produce electrical power and keep the engine running warm. Through this study, a steam generator mechanism has been developed in interest to utilize the wasted energy from exhaust system of engine.

ABSTRAK

Di zaman moden ini, peningkatan kenderaan bermotor menyebabkan pemanasan global dengan membuang gas karbon dioksida, gas karbon monoksida dan lain-lain. Dalam usaha untuk mengatasi fenomena ini, teknologi baru dalam kenderaan bermotor harus diperkenalkan. Tujuan kajian ini adalah untuk menentukan prestasi penukar haba sebagai penjana stim pemulihan haba sisa. Biasanya, aliran tenaga enjin dalam kenderaan bermotor mula daripada bahan api ke enjin pembakaran dalaman dan menghasilkan tenaga haba. Tenaga haba yang dihasilkan itu akan dipindahkan ke sistem ekzos. Tanpa disedari, banyak tenaga sia-sia telah hilang apabila enjin mula berfunsi dan kecekapan enjin juga akan menurun. Oleh itu, sistem ciptaan mekanikal iaitu penukar haba digunakan untuk menukarkan tenaga haba sisa kepada tenaga haba pemulihan. Penukar haba memainkan peranan penting dengan menyerap haba yang dikeluar daripada sistem ekzos enjin dan menukar cecair menjadi stim. Di samping itu,suhu tinggi yang dikeluarkan oleh sistem ekzos adalah tenaga pemulihan. Akhirnya, kuasa elektrik telah dihasilkan daripada bantuan sumber tenaga kuasa dan menjalankan enjin dengan baik. Melalui kajian ini, satu mekanisme penjana stim telah dihasilkan untuk menukar haba sisa yang keluar daripada sistem ekzos enjin ke haba pemulihan.

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3D	Three dimensional
ICE	Internal Combustion Engine
TEMA	Tubular Exchanger Manufacturers Association Community
Cu	Copper
℃	Degree Celcius
PSM	Projek Sarjana Muda
mPa	Mega-Pascal
CAD	Computer Aided Diagram
Σ	Summation
Hz	Frequency
W	Watt
V	Volt
min	Minutes
ϵ	Effectiveness
ηp	Pump Efficiency
$\dot{m}$	Mass flow rate
Cp	Constant specific heat capacity
ΔTh	Temperature difference of hot stream

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The issue of global warming has pushed the effort of researchers not only to find alternative renewable energy, but also to improve performance of machines in order to save energy. This includes the utilization of waste energy into 'useful energy'. Once heat losses are minimised, investing in waste heat recovery can yield significant energy savings. The higher the temperature, the higher the quality and the more cost effective the heat recovery will be. (BCS, Incorporated 2008). Moreover, just 15 percent of the energy from the fuel we put in conventional vehicle is utilized to move your car down the road depending on the drive cycle or it used to run useful accessories, for example air conditioning heater and etc. (Jadhoa Js, T.D , 2013). The rest of the energy is lost to engine and used to power accessories. There are many technology developed to improve fuel efficiency one of it is by using back the waste heat produced. There are three main components used to create this recovery system such as heat exchanger, steam turbine and generator.

Heat exchanger is a device that is used for transfer thermal energy between two or more fluid, between a solid surface and a fluid, or between solid particulates and a fluid, at differing temperatures. Normally, heat exchanger related to two different temperature of streams which are hot stream and cold stream. (M.Seifert, and J.Ringler, 2013).

The heat transfer surface is a surface of the exchanger core that is in direct contact with fluids and through which heat is transferred by conduction. To increase heat transfer are, appendages known as fins may be intimately connected to the primary surface to provide extended, secondary or indirect surface. Thus, the addition of fins reduce the thermal resistance. The heat transfer coefficient can also be higher for fins. (R.K.Shah and D.P Sekulic, 2009).

1.2 PROBLEM STATEMENT

The rapidly increase of motor vehicles globally increase the usage of petroleum and also increase of carbon dioxide in the atmosphere which can cause global warming. As to overcome this phenomenon, new motor vehicles technology should be introduced without increasing harmful emissions. Internal combustion engine in most typical gasoline fuelled vehicles, which mostly used in passenger car, it was approximated that 21% of the fuel energy is wasted through the exhaust. (R.E.Chammas and D.Clodic, 2005). The remaining heat is expelled to the environment through exhaust gases and engine cooling system. It means estimate 60 to 70% energy losses as a waste heat through exhaust. Therefore an interest to utilize the wasted energy by developing a heat recovery mechanism of exhaust gas from internal combustion engine with the aim that it will increase the efficiency of the engine. The energy from the exhaust gas can be make use to supply an extra power source for vehicles and theoretically proven that it also can be an overall reduction in greenhouse gas emission.

1.3 OBJECTIVES

The objectives of this project are as follows:

Objective 1

-The first objective for this project is to design a new heat exchanger mechanism to optimize the waste heat that implemented in the vehicle.

Objective 2

-The second objective is to determine the performance of the heat exchanger of waste heat recovery system.

1.4 SCOPE OF PROJECT

In this research, the result will be conduct experimentally and also will be analysed and interpret. Below are the scope of the project:

a) Based on objective 1, my scope of project is:

   -To study the material properties of heat exchanger using CES Edu pack software.

   - To design a new heat exchanger by using Solid Work software

b) Based on objective 2, my scope of project is:

   -To determine the performance analysis for the heat exchanger (new and current) in term of ability to absorb heat.

   - To determine the rate of heat transfer and effectiveness of the heat exchanger.

1.5 GENERAL METHODOLOGY

Simulation and experimental progress were carried out to achieve the objectives and the scopes in this project. The purpose of this simulation is to give better understanding on the ability of heat exchanger to absorb the heat.

First, find the material data that need to design the heat exchanger by using CES Edu pack. Choose the best material by understanding the material properties and compare the materials. CES Edupack is a solitary set of teaching resources that support Materials Education across Engineering Design and Sustainable Development. The CES Edupack software also provides engaging ways to explore and understand the world of material. The three main characteristics of this software are it is very familiar with material space, it can visualize the properties using charting tools, and also can match the materials to application for better understanding.

Next, design a new heat exchanger by using SolidWork software. SolidWork is a solid modelling computer-aided design (CAD) and computer aided engineering (CAE) that covers all aspects of your product development process with a seamless, integrated workflow, sustainable design. Engineers can span multiple disciplines with ease, shortening the design cycle and delivering innovative products. It is a dedicated software for modelling and has the following characteristics:

a) **3D CAD** – Draw in 3d view and quickly transform into new ideas.
b) **Visualization** – Design the model faster by turning imagination into reality.

Next, conduct an experiment to collect data regarding the performance of the heat exchanger as steam generator. The experimental work will be conducted in several condition with variety of inputs such as engine speed, vehicle speed, and number of passengers. Moreover the analysis also will be carry on to improve the performance of the steam generator. Based on the results, do comparison between new and current heat exchanger to determine the best heat exchanger with the ability of good absorb of heat. At last, a report writing for this project will be written at the end of this project.

CHAPTER II

LITERATURE REVIEW

This chapter will explain about the literature reviews that have been done to guide the research in the future. Based on that, a lot of theories and definition could be found in this literature review in order to improve application of heat exchanger. This chapter was ongoing process throughout the project to obtain more knowledge and skill to complete this project. In addition, furthermore source of references were gain from book, thesis and journals.

2.1 ENERGY LOSSES IN VEHICLES

A vehicle need around 15 percentage of energy from the fuel to move the car down on the road or use for function other accessories. (U.S Department of Energy, 2014). The rest of the energy from the fuel is lost to engine, driveline inefficiencies and idling. Therefore, the remaining energy that produced from the fuel can be reused or recycled back for usage of other accessories and thus can increasing the performance of the engine. Besides that, in gasoline powered vehicles, 68 to 72 percentage of fuel's energy is lost in the internal combustion engine (ICE). ICE engines are considered as very inefficient in converting the fuel's chemical energy to mechanical energy, losing energy to engine friction, and wasted heat (U.S Department of Energy, 2014). Moreover, in urban driving significant energy is lost due to idling at stop lights or in traffic. Current technologies help to reduce these losses by automatically turning the engine off when the vehicle comes to a stop and restarting it instantaneously when the accelerator is pressed (Consumer Energy Center, 2014).

2.2 HEAT EXCHANGER

A heat exchanger is a device that is used to transfer or exchange thermal energy which know as enthalpy between two or more fluids, between a solid surface and fluid, or between solid particles and a fluid, at different temperatures and in thermal contact. It means that the heat exchanger is a piece of equipment built for one medium to another of two different fluid to be exchange the heat transfer properties. (shah, 2015). In addition, the most well-known type of heat exchanger is an automobile radiator, which used to transfer heat from a fluid on one side wall to a fluid on the other side without bringing the fluid into direct contact. This process helps to keep a car's engine from overheating by the solution of antifreeze to exchange the heat from the engine to the radiator and then to ambient air flowing through it. (D.Denkenberger, M.Parisi, 2014). There are many different types of heat exchanger available and the most important is to understand the mechanical function and operate of the heat exchanger. The function of heat exchanger are to heat a cooler fluid by using a hotter fluid, to minimize the temperature of hot fluid, to condense a gaseous fluid and etc.

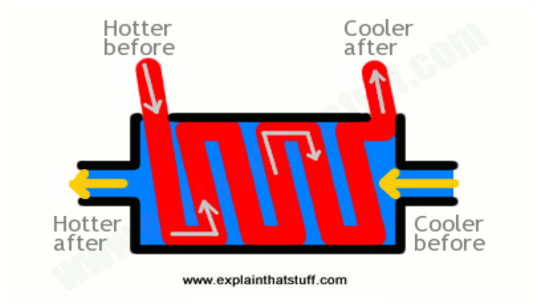


Figure 2.0 Fluid flow direction in heat exchanger

2.3 CLASSIFICATION OF HEAT EXCHANGERS

Most of chemical industries are using application of heat transfer to transfer heat from one fluid to another by heat transfer equipment which called Heat Exchanger. (Jadhoa Js, T.D, 2013). There are many different type of heat exchanger available. General classification of heat exchangers is shown in the figure 2.2.

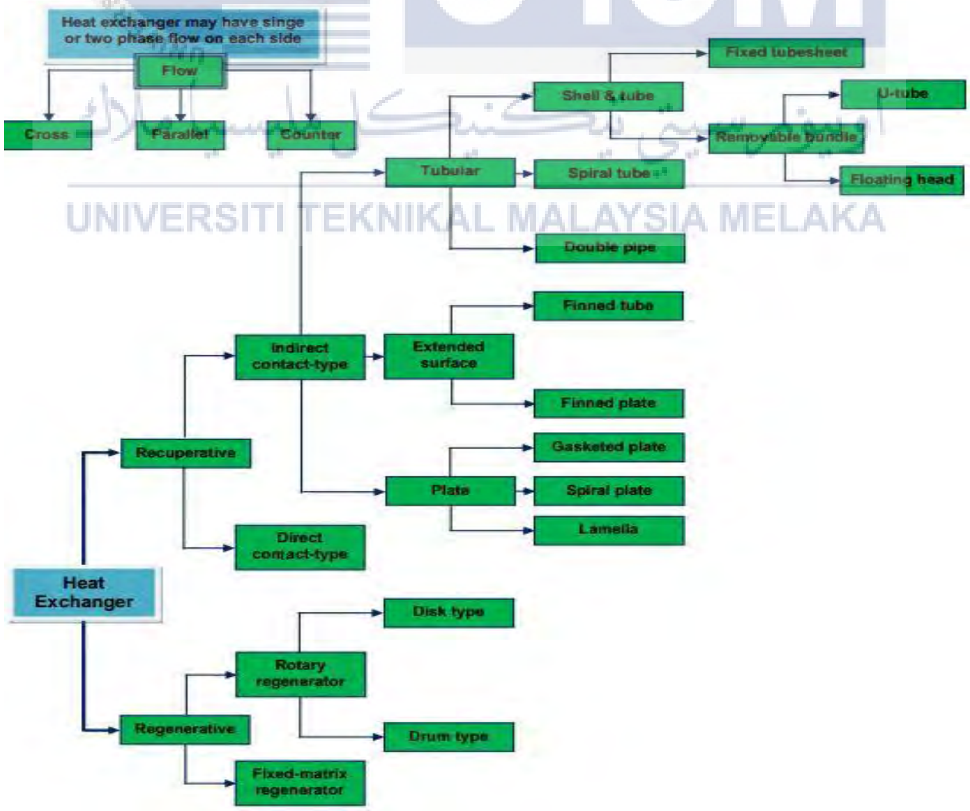


Figure 2.1 Classification of Heat exchangers

Among of all type of heat exchangers, shell and tube heat exchangers are mostly used in industries. Shell and tube heat exchanger is considered as indirect contact tubular type. Based on the figure 2.2, shell and tube heat exchangers can categorized as fixed tube-sheet exchanger and removable bundle exchanger.

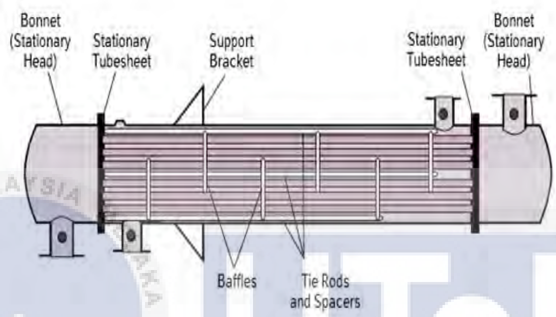


Figure 2.2 Shell and Tube heat exchanger

Fixed tube sheet exchanger is the simplest and cheapest type with fixed tube sheet design. This type of exchangers provides maximum heat to the transfer area at given diameter. In fixed tube sheet exchanger the tube sheet is welded to the shell and the velocity of fluid is very appropriate because it provides single and multiple tube to passes around. Moreover, the tubes bores can cleaned mechanically or chemically and it also considered as the cheapest of all removable bundle designs. (Gulf, 2016)

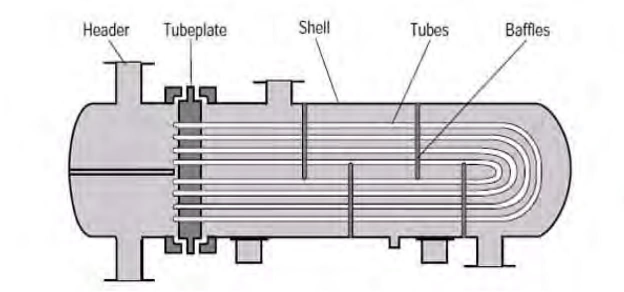


Figure 2.3 Fixed tube sheet heat exchanger

However, removable bundle can categorize as U-tube Exchangers and Floating Head exchanger. U-tube exchanger consists of tubes which are bent in the form of a "U" shape and it will be rolled back into the tube sheet. Additionally, the advantages of U tube exchanger is the tubes can expand freely towards the end part of "U" bend. This design allow infinite thermal expansion between shell and the tube bundle, simplest design and also it can be cleaned mechanically. U-tube exchangers are less costly than the floating head design.

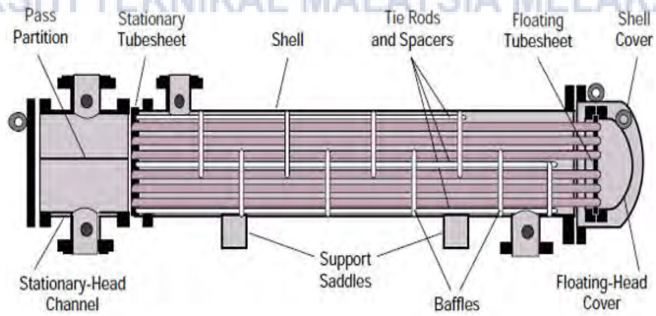


Figure 2.4 U-tube heat

According floating head heat exchanger, it can be designed in various types, and it is the most versatile type shell and tube heat exchangers. Furthermore, it consists of stationery tube sheet which clamped with the shell flange to allow the free expansion of the tube bundle. Floating heat exchanger can be classified as various types, such as:

a) TEMA P - Outside packed stuffing box
b) TEMA W- Outside packed lantern ring
c) TEMA S- Floating head with backing device
d) TEMA T- Pull through design

The advantage of this design is can reduce the maintenance time by removing the tube bundle without taking off the shell of floating head cover. Due to bigger area shell, this design of all exchanger has the highest cost.

2.4 FLOW ARRANGEMENT OF HEAT EXCHANGER

Flow arrangement playing a major role in heat exchanger. There are three main classification of flow arrangement in heat exchanger which are parallel flow, counter flow and cross flow. In parallel flow arrangement the two fluid move in same path such that at one terminal point and travel in parallel to one another to the other side. This happen when the hot fluid side inlet temperature is in contact with the cold fluid site inlet temperature. However, if the exiting temperature of two fluids have close range it means parallel flow arrangement is frequently used in particular application. Furthermore, counter flow heat exchangers is the most efficient design which can transfer the most heat from heat transfer. This type of arrangement fluid enter the exchanger from opposite ends. Temperature cross occurs when the desired outlet temperature of one fluid is between the inlet and outlet temperatures of the other fluid. The more uniform temperature difference turn out a more uniform rate of heat transfer all over the heat exchanger. (Engineers edge, 2014). Cross flow heat exchanger design to flow the fluid at right angles to one another through the exchanger. Mostly shell and tube exchanger, cooling and ventilation system using cross flow heat exchanger. (Cengel, Y.A, 2013). Moreover, the thermal efficiency of cross flow heat exchanger can be up to 40-65%, due to the surface area of the wall between the two fluids. The maximum surface area design, the higher the efficiency occur. This type of flow typically less cost than other types of heat exchangers. Profile in multi-pass arrangement explains that temperature cross can be occur in cross flow heat exchanger but not to the same degree as in a true counter flow arrangement. (Deltathx, 2014)

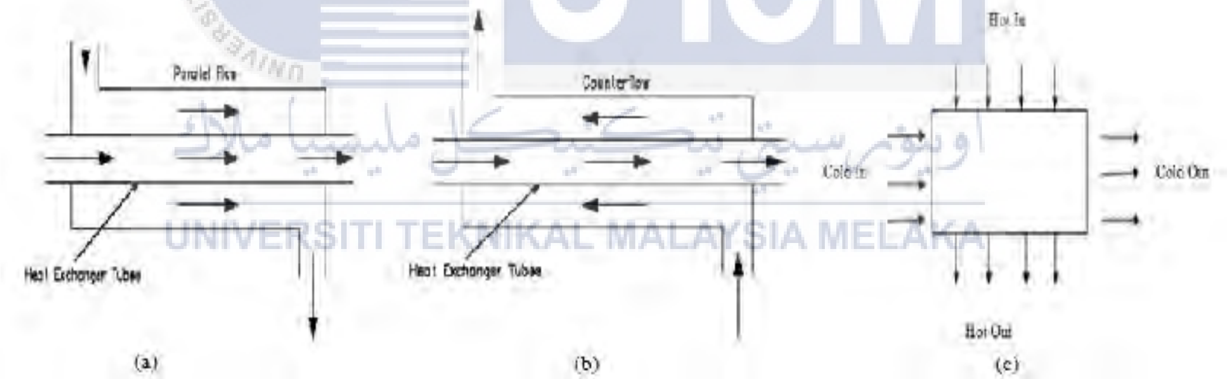


Figure 2.5: Parallel flow   Figure 2.6: Counter flow   Figure 2.8: Cross flow

2.5 CONSIDERATION OF HEAT EXCHANGER

There are many feature to evaluate to select a best design of heat exchanger. Basically all type of heat exchanger which mainly used in processing industrials are selected based on TEMA Standards. (A.L Ling, ViscaMulyan, 2010). TEMA stands for Tubular Exchanger Manufacturers Association, which manufactures of shell and tube heat exchangers based on mechanical standard. In order to produce an efficient heat exchanger the following criteria can help to select the heat exchanger.

2.5.1 MATERIAL SELECTION FOR HEAT EXCHANGER

The right type of material playing a major role to make an effective heat exchanger. Selecting an appropriate material for heat exchangers are included in the duties of a professional engineer and designer by involving in the construction, operation and maintenance of the heat exchanger. In the mechanical design, physical properties, mechanical properties and corrosion resistance are the special considerations which affect material selection of a heat exchanger. (P.Rodriguez, 1997).

a) **Physical Properties**

- It requires high heat exchange or high thermal conductivity of material.
- Low thermal expansion coefficient which suited the materials used for tubesheet and shell to contribute to thermal cycling.

b) **Mechanical Properties**

- It requires a high creep rupture strength and adequate creep ductility at high temperature.
- A high durability of fracture and impact power to prevent fast rupture.
- Corrosion fatigue, creep fatigue and good fatigue feature.

c) **Corrosion Resistance**

- The rate of corrosion require low to minimize the corrosion existence.
- Good understanding to chemistry resulting from mix up of shell and tube fluids.

Based on the criteria above, the suitable material for heat exchanger are copper (Cu). Copper is most commonly used when materials of high thermal conductivity are required, (D.D.L.Chung, 2001), because it is an excellent conductor of heat that enable the heat to pass through it quickly. Thermal conductivity is the quantity of heat transmitted due to a unit temperature gradient, in unit time under steady conditions in a normal direction to a surface of the unit area. Moreover, it consider as temperature dependant because as the average temperature increases the conductive of heat to material will be high. There are other beneficial features about copper material, which has:

a) Maximum allowable stress.

b) Maximum fatigue strength.

c) High creep rupture strength.

d) High tensile and yield strength.

e) High melting point.

f) Ease of fabrication.

MECHANICAL AND PHYSICAL PROPERTIES OF ALLOYS

a) Based on the table below, the types of Copper-Nickel has the high value density compared to types of Brass. Whereas for thermal conductivity and thermal expansion 90/10 copper-nickel are lower than admiralty brass but higher than 80/20 and 70/30 Copper-Nickel at the range of 20-300℃. Specific heat capacity for all the alloy below are same. Moreover, compared to the alloys below 70/30 Copper-Nickel has the high modulus and Aluminium brass has the low modulus. Its shows that, 70/30 copper-nickel defines as stiff material where aluminium brass as flexible material. The physical properties between copper-nickel n brass types 90/10 copper-nickel and admiralty brass has the desirable properties for thermally efficient.

Table 2.0: Physical properties of alloy. (Source: Shinko Metal, 1988)

	Density g/cm^3 (20°C)	Thermal conductivity W/(m·K) (20°C)	Thermal expansion 1/K (20-300°C)	Specific heat J/(g·K) (20°C)	Modulus of elasticity N/mm^2 (R.T.)
Aluminum brass	8.4	1.0×10^{2}	18.5×10^{-6}	0.38	11×10^{4}
Admiralty brass	8.6	1.1×10^{2}	20.2×10^{-6}	0.38	11×10^{4}
90/10 Copper-Nickel	8.9	0.5×10^{2}	17.1×10^{-6}	0.38	12×10^{4}
80/20 Copper-Nickel	8.9	0.3×10^{2}	16.8×10^{-6}	0.38	14×10^{4}
70/30 Copper-Nickel	8.9	0.3×10^{2}	16.2×10^{-6}	0.38	15×10^{4}

b) The table below shows, the mechanical properties of alloys based on yield strength, tensile strength, elongation and reduction area at high temperature.70/30 copper-nickel has the favourable option compared to other alloys in table below. Besides that, the reduction area and elongation are differ compare to other alloy. For the reduction area, 80/20 copper-nickel has the high reduction area from room temperature, (R.T) to high temperature, 550°C. It is ensure that, in order to 80/20 copper-nickel comply with its respective specification it must reduce in diameter minimum 81% before breaking at room temperature. While, the elongation percentage of 90/10 copper-nickel has high percentage compared to other alloys. It proves that the ductility of 90/10 copper-nickel is high and has a quality control measure to assess the level of impurities and proper processing of a material.

Table 2.1: Mechanical properties at high temperature.

(Source: Shinko Metal, 1988)

Test temperatures °C	0.2% Yield strength N/mm²	Tensile strength N/mm²	Elongation %	Reduction of area %
Aluminum brass				
R.T.	246	455	39	65
100	234	437	37	63
200	223	410	39	60
300	209	333	26	30
400	129	279	22	23
500	71	157	30	30
90/10 Copper-Nickel (ann.)				
R.T.	106	312	45	78
200	89	268	35	78
300	85	258	32	61
400	86	237	30	60
550	79	150	41	40
80/20 Copper-Nickel (ann.)				
R.T.	121	329	44	81
200	105	284	38	80
300	90	270	35	76
400	92	250	31	56
550	88	160	17	15
70/30 Copper-Nickel (ann.)				
R.T.	144	366	41	75
200	126	318	37	73
300	119	287	35	65
400	104	243	19	15
550	93	175	16	15

c) The table below, define the rupture strength of the alloys based on temperature and time (h). Rupture strength also known as flexural strength, determined the stress in a material just before it yields in a rupture test. The data shows that 90/10 copper nickel has 260 Mpa of rupture strength for the first 200°C (1000h) compare to other types of copper material.

Table 2.2: Creep rupture strength. (Source: Shinko Metal, 1988)

Test temperature °C	Rupture strength N/mm²			
	100h	1,000h	10,000h	100,000h
Aluminum brass				
100	430	420	–	–
200	280	250	190	160
300	110	80	60	–
90/10 Copper-Nickel (ann.)				
200	–	260	–	–
300	260	250	220	200
400	190	170	160	140
80/20 Copper-Nickel (ann.)				
200	–	–	–	–
300	260	230	210	200
400	170	140	120	110
70/30 Copper-Nickel (ann.)				
200	–	–	–	–
300	260	230	200	180
400	140	120	90	50

d) Based on the table below, aluminium brass has the high tensile strength of pressure, elongation and fatigue strength. Besides that, in copper categories 70/30 copper-nickel has high tensile strength, fatigue strength and elongation percentage.

Table 2.3: Fatigue strength. (Source: Shinko Metal, 1988)

	Tensile Strength N/mm²	Elongation %	Fatigue Strength (10^7 cycle of reversed stress) N/mm²
Aluminum brass	450	46	230
90/10 Copper - Nickel	310	45	150
80/20 Copper - Nickel	340	45	150
70/30 Copper - Nickel	390	45	170

2.6 DESIGN SELECTION

Many variable are involved to select an efficient heat exchanger. Most of the heat exchangers are selected by computer programs such as systems designers or equipment vendors. As an engineer, to select an optimal heat exchanger must consider several factors which shown below:

2.6.1 HEAT TRANSFER RATE

Heat transfer rate is a major option in selection of heat exchanger. The heat transfer represents the total rate of transferring heat to desired temperature at specified mass flow rate. (Cengel, 2013).

2.6.2 COST

This factor is the second major role in selection of heat exchangers. There are many criteria to make a final selection based on cost factor, such as initial cost, maintenance cost, and cost of loss in production and consequences of failure cost. (Cengel, 2013).

2.6.3 SIZE AND WEIGHT

Generally, small size and light weight of heat exchanger is more preferable than the bigger size of heat exchanger, especially in automotive application. Moreover, larger size of heat exchanger is more expensive compared to smaller size. The smaller size system will be more lighter, compact and high efficiency. (Cengel, 2013).

2.6.4 PRESSURE DROP

At the design stage, pressure drop in heat exchanger will play the important role. Most of cases, heat exchanger has either two internal streams or an internal and external stream. So that, pressure drop calculations are necessary for both fluid streams. Generally, a fluid will meet an entrance loss as it flows into the heat exchanger due to sudden reduction area. In the center of the heat exchanger contributes a loss due to friction and other internal losses. Lastly as the fluid pass the core of heat exchanger it will come up loss due to a sudden expansion. There are several calculations to calculate the total pressure drop. (Kakac, S. and Liu, H, 1998)

- **ENTRANCE LOSS**

Based on Bernoulli's equation with a loss coefficient and mass conservation can obtain the entrance loss.

$$\Delta p_i = \left(1 - \sigma_i^2 + K_c\right) \frac{1}{2} \frac{G^2}{\rho_i} \qquad \text{(Eq2.1)}$$

where σ means the passage contraction ratio and G = m/A, the mass flux of fluid. In general,

$$\sigma = \frac{\text{minimum flow area}}{\text{frontal area}} \qquad \text{(Eq2.2)}$$

- **CORE LOSS**

Care loss will be calculated based on Fanning friction in terms of:

$$\Delta p_c = \frac{4fL}{D_h}\frac{1}{2}\frac{G^2}{\rho_m} \qquad \text{(Eq2.3)}$$

Due to change of fluid density, acceleration or deceleration may occur. So that, momentum balance across the core may occur as shown below:

$$\Delta p_a A_c = \dot{m}(V_e - V_i) \qquad \text{(Eq2.4)}$$

which simplify as:

$$\Delta p_a = G^2\left(\frac{1}{\rho_e} - \frac{1}{\rho_i}\right) \qquad \text{(Eq2.5)}$$

where V = G/ρ, since Gi = Ge.

- **EXIT LOSS**

The same application of Bernoulli's equation with mass conservation is used to calculate the exit loss as the flow exits the center of the heat exchanger as shown below:

$$\Delta p_e = -\left(1 - \sigma_e^2 - K_e\right)\frac{1}{2}\frac{G^2}{\rho_e} \qquad \text{(Eq2.6)}$$

TOTAL PRESSURE DROP

The summation of all the loss calculated is known as the total pressure drop across the heat exchanger. That is

$$\Delta p = \Delta p_i + \Delta p_c + \Delta p_a + \Delta p_e \qquad \text{(Eq2.7)}$$

The general expression of the total pressure loss shown below is the combination of all loss effect:

$$\Delta p = \frac{G^2}{2\rho_i}\left[\left(1 - \sigma_i^2 + K_c\right) + f\frac{4L}{D_h}\left(\frac{\rho_i}{\rho_m}\right) + 2\left(\frac{\rho_i}{\rho_e} - 1\right) - \left(1 - \sigma_e^2 - K_e\right)\left(\frac{\rho_i}{\rho_e}\right)\right] \qquad \text{(Eq2.8)}$$

Based on application of conservation of energy, fluid pumping power is related with overall pressure drop due to the presence of friction losses,

$$\dot{W}_p = \frac{1}{\eta_p}\frac{\dot{m}}{\rho}\Delta P \qquad \text{(Eq2.9)}$$

where ηp is the pump efficiency.

2.6.5 EFFECTIVENESS OF HEAT EXCHANGER

Heat exchanger effectiveness allows engineers to predict the performance of a heat exchanger. Essentially, it also helps to prophesy the stream outlet temperature without a trial and error solution. Effectiveness defined as the ratio of the actual amount of heat transferred to the maximum possible amount of heat that could be transferred with an infinite area. (Mardiana I Ahmad, Masitah, 2015). The equation are shown below:

$$\varepsilon = \frac{q}{q_{\max}} \qquad \text{(Eq3.0)}$$

where q is actual heat transfer and q max are maximum possible heat transfer.

To elucidate the effectiveness of the heat exchanger, the maximum possible heat transfer can be hypothetically determined in a counter flow heat exchanger by finding the temperature difference between inlet temperature of hot stream and inlet temperature of cold stream.

The actual heat transfer rate in heat exchanger can be determined theoretically from energy balance equation by finding the difference between inlet temperature of the hot stream and outlet temperature of the hot stream. The overall equation of heat exchanger effectiveness are shown below:

$$\epsilon = q / q_{max} = (C(h) \cdot (T_{h,i} - T_{h,o})) / ((C_{min}) \cdot (T_{h,i} - T_{c,i}) \qquad \text{(Eq3.1)}$$

Since the specific heat capacity of hot stream is lower than specific heat capacity of cold stream, C(h) = C (min),

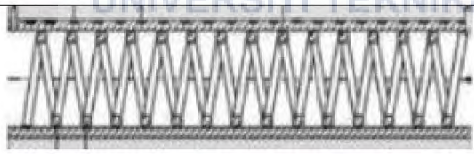
$$\epsilon = (T_{h,i} - T_{h,o}) / (T_{h,i} - T_{c,i}) \quad \text{(Eq3.2)}$$

Basically, concentric tube heat exchangers and shell & tube heat exchanger had similar effectiveness relationship, but this relationship are differentiated based on the type of flow, the number of passes and type of flow stream.

2.7 DESIGN OF HEAT EXCHANGER

The aim of the discussion of literature review and the case study of this whole report, are to design a heat exchanger based on the good characteristic of mechanical and physical properties. Generally, they are many types of design in current technology application, but the most widely used design in industrial application are helical coil design of heat exchangers. Helical coil have compact size and high heat transfer coefficient. This is because helical coil design of heat exchanger has large heat transfer area in small area. There are several sketch of helical coil design of heat exchanger below:

Table 2.4: Sketches of Various wire coils. (Source: http://www.ijesrt.com)

Sketches of wire coil	Pattern
	Coil square wire
	Non- uniform wire coil combine with twisted tape
	Coil wire turbulators
	Twisted tape and wire coil
	Triangle cross sectioned coiled wire
	Wire coil in pipe

2.8 WASTE HEAT RECOVERY PRODUCE IN HEAT EXCHANGER

Waste heat recovery include exchange of heat between gases or liquid, transferring thermal to the load entering furnace, using heat with a heat pump for heating or cooling facilities. The usage for heat recovery technologies regularly varies among different industries. Moreover, heat exchanger are the most commonly used to exchanger the heat from combustion exhaust gases to combustion air entering furnaces. As the combustion air, flows the furnace at high temperature, it compulsory to supply the fuel with less energy. There are various type of technologies used for air preheating such as recuperators that recover exhaust gas waste heat in medium to high temperature, furnace regenerators that absorb the heat from the combustion gas and increase the temperature and passive air preheaters that gas to gas heat recovery devices for low to medium temperature. (D.A.Reay, E & F.N.Span, 1979).

CHAPTER III

METHODOLOGY

3.0 INTRODUCTION

This section will describe the procedure that have been used for this in order to complete the project successfully. Moreover, in the methodology section include the phases of heat exchanger has be done in both PSM 1 and PSM 2. To achieve these study, an experiment will be done to investigate the efficient heat exchanger for steam generator as heat recovery by analysing the temperature data, volume flow rate, rate of heat transfer and effectiveness. Based on the result, a good performance of heat exchanger will be chosen. The methodologies has been carried out in order to fulfil the objective by following the scopes. The overall sequences to design the project is shown in flow chart below.

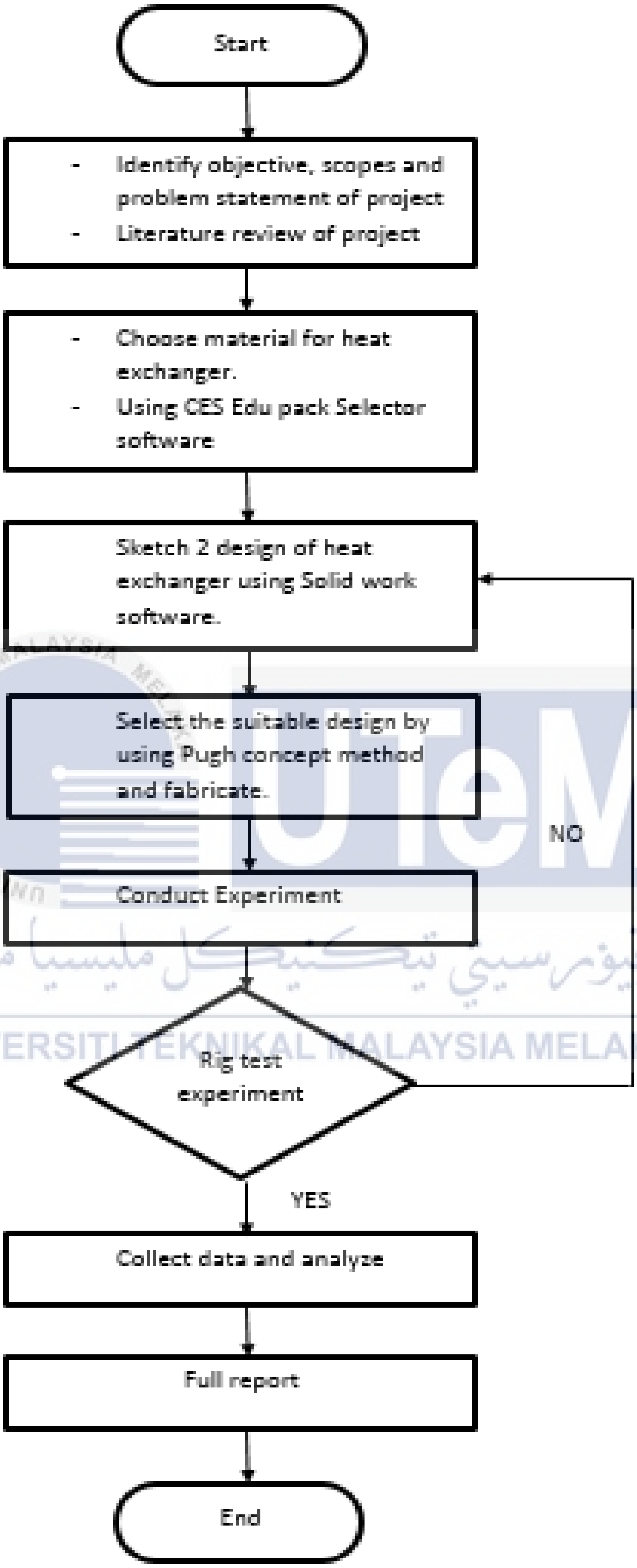


Figure 3.0: Flow chart of PSM project

3.1 CES EDUPACK SELECTOR

CES Edupack selector is a unique tool for rational finding and selection of engineering material data across Engineering Design and Sustainable Development. This software visualize the properties by plotting chart tools, and can match the materials and do comparison of the properties for better understanding. There are three type of stages and several procedure to find the suitable material for heat exchanger.

3.1.1 DATA SELECTION

Based on research review in chapter 2, suitable material for heat exchanger was found. There are two types of copper material have been selected to fabricate heat exchanger. Firstly, the copper materials that has been selected was input in material database to envision the properties into graph.

Table 3.0: Material selection rank

Rank	Material
1	Copper-nickel alloy, C96200, cast (90/10 copper-nickel)
2	Copper-nickel alloy, C96400, cast (70/30 copper-nickel)

3.1.2 STAGES SELECTION

In this stage, the selection is classified into two phase such as graph selection and limit selection. In graph selection the graph were plotted as Tensile strength (Mpa) vs Thermal Conductivity (W/m.°C).

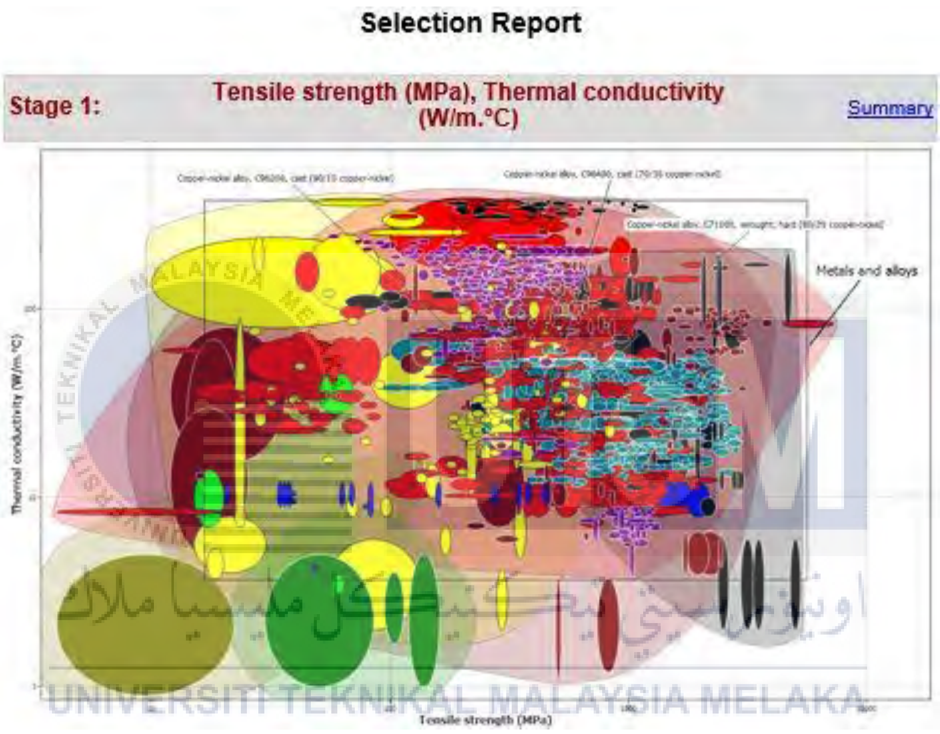


Figure 3.1: Bubble chart of Tensile strength (Mpa) vs Thermal Conductivity (W/m.°C).

The figure above shows, the full range of visualization of bulk engineering materials in property space based of the material selection in first stage. From the chart, we can identify the range of tensile strength and thermal conductivity material, such as metal and alloy material located at top right corner in chart can be consider as high tensile strength and thermal conductivity.

3.1.3 LIMIT SELECTION

In second phase, limit selection has to be done to find out the appropriate material for heat exchanger from the bulk engineering material as shown in graphical chart. The limit data as shown in table below is based on the research review from chapter 2. All the limit range are precise for a heat exchanger material.

Table 3.1: Material Limit

Attribute	Constraints
Density (kg/m^3)	≥ 8.9e3
Base	Cu (Copper) Ni (Nickel)
Yield strength (elastic limit) (MPa)	79 to 106
Tensile strength (MPa)	150 to 312
Flexural strength (modulus of rupture) (MPa)	≤ 260
Elongation (% strain)	≤ 45
Fatigue strength at 10^7 cycles (MPa)	≥ 150
Thermal conductivity (W/m.°C)	30 to 50
Specific heat capacity (J/kg.°C)	≤ 0.38

3.1.4 RESULTS

Based on the mechanical and physical properties limit, 2131 out of 3905 material has been selected in graphical chart. From the 2131 materials only three materials of copper and nickel base were selected with the limit requirements.

Box Selection

Thermal conductivity (W/m.°C):	3.65 to 378
Tensile strength (MPa):	16.7 to 5.6e3
Display & selection settings:	
Results intersection:	Off
Fail estimated records:	Off
Pass when:	Any part of record within selection
Records passing:	2131 of 3905

Figure 3.2: Record passing for material

Table 3.2: Selected material comparison

	Copper-nickel alloy, C96200, cast (90/10 copper-nickel)	Copper-nickel alloy, C96400, cast (70/30 copper-nickel)	Copper-nickel alloy, C71000, wrought, soft (80/20 copper-nickel)	Copper-nickel alloy, C71000, wrought, hard (80/20 copper-nickel)
General Properties				
Density (kg/m^3)	8850 - 8890	8850 - 8890	8700 - 8750	8700 - 8750
Price (MYR/kg)	30.5 - 33.5	37 - 40.7	34.2 - 37.6	34.2 - 37.6
Composition overview				
Base	Cu (Copper)	Cu (Copper)	Cu (Copper)	Cu (Copper)

Table 3.2 shows the 3 material selected from the limit requirement. There are copper-nickel alloy cast (90/10), (70/30) and copper nickel alloy wrought soft (80/20), hard (80/20). Based on the table above, can conclude that, copper nickel alloy of 90/10 type has

the lowest cost per kg compared to other 2 type of material. The density of all the material above is almost same.

Table 3.3: Mechanical properties comparison

Mechanical properties				
Young's modulus (GPa)	120 - 125	145 - 150	145 - 150	145 - 150
Flexural modulus (GPa)	120 - 125	145 - 150	145 - 150	145 - 150
Shear modulus (GPa)	44.4 - 46.3	53.7 - 55.5	53.7 - 55.5	53.7 - 55.5
Bulk modulus (GPa)	130 - 135	157 - 162	157 - 162	157 - 162
Poisson's ratio	0.34 - 0.35	0.34 - 0.35	0.34 - 0.35	0.34 - 0.35
Shape factor	30	30	30	25
Yield strength (elastic limit) (MPa)	128 - 140	118 - 220	110 - 120	310 - 490
Tensile strength (MPa)	290 - 310	405 - 430	330 - 340	400 - 550
Compressive strength (MPa)	128 - 140	118 - 220	110 - 120	310 - 490
Flexural strength (modulus of rupture) (MPa)	128 - 140	118 - 220	110 - 120	310 - 490
Elongation (% strain)	27 - 30	30 - 35	38 - 40	20 - 32
Hardness - Vickers (HV)	90 - 100	100 - 110	80 - 85	120 - 165
Fatigue strength at 10^7 cycles (MPa)	144 - 150	178 - 185	156 - 159	177 - 218
Fatigue strength model (stress range) (MPa) #	137 - 158	170 - 194	152 - 163	144 - 269
Fracture toughness (MPa.m^0.5)	65.5 - 68.3	51.4 - 70.9	70.4 - 73.1	29.7 - 41.3

Table 3.3 shows the mechanical properties comparison between three materials. From the table below we can observe that, the Young, Flexural, Shear and Bulk modulus of three material are in same range. Whereas, the Tensile, Yield, Compressive and Flexural strength has different properties range. The Copper-Nickel alloy of wrought hard (80/20) has a high range properties compared to others copper material except fatigue strength and fracture toughness.

Table 3.4: Thermal properties comparison

Thermal properties				
Melting point (°C)	1120 - 1150	1180 - 1240	1160 - 1180	1160 - 1180
Maximum service temperature (°C)	150 - 180	170 - 200	200 - 210	200 - 210
Minimum service temperature (°C)	-273	-273	-273	-273
Thermal conductivity (W/m.°C)	40 - 44	19 - 23	30 - 33	30 - 33
Specific heat capacity (J/kg.°C)	385	385	384 - 385	384 - 385
Thermal expansion coefficient (µstrain/°C)	16 - 17	16 - 17	16 - 17	16 - 17
Latent heat of fusion (kJ/kg)	220 - 240	220 - 240	220 - 240	220 - 240

Table 3.4 shows the thermal properties comparison of three copper-nickel materials. Thermal conductivity of a material is very important in the process of heat exchanger and it define as the property of a material to conduct heat. Based on the table above, thermal conductivity of copper-nickel (90/10) has the high range of thermal conductivity. Besides that, melting point of copper-nickel (70/30) has slight high of range value compared to other material, but the specific heat capacity, thermal expansion coefficient and latent heat for all the material above have equivalent properties range.

3.1.5 SUMMARY

From the unique tool of CES Edupack Selector, Copper-Nickel alloy C96200 cast (90/10) choose as the suitable material for heat exchanger. The mechanical properties and thermal properties of the material are more favourable than other type of material. Moreover, in some specific properties copper nickel alloy (90/10) has low range value compared to other material, but for a spiral coil heat exchanger it does not need over qualify range of material. This is because, properties with high range value has high cost value and larger in size. Generally, the smaller and lighter the heat exchanger, the better the performance.

3.2 SOLIDWORK

Solid work is a solid modelling computer aided tool that create models and cover all aspects by utilize a parametric feature. In this solid work section, will explain about the 3D design of heat exchanger. Two types of heat exchanger was design with require parameters to select the prefer heat exchanger before install into the car.

Table 3.5: Design parameters

Type	 Type A : Helical coil heat exchanger	 Type B : Twisted finned of Helical coil heat exchanger
Copper size	6 mm	6mm
Length	70 cm	70 cm
Diameter	7.62 cm	6.35 cm
Coil pitch	3 cm	0.2 cm
Plate Length	-	0.7cm

3.2.1 TYPE A HEAT EXCHANGER DESIGN

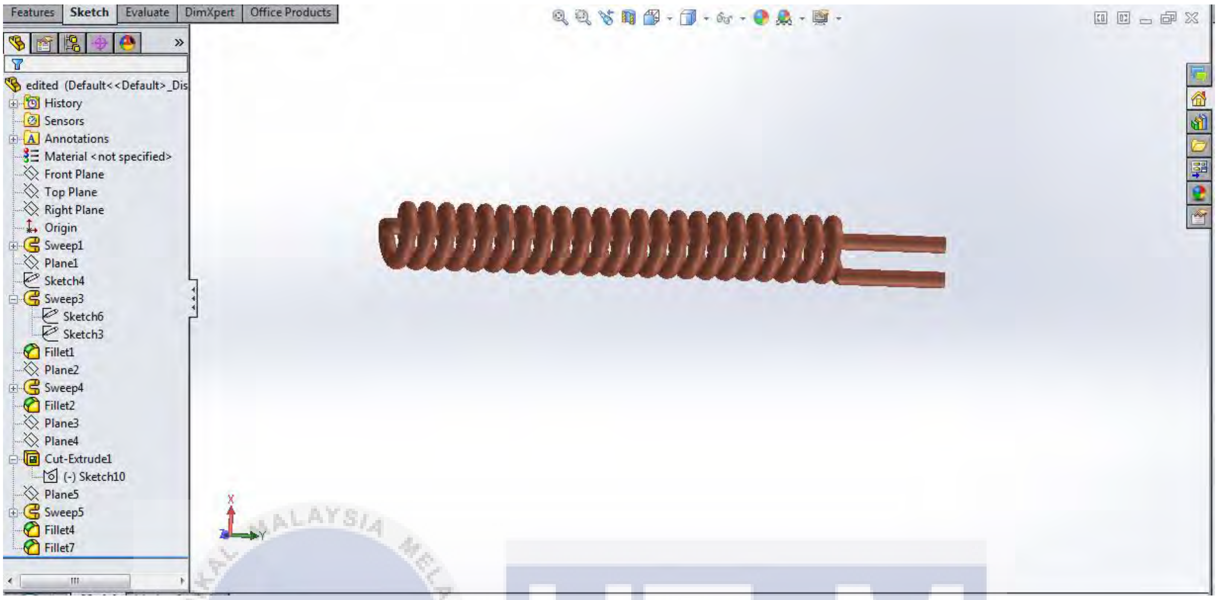


Figure 3.3: Design type A heat exchanger

3.2.2 TYPE B HEAT EXCHANGER DESIGN

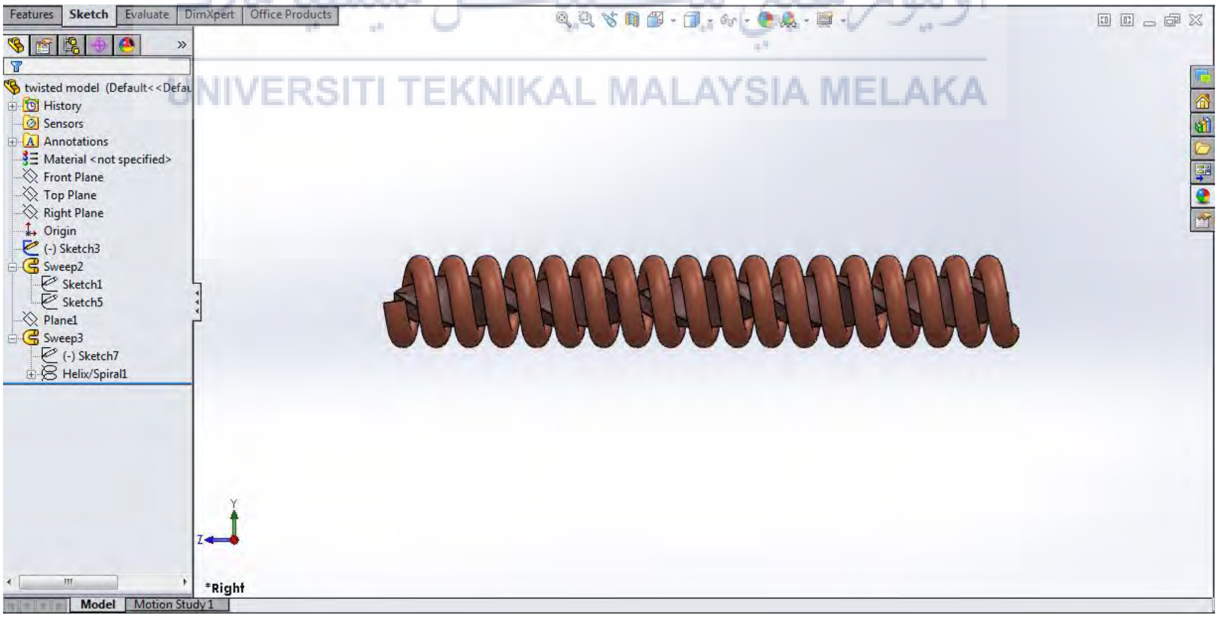


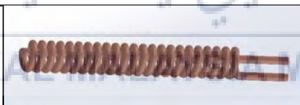
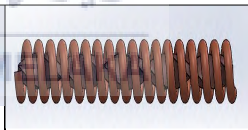
Figure 3.4: Design type B heat exchanger

3.3 **CONCEPT EVALUATION**

The method concept evaluation used to evaluate the conceptual design are Pugh Concept Method. This method used to determine the relative important of the selected criteria. Application of Pugh concept selection method for selecting conceptual design at conceptual design stage can improve quality of product and shorten the product development process. There are several criteria has to be evaluate to determine the best concept design:

1. Low cost
2. Simplicity of design
3. High strength
4. Ease of fabrication
5. Ease of installation
6. Low weight
7. Thermal conductivity

Table 3.6: Pugh Concept Method for Two design

Design	Original	 Type a	 Type b
Low cost	DATUM	=	+
High strength		-	+
Simplicity of design		+	-
Ease of fabrication		=	-
Ease of installation		-	=
Low weight		-	+
Thermal conductivity		+	+
Σ +	NA	2	4
Σ −	NA	3	2
ΣS	NA	-1	2

From the Pugh Concept table, we can see that this method is used to determine the relative important of the selected criteria. Based on the result above, the best design between conceptual designs is type B heat exchanger. This is because the criterion are better performance, less weight and high strength compare to the original design.

3.4 **HEAT EXCHANGER MODEL**

For the best heat exchanger model, the type B twisted finned helical coil was chosen for this experiment to determine and analyse the effectiveness. The fabrication process will be done with the guide of supervisor and technician based on the require parameters as shown in table 3.5 above and figure 3.5 below.

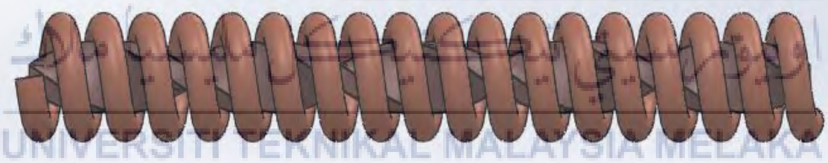


Figure 3.5: Selected model for Heat Exchanger

3.5 **MODEL ON RIG TESTING**

The completion of type B heat exchanger fabrication process has been carry on to conduct rig test experiment. The aim of the experiment is to simulate the efficient of heat exchanger by recording the temperature difference of inlet and outlet of cold stream. There are several type of apparatus to begin the experiment, such as:

- Tube bender

Tube bender is used to bend the copper tube in helical coil. In order to prevent the copper tube bend or broken, tube bender device has been used.

Figure 3.6: Tube bender

Figure 3.7: Helical coil patter with Twisted Finned

At the end, the helical shape of copper tube has been bend. The twisted finned is a stainless steel material. Stainless steel material has low thermal conductivity compare to copper material. Thus, stainless steel enable the heat transfer rate high to copper.

* Angel grinder & Static grinder

Angel grinder and static grinder are widely used in metal working and construction. Static grinder are used to cut the edge part of old exhaust pipe to fit in new exhaust pipe. Angel grinder are used to do surface finishing to the edge part.

Figure 3.8: Angel Grinder and safety google

Figure 3.9: Static Grinder

Figure 3.10: Edge part of exhaust pipe

- Flaring tool

Flaring tool is known as a tool kit that used to joint copper tube by soldering or brazing. There are several tools inside the flaring tool box. The tools has been used to cut the copper tube correctly and mated with another tube at the two end of copper coil. Copper coil brazing has been done with proper guidance of technician.

Figure 3.11: Full set of Flaring tool

Figure 3.12: Copper tube Brazing

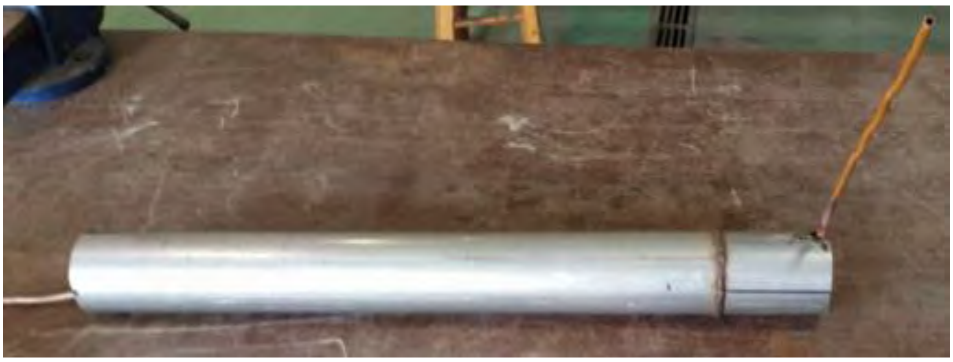


Figure 3.13: Full helical coil fit in exhaust pipe

- Heat gun

Heat gun define as a device that radiate the hot air stream as hot fluid that can produce 100 to 650°C, which can held by hand. Moreover, the axial velocity of the hot air stream flow is high due to the fans inside the heat gun. The specification of the heat gun are shown in table 3.7.

Figure 3.14: Heat gun

Table 3.7 Heat gun Specification

Model Name	Voltage	Watt	Temperature	Air Volume
ss-611B	240 v 50 Hz	2000W	$100-650^{0}C$	500*l*/min

- Adjustable adaptor & Thermometer

The primary function of an adjustable adaptor is to supply the voltage amount from the range of 1.5V to 9V. Moreover, thermometer is an instrument for measuring and indicating temperature digitally.

Figure 3.15: Adjustable Adaptor

Figure 3.16: Digital Thermometer

3.5.1 **EXPERIMENT PROCEDURE**

I. All the apparatus must set up as shown in the figure below:

II. Maintained the temperature of heater gun at 400,450,500 as hot source.

III. Set up the volume flow rate of air by using 3 mode of fans speed with 100L/min, 200L/min and 500L/min

IV. For every 5 minutes take the temperature of blower with respected volume flow rate of air.

V. Measure the temperature of water before and after the blower switch on by using thermometer.

VI. Record the temperature reading of water for first 5 mins.

VII. Repeat step 2 with different temperature source of blower and volume flow rate of air.

VIII. All the data obtain from the experiment recorded in tables as shown in table 3.8.

Table 3.8: Data collected table

i. For hot inlet 400^0C and flow rate at 100L/min,200L/min,500L/min

Time (min)	5	10	15
Tin,water (^{o}C)			
Tout,water (^{o}C)			

ii. For hot inlet 500^0C and flow rate at 100L/min,200L/min,500L/min

Time (min)	5	10	15
Tin,water (^{o}C)			
Tout,water (^{o}C)			

iii. For hot inlet 600^0C and flow rate at 100L/min,200L/min,500L/min

Time (min)	5	10	15
Tin,water (^{o}C)			
Tout,water (^{o}C)			

CHAPTER IV

RESULT AND DISCUSSION

4.0 INTRODUCTION

This chapter will explain all the results from the experiments that had been carried out. In test rig experiment, two types of heat exchanger had been used, which is type A and type B. The experiment had been done at Air – Conditioning Lab. The experiment was tested on the performance of heat exchanger by using different volume flow rate and different temperature from the heat gun. The heat source from heat gun will flow through the exhaust and exchange the water supply into steam. All the temperature and volume flow rate was recorded during the test rig. The data taken out for two types of heat exchanger, type A for helical coil heat exchanger and type B twisted finned helical coil heat exchanger. The data were analyze and compared.

4.1 TEST RIG

The experiment had been carried out by two types of heat exchanger. First type B heat exchanger was tested with three different temperature source at 400^0C, 500^0C, 600^0C and different flow rate based on the speed of blower.

4.1.1 Heat exchanger type A

The heat exchanger of type A was designed as helical shape of coil heat exchanger as shown in Figure 4.1 below. The heat exchanger was fit inside an exhaust pipe and welded. The heat source that given by the heat gun will spread all over the exhaust pipe to heat up the heat exchanger coil. The result of the experiment had been recorded with different temperature and air flow rate.

Figure 4.0: Type A- Helical coil heat exchanger without twisted finned

i. For hot inlet 400^{0}C and flow rate at 100L/min

Table 4.0: Rig test result at 400^{0}C at 100 L/min

Time (min)	5	10	15
Tin,water (^{o}C)	31	31	31
Tout,water (^{o}C)	50	53	55

ii. For hot inlet 400^{0}C and flow rate at 200L/min

Table 4.1: Rig test result at 400^{0}C at 200 L/min

Time (min)	5	10	15
Tin,water (^{o}C)	31	31	31
Tout,water (^{o}C)	54	54	56

iii. For hot inlet 400^{0}C at volume flow rate 500L/min

Table 4.2: Rig test result at 400^{0}C at 500 L/min

Time (min)	5	10	15
Tin,water (^{o}C)	31	31	31
Tout,water (^{o}C)	58	62	62

i. For hot inlet 500^0C at volume flow rate 100L/min

Table 4.3: Rig test result at 500^0C at 100 L/min

Time (min)	5	10	15
Tin,water (°C)	31	31	31
Tout,water (°C)	53	52	55

ii. For hot inlet 500^0C at volume flow rate 200L/min

Table 4.4: Rig test result at 500^0C at 200 L/min

Time (min)	5	10	15
Tin,water (°C)	31	31	31
Tout,water (°C)	60	62	62

iii. For hot inlet 500^0C at volume flow rate 500L/min

Table 4.5: Rig test result at 500^0C at 500 L/min

Time (min)	5	10	15
Tin,water (°C)	31	31	31
Tout,water (°C)	63	63	65

i. For hot inlet 600^{0}C at volume flow rate 100L/min

Table 4.6: Rig test result at 600^{0}C at 100 L/min

Time (min)	5	10	15
Tin,water (^{o}C)	31	31	31
Tout,water (^{o}C)	63	66	66

ii. For hot inlet 600^{0}C at volume flow rate 200L/min

Table 4.7: Rig test result at 600^{0}C at 200 L/min

Time (min)	5	10	15
Tin,water (^{o}C)	31	31	31
Tout,water (^{o}C)	68	73	74

iii. For hot inlet 600^{0}C at volume flow rate 500L/min

Table 4.8: Rig test result at 600^{0}C at 500 L/min

Time (min)	5	10	15
Tin,water (^{o}C)	31	31	31
Tout,water (^{o}C)	74	77	78

4.1.2 Heat exchanger type B

The heat exchanger of type B was designed as same shape of Type A heat exchanger but the additional part is twisted finned inside helical coil. Type B heat exchanger is shown in Figure 4.2 below. The designed was fabricated to flow the heat source in a helicoidally path rather than flow in a straight line. The result of the experiment had been recorded with different temperature and air flow rate.

Figure 4.1: Type B- Helical coil heat exchanger with twisted finned.

i. For hot inlet 400^0C at volume flow rate 100L/min

Table 4.9: Rig test result at 400^0C at 100 L/min for Type B

Time (min)	5	10	15
Tin,water (°C)	31	31	31
Tout,water (°C)	56	58	58

ii. For hot inlet 400^0C at volume flow rate 200L/min

Table 4.10: Rig test result at 400^0C at 200 L/min for Type B

Time (min)	5	10	15
Tin,water (°C)	31	31	31
Tout,water (°C)	60	62	64

iii. For hot inlet 400^0C at volume flow rate 500L/min

Table 4.11: Rig test result at 400^0C at 500 L/min for Type B

Time (min)	5	10	15
Tin,water (°C)	31	31	31
Tout,water (°C)	67	64	66

i. For hot inlet 500^{0}C at volume flow rate 100L/min

Table 4.12: Rig test result at 500^{0}C at 100 L/min for Type B

Time (min)	5	10	15
Tin,water (°C)	31	31	31
Tout,water (°C)	66	66	68

ii. For hot inlet 500^{0}C at volume flow rate 200L/min

Table 4.13: Rig test result at 500^{0}C at 200 L/min for Type B

Time (min)	5	10	15
Tin,water (°C)	31	31	31
Tout,water (°C)	74	76	77

iii. For hot inlet 500^{0}C at volume flow rate 500L/min

Table 4.14: Rig test result at 500^{0}C at 500 L/min for Type B

Time (min)	5	10	15
Tin,water (°C)	31	31	31
Tout,water (°C)	75	82	84

i. For hot inlet 600^0C at volume flow rate 100L/min

Table 4.15: Rig test result at 600^0C at 100 L/min for Type B

Time (min)	5	10	15
Tin,water (°C)	31	31	31
Tout,water (°C)	78	84	84

ii. For hot inlet 500^0C at volume flow rate 200L/min

Table 4.16: Rig test result at 600^0C at 200 L/min for Type B

Time (min)	5	10	15
Tin,water (°C)	32	32	32
Tout,water (°C)	82	86	87(partially steam)

iii. For hot inlet 600^0C at volume flow rate 500L/min

Table 4.17: Rig test result at 600^0C at 100 L/min for Type B

Time (min)	5	10	15
Tin,water (°C)	32	32	32
Tout,water (°C)	85	98	steam

4.2 Performance of heat exchanger

The two types of heat exchanger were analyses at the lab. Both helical coil pattern heat exchangers had smaller diameter to increase the steam exit velocity, and to make up more surface contact area inside the exhaust pipe. Moreover, both heat exchanger test experiment was conducted in a counter flow arrangement because it can transfer the most heat from heat transfer effectively. Based on the data recorded, the performance of heat exchanger is determined by the rate of heat transfer and the effectiveness of both heat exchanger.

4.2.1 Rate of heat transfer

Rate of heat transfer was describes the rate exchange of thermal energy between wall contact depending on temperature by dissipating heat. Under the first law of thermodynamics, the rate of heat transfer from the hot fluid is equal to the rate of heat transfer to be a cold one. Table below shows the rate of heat transfer for each type of heat exchanger.

$$q = \dot{m} \cdot Cp \cdot \Delta Th \quad \text{(Eq 4.0)}$$

where q is the rate of heat transferred per sec and it can be measure in Joules per second or in Watts. $\dot{m}$, kg/s is the mass flow rate of water that flow in coil. Whereas, Cp is the constant specific heat capacity of water, approximately 4.187 kJ/kg. °C. ΔTh, °C is the temperature difference flow outlet and flow inlet of water. So that, the rate of heat transfer is equal to the mass flow rate of water multiplied by constant specific heat capacity of water and temperature difference of inlet and outlet of water.

For heat exchanger type A :

i. Rate of heat transfer for hot inlet 400^0C at volume flow rate 100L/min

ΔTwater =Tout,water – Tin,water

= 52.67 - 31

= 21.67

Cp = 4.186 kJ/kg.K

m = 0.0833 kg/s

q = m . Cp . ΔTh

= 0.0833x4.186x21.67

= 7.556kW

ii. Rate of heat transfer for hot inlet 400^0C at volume flow rate 200L/min

ΔTwater =Tout,water – Tin,water

= 54.67 – 31

=23.67

Cp = 4.186 kJ/kg.K

m = 0.0833 kg/s

q = m . Cp . ΔTh

= 0.0833 x4.186x23.67

= 8.254 kW

iii. Rate of heat transfer for hot inlet 400^0C at volume flow rate 500L/min

ΔTwater =Tout,water – Tin,water

= 60.67 - 31

= 29.67

Cp = 4.186 J/kg.K

m = 0.0833 kg/s

q = m . Cp . ΔTh

= 0.0833x4.186x29.67

= 10.346 kW

i. Rate of heat transfer for hot inlet 500^{0}C at volume flow rate 100L/min

ΔTwater =Tout,water – Tin,water

= 53.33- 31

=22.33

Cp = 4.186 J/kg.K

m = 0.0833 kg/s

q = m . Cp . ΔTh

= 0.0833x4.186x22.33

= 7.786 kW

ii. Rate of heat transfer for hot inlet 500^{0}C at volume flow rate 200L/min

ΔTwater =Tout,water – Tin,water

= 61.33 - 31

=30.33

Cp = 4.186 J/kg.K

m = 0.0833 kg/s

q = m . Cp . ΔTh

= 0.0833x4.186x30.33

= 10.576 kW

iii. Rate of heat transfer for hot inlet 500^{0}C at volume flow rate 500L/min

ΔTwater =Tout,water – Tin,water

= 63.67 - 31

= 32.67

Cp = 4.186 J/kg.K

m = 0.0833 ml/s

q = m . Cp . ΔTh

= 0.0833x4.186x32.67

= 11.392 kW

i. Rate of heat transfer for hot inlet 600^0C at volume flow rate 100L/min

ΔTwater =Tout,water – Tin,water

= 65 - 31

= 34

Cp = 4.186 J/kg.K

m = 0.0833 kg/s

q = m . Cp . ΔTh

= 0.0833x4.186x34

= 11.856 kW

ii. Rate of heat transfer for hot inlet 600^0C at volume flow rate 200L/min

ΔTwater =Tout,water – Tin,water

= 71.67 - 31

= 40.67

Cp = 4.186 J/kg.K

m = 0.0833 kg/s

q = m . Cp . ΔTh

= 0.0833x4.186x40.67

= 14.181 kW

iii. Rate of heat transfer for hot inlet 600^0C at volume flow rate 500L/min

ΔTwater =Tout,water – Tin,water

= 76.33 - 31

=45.33

Cp = 4.186 J/kg.K

m = 0.0833 kg/s

q = m . Cp . ΔTh

= 0.0833x4.186x45.33

= 15.806 kW

For heat exchanger type B:

i. Rate of heat transfer for hot inlet 400^0C at volume flow rate 100L/min

$\Delta T_{water} = T_{out,water} - T_{in,water}$

$= 57.33 - 31$

$= 26.33$

Cp = 4.186 J/kg.K

m = 0.0833 kg/s

$q = m \cdot Cp \cdot \Delta Th$

$= 0.0833 \times 4.186 \times 26.33$

$= 9.181$ kW

ii. Rate of heat transfer for hot inlet 400^0C at volume flow rate 200L/min

$\Delta T_{water} = T_{out,water} - T_{in,water}$

$= 62 - 31$

$= 31$

Cp = 4.186 J/kg.K

m = 0.0833kg/s

$q = m \cdot Cp \cdot \Delta Th$

$= 0.0833 \times 4.186 \times 31$

$= 10.810$ kW

iii. Rate of heat transfer for hot inlet 400^0C at volume flow rate 500L/min

$\Delta T_{water} = T_{out,water} - T_{in,water}$

$= 65.67 - 31$

$= 34.67$

Cp = 4.186 J/kg.K

m = 0.0833 kg/s

$q = m \cdot Cp \cdot \Delta Th$

$= 0.0833 \times 4.186 \times 34.67$

$= 12.090$ kW

i. Rate of heat transfer for hot inlet 500^{0}C at volume flow rate 100L/min

ΔTwater =Tout,water – Tin,water

= 66.67 - 31

=35.67

Cp = 4.186 J/kg.K

m = 0.0833kg/s

q = m . Cp . ΔTh

= 0.0833x4.186x35.67

= 12.438 kW

ii. Rate of heat transfer for hot inlet 500^{0}C at volume flow rate 200L/min

ΔTwater =Tout,water – Tin,water

= 75.67 - 31

= 44.67

Cp = 4.186 J/kg.K

m = 0.0833 kg/s

q = m . Cp . ΔTh

= 0.0833x4.186x44.67

= 15.576 kW

iii. Rate of heat transfer for hot inlet 500^{0}C at volume flow rate 500L/min

ΔTwater =Tout,water – Tin,water

= 80.33 - 31

=49.33

Cp = 4.186 J/kg.K

m = 0.0833kg/s

q = m . Cp . ΔTh

= 0.0833x4.186x49.33

= 17.201 kW

i. Rate of heat transfer for hot inlet 600^{0}C at volume flow rate 100L/min

ΔTwater =Tout,water – Tin,water

= 82 - 31

=51

Cp = 4.186 J/kg.K

m = 0.0833 kg/s

q = m . Cp . ΔTh

= 0.0833x4.186x51

= 17.783 kW

ii. Rate of heat transfer for hot inlet 600^{0}C at volume flow rate 200L/min

ΔTwater =Tout,water – Tin,water

= 85 - 31

=54

Cp = 4.186 J/kg.K

m = 0.0833 kg/s

q = m . Cp . ΔTh

= 0.0833x4.186x54

= 18.829 kW

iii. Rate of heat transfer for hot inlet 600^{0}C at volume flow rate 500L/min

ΔTwater =Tout,water – Tin,water

= 96 - 31

=65

Cp = 4.186 J/kg.K

m = 0.0833 kg/s

q = m . Cp . ΔTh

= 0.0833x4.186x65

= 22.665 kW

Table 4.18: Comparison of rate of heat transfer.

i. **Rate of heat transfer for hot inlet 400^{0}C**

Volume flow rate of air (L/min)	100	200	500
Type A	7.556 kW	8.254 kW	10.346 kW
Type B	9.181 kW	10.810 kW	12.090 kW

ii. **Rate of heat transfer for hot inlet 500^{0}C**

Volume flow rate of air (L/min)	100	200	500
Type A	7.786 kW	10.576 kW	11.392 kW
Type B	12.438 kW	15.576 kW	17.201 kW

iii. **Rate of heat transfer for hot inlet 600^{0}C**

Volume flow rate of air (L/min)	100	200	500
Type A	11.856 kW	14.181 kW	15.806 kW
Type B	17.783 kW	18.829 kW	22.665 kW

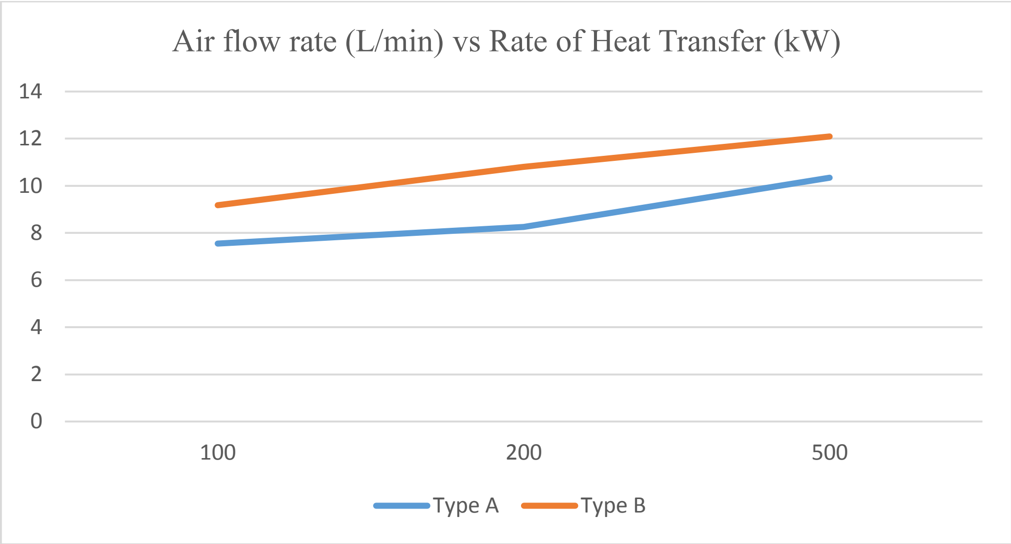


Figure 4.2: Comparison of rate of heat transfer at 400^0C

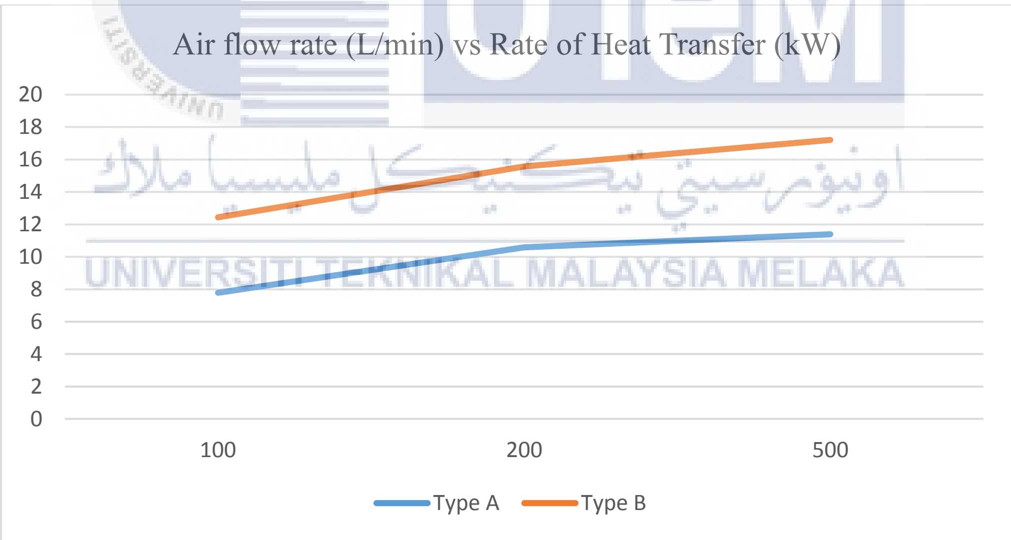


Figure 4.3: Comparison of rate of heat transfer at 500^0C

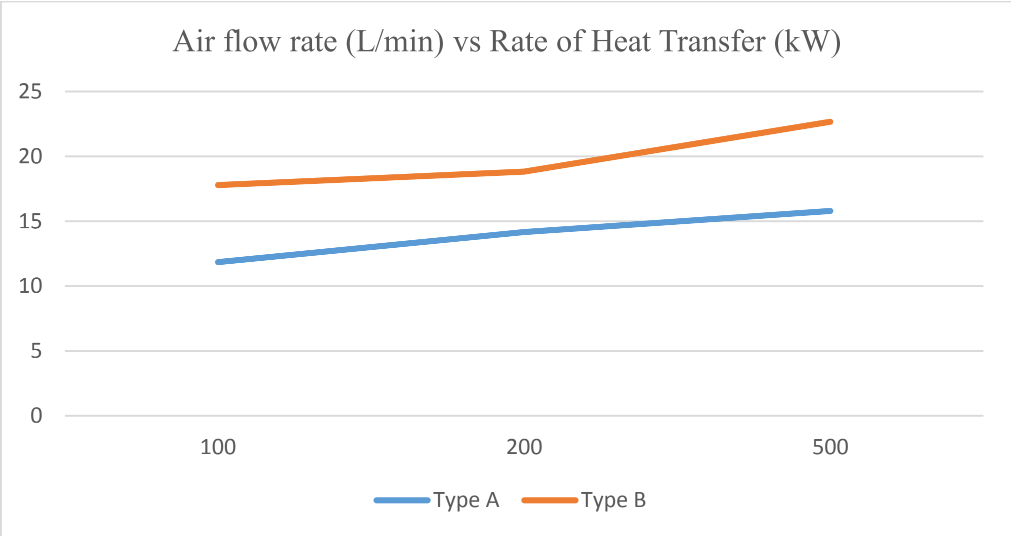


Figure 4.4: Comparison of rate of heat transfer at 600^0C

Based on the table 4.18 above, it shows the comparison of rate of heat transferred between type A heat exchanger and type B heat exchanger. In this study, the heat transferred in heat exchanger type A is found in range of 7.556kW to 11.856kW and for heat exchanger type B is found in range of 9.181kW to 17.783kW with the lowest air flow rate of 100 L/min and air velocity of 0.5 m/s and the highest correspond of air flow rate is 500 L/min and air velocity 2.5m/s. Thus, it clearly shows that the heat transferred heat increases as air velocity/ air flow rate increases. Moreover, twisted finned plays a significant role to the transferred heat. The maximum heat transferred of 15.806kW is achieved at 600^0C in type A heat exchanger whereas maximum heat transferred of 22.665kW is achieved at 600^0C in type B. Therefore, it can be seen maximum transferred heat in type B heat exchanger is high compared to type A heat exchanger. It is due to the presence of turbulator knows as twisted finned inside heat exchanger. It makes exchanger heating homogenously and also it improves the heat transfer speed.

4.2.2 Exit Temperature of Hot Stream

- Type A Heat Exchanger

Table 4.19 Exit temperature of hot stream of Type A

Temp. (in) blower (°C)	400			average temp.(out) blower (°C)
Air flow rate (L / min)	100	200	500	
Temp. (out) blower (°C)	258.38	261.51	265.38	261.76
Temp. (in) blower (°C)	500			average temp.(out) blower (°C)
Air flow rate (L / min)	100	200	500	
Temp. (out) blower (°C)	283.81	306.94	317.47	302.74
Temp. (in) blower (°C)	600			average temp.(out) blower (°C)
Air flow rate (L / min)	100	200	500	
Temp. (out) blower (°C)	340.25	357.21	376	357.82

- Type B Heat Exchanger

Table 4.20 Exit temperature of hot stream of Type B

Temp. (in) blower (°C)	400			average temp.(out) blower (°C)
Air flow rate (L / min)	100	200	500	
Temp. (out) blower (°C)	179.92	195.7	208.38	194.67
Temp. (in) blower (°C)	500			average temp.(out) blower (°C)
Air flow rate (L / min)	100	200	500	
Temp. (out) blower (°C)	232.04	251.91	267.37	250.44
Temp. (in) blower (°C)	600			average temp.(out) blower (°C)
Air flow rate (L / min)	100	200	500	
Temp. (out) blower (°C)	289.98	304.94	318.57	304.5

For Heat Exchanger Type A

i. **Effectiveness for hot inlet 400^{0}C at volume flow rate 100L/min, 200L/min, 500L/min**

ΔT blower =Tin, blower – Tout, blower

Tin, blower = 400^{0}C

Tin, Water = 31

Tout, blower= 261.76^{0}C

$$\epsilon = q / q_{max} = (C(h) . (Th,i - Th,o)) / ((Cmin) . (Th,i - Tc,i)$$

$= (400 - 261.76) / (400 - 31)$

$= 0.375$

$= 37.5\ \%$

ii. **Effectiveness for hot inlet 500^{0}C at volume flow rate 100L/min, 200L/min, 500L/min**

ΔT blower =Tin, blower – Tout, blower

Tin, blower = 500^{0}C

Tin, Water = 31

Tout, blower= 302.74^{0}C

$$\epsilon = q / q_{max} = (C(h) . (Th,i - Th,o)) / ((Cmin) . (Th,i - Tc,i)$$

$= (500 - 302.74) / (500 - 31)$

$= 0.271$

$= 27.1\ \%$

iii. Effectiveness for hot inlet 600^{0}C at volume flow rate 100L/min, 200L/min, 500L/min

ΔT blower =Tin, blower – Tout, blower

Tin, blower = 600^{0}C   Tin, Water = 31

Tout, blower= 357.82^{0}C

$$\epsilon = q / q_{max} = (C(h) . (T_{h,i} - T_{h,o})) / ((C_{min}) . (T_{h,i} - T_{c,i})$$

$$= (600 - 357.82) / (600 - 31)$$

$$= 0.426$$

$$= 42.6\ \%$$

For heat exchanger Type B

i. Effectiveness for hot inlet 400^{0}C at volume flow rate 100L/min, 200L/min, 500L/min

ΔT blower =Tin, blower – Tout, blower

Tin, blower = 400^{0}C   Tin, Water = 31

Tout, blower= 194.67^{0}C

$$\epsilon = q / q_{max} = (C(h) . (T_{h,i} - T_{h,o})) / ((C_{min}) . (T_{h,i} - T_{c,i})$$

$$= (400 - 194.67) / (400 - 31)$$

$$= 0.556$$

$$= 55.6\ \%$$

ii. Effectiveness for hot inlet 500^{0}C at volume flow rate 100L/min, 200L/min, 500L/min

ΔT blower =Tin, blower – Tout, blower

Tin, blower = 500^{0}C　　　　　　　　　　　Tin, Water = 31

Tout, blower= 250.44^{0}C

$$\epsilon = q / q_{max} = (C(h) \cdot (T_{h,i} - T_{h,o})) / ((C_{min}) \cdot (T_{h,i} - T_{c,i})$$

$= (500 - 250.44) / (500 - 31)$

$= 0.532$

$= 53.2\ \%$

iii. Effectiveness for hot inlet 600^{0}C at volume flow rate 100L/min, 200L/min, 500L/min

ΔT blower =Tin, blower – Tout, blower

Tin, blower = 600^{0}C　　　　　　　　　　　Tin, Water = 31

Tout, blower= 304.5^{0}C

$$\epsilon = q / q_{max} = (C(h) \cdot (T_{h,i} - T_{h,o})) / ((C_{min}) \cdot (T_{h,i} - T_{c,i})$$

$= (600 - 304.5) / (600 - 31)$

$= 0.519$

$= 51.9\ \%$

Table 4.21: Effectiveness of Type A and Type B heat exchanger

	Temp. (in) blower (°C)	Effectiveness (%)
TYPE A	400	37.5
	500	27.1
	600	42.6
TYPE B	400	55.6
	500	53.2
	600	51.9

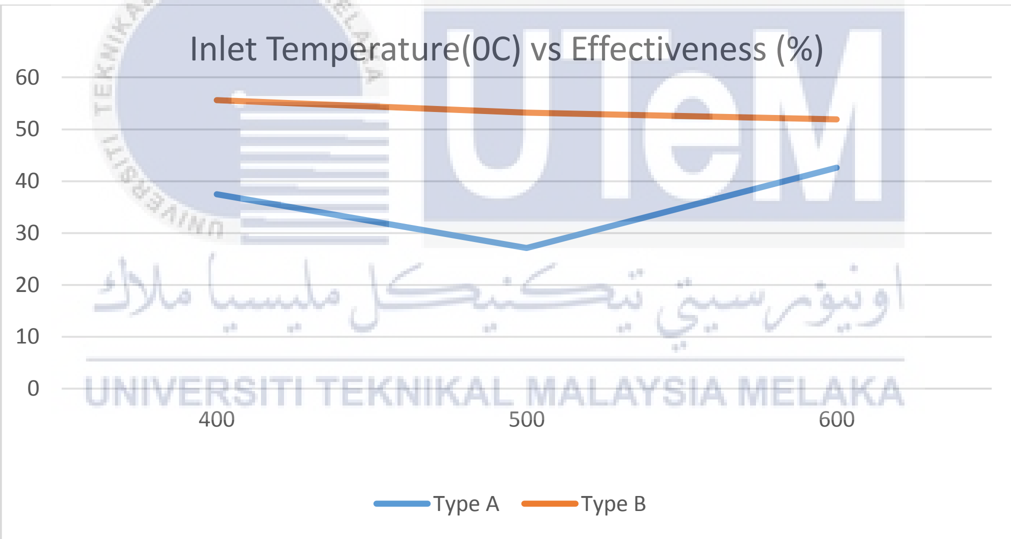


Figure 4.5: Two types of heat exchanger’s overall effectiveness at different temperature

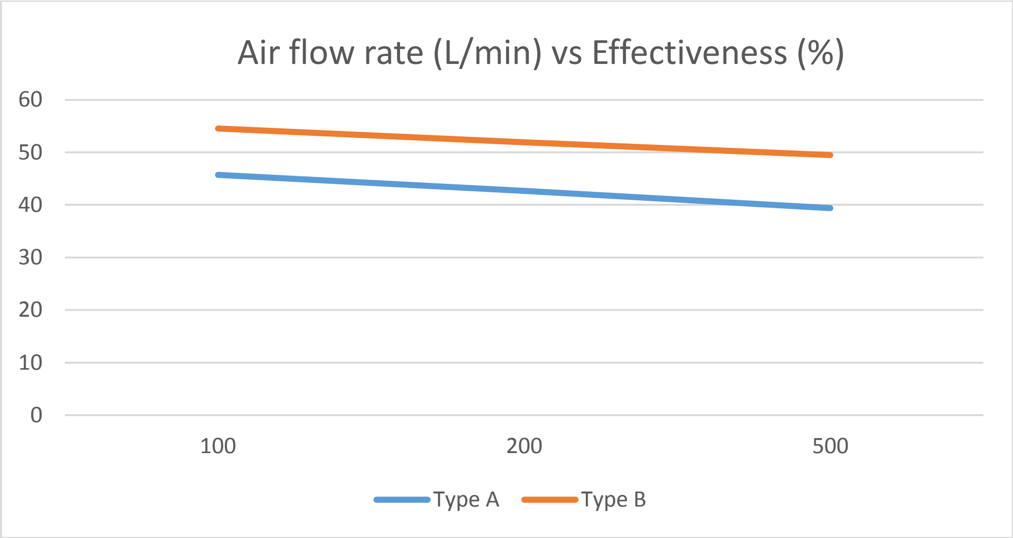


Figure 4.6: Two types of heat exchanger's effectiveness at 600^0C with different air flow rate

Based on the result in table 4.2, shows that the comparison of heat exchanger effectiveness for Type A and Type B. The effectiveness is found to be in range of 37.5% to 42.6% for type A helical coil heat exchanger coil and for type B twisted finned helical coil heat exchanger found in range of 51.9% to 55.6%. Therefore, it clearly proved that heat exchanger with twisted finned inside has good performance compared to heat exchanger without twisted finned. This is because fins are used to improve heat transfer and most importantly it enable an open spaces toward optimization. In type B heat exchanger, heat flows in helicoidally path by twisted finned and allow copper coil to absorb heat in high concentration. Furthermore, results shown in figure 4.3 explains that the effectiveness decreases as air flow rate increases. The effectiveness of type B heat exchanger is 54.5% at 100L/min flow rate and at 0.5m/s air velocity, whereas 49.5% at 500L/min flow rate and at 2.5m/s air velocity. Theoretically, air velocity gives a significant impact to effectiveness. This is because as the air velocity increase, the residence time will be high. So that, it will affect the amount of energy transferred as less.

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

At the end of this project, an optimal heat exchanger has been developed successfully. The first phase of the experiment which is to design a new heat exchanger. To design the new heat exchanger, material selection playing a significant role. A unique tool of CES Edupack selector, a bulk engineering material database has been used to select the best and suitable material for heat exchanger. Based on the mechanical properties, physical properties, and thermal properties the best material has been done. Two types of heat exchanger were design and the best design has been selected using Pugh concept method with some design specification. The chosen design has been fabricated and set up for rig test experiment. The data of outlet temperature has been recorded in experiment and analyzed.

By referring to the analysis that has been done, the lab scale experimental rig of heat exchanger operated well and successfully achieved the required objective and scope. The helical coil heat exchanger with twisted finned and helical coil without twisted finned was used in rig test experiment in order to analyze the rate of heat transfer. Based on the rate of heat transfer data, the best type of heat exchanger has been chosen and do some calculation to experimentally proven. Successfully, the calculation to determine the effectiveness and efficiency has been done. The outlet temperature of water is high in type B heat exchanger compare to heat exchanger type A.

As the inlet temperature of hot stream increase, the fluid inside the helical coil in type B heat exchanger was fully converted into enough steam to generate the steam turbine system continuously. The type of heat exchanger are affected the performance in heat transfer. The type B of the heat exchanger was chosen. Finally, the second phase of the objective which to determine the good performance of heat exchanger for waste recovery system has been done. Type B, helical coil with twisted finned chosen as an optimal heat exchanger.

5.2 RECOMMENDATION

In the future, different type of material for twisted finned can be used. For example, use aluminium or copper material of twisted finned and determine the rate of heat transfer and effectiveness. The helical pattern are difficult to fabricate for the smoothness of coil which is very brittle if bend. On top of that, the fabrication process of the heat exchanger should be done by someone expertise which could be minimize error of the result. Moreover, in fabricating process the copper must be handle it carefully to prevent the copper bend or broken. In order of that, use the flaring tools with proper guidance of technician for the copper connection. Besides that, use more reliable thermometer device to avoid instrumental error. The knowledge and technical skill that learn in UTeM can apply for the overall project.

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APPENDIX A

No	TASK	PSM I															PSM II													
		WEEK															WEEK													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	OBJECTIVE AND SCOPE OF PROJECT	■	■																											
2	LITERATURE REVIEW		■	■	■	■	■									S														
3	METHODOLOGY					■	■	■	■	■						E														
4	PRELIMINARY RESULTS									■	■	■				M														
5	SLIDE PREPARATION												■	■																
6	SEMINAR PSM														■	B														
7	EXPERIMENTAL SET UP															R		■	■	■										
8	CONDUCT EXPERIMENT															E				■	■	■	■	■	■	■	■	■		
9	RESULT AND DATA ANALYZE															A				■	■	■	■	■	■	■	■	■		
10	CONCLUSION															K										■	■	■		
11	SLIDE PREPARATION																											■	■	
12	SEMINAR PSM																													■