CHAPTER I
INTRODUCTION

1.1 Background

Heat transfer is the study of the speed of heat transfer from a heat source (hot body) to a heat receiver (cold body). The benefit of this science is to help engineers designing tools related to heat transfer, such as coolers, condensers, reboilers, evaporators, heat exchangers, and so on.

In industry, after the heat exchanger is designed, parameters such as the dirtiness factor are needed which indicates whether or not a heat exchanger is used and when it needs to be cleaned.

By knowing whether or not a heat transfer device is still feasible which can be known from the calculation of the temperature of the incoming hot fluid (T_{hi}), the temperature of the outgoing hot fluid (T_{ho}), the temperature of the incoming cold fluid (T_{ci}), and the temperature of the outgoing cold fluid (T_{co}) based on observations, the calculation of the heat balance can be used to design a heat exchanger.

1.2 Problem Statement

In this practicum, we will study the effect of the increase in flowrate scale on hot fluid flow and the difference in hot fluid initial temperature on parameters that affect the heat transfer process. The performance of a heat exchanger is influenced by the type of flow (co-current and counter-current), flow velocity, and fluid temperature. The heat transfer process parameters that will be calculated based on data on temperature changes during the practicum, namely U. For this reason, it is necessary to conduct an experiment to determine the performance of the heat exchanger against these parameters.

1.3 Practicum Objectives

1. Able to understand how heat transfer works through the Brazed Plate Heat Exchanger tool.
2. Able to calculate and compare theoretical and practical U values.
3. Able to draw theoretical and practical flowrate vs U relationship graphs.
4. Able to determine the correlation between Nusselt, Prandtl, and Reynold numbers and compare them between theoretical and practical data.

5. Able to evaluate the effect of hot fluid temperature on heat transfer value.

1.4 Practicum Benefits

The benefit of this experiment is to help understand the basic design of devices related to heat transfer such as coolers, condensers, reboilers, evaporators, and heat exchangers.

CHAPTER II
LITERATURE REVIEW

2.1. Theory of Heat Transfer

Heat transfer is a science that studies the speed of heat transfer between a heat source (hot body) and a heat receiver (cold body). One of these relationships is to help us in designing tools related to heat transfer, such as coolers, heaters, condensers, reboilers, evaporators, and heat exchangers.

The experiment was carried out with a type of Brazed Plate Heat Exchanger tool which is a Plate and Frame heat exchanger that is operated in the opposite direction or counter-current. Before operation, the hot fluid is made first through a hot tank with an electric heater and the cold fluid is made through a tank which is a refrigerator.

The principle of the experiment is to find the amount of overall heat transfer coefficient (U) in the tool with various variations in the speed of the hot fluid and cold fluid flowing in the heat exchanger. The amount of heat transferred can be calculated by knowing the temperature change of the incoming and outgoing fluid at a certain speed. While the logarithmic average temperature can be calculated from the changes in temperature in and out, both from hot and cold fluids.

The price of U can be calculated based on the size of the heat exchanger which is formulated by the equation

$$Q = U.A.LMTD \tag{2.1}$$

With,

Q = conduction heat transfer rate (Btu/hr)

U = heat transfer coefficient (J/s.m^2.)°C

A = heat transfer area (ft^2)

LMTD = logarithmic average temperature difference (°C)

From various variations of flow velocity changes, it can be seen that there is a change in the price of U against changes in flow velocity.

To find out the amount of heat transferred can use a tool in the form of a heat exchanger (HE). There are several types of heat exchangers, namely:

1. Shell and tube heat exchanger
2. Double pipe heat exchanger
3. Extended surface heat exchanger
4. Air cool heat exchanger
5. Plate and frame heat exchanger

Plate and frame heat exchangers are used because of the following advantages when compared to other types of heat exchangers.

1. Modifications are easily done by adding/subtracting plates or rearranging the number of passes.
2. Has good temperature control.
3. Relatively inexpensive.
4. Flow is turbulent so that the heat transfer process becomes better.
5. Requires a small area compared to other types.
6. Minimal fouling due to turbulent flow and low residence time.
7. Easy cleaning and inspection of fluidized parts as components can be separated.
8. There is a partition that prevents fluids from mixing in the event of an operating failure.

In addition to its advantages, the plate and frame type heat exchanger also has several disadvantages such as the following:

1. Limited operation at temperatures and pressures not so high.
2. Large pressure drop due to small flow area.
3. Not recommended for operation with gaseous or vapor fluids.
4. Not recommended for operation with high viscosity fluids as it can cause greater pressure drop and flow distribution problems.
5. Cannot be used for flammable and toxic fluids due to potential leakage.
6. Friction between plates can cause small holes that are difficult to find.

The heat transfer that occurs in the heat exchanger will be preceded by the heat that occurs in each pipe and depends on the nature of the material and the diameter of the pipe. The larger the pipe diameter the greater the heat transfer. Usually, the heat passing through the wall as a whole is determined by the outer and inner coefficients. For conduction, it is determined by pipe thickness and pipe material. The heat conductivity of the heat exchanger is determined by the overall heat transfer coefficient (U).

2.2. Types of Heat Transfer

According to the way of conducting, heat transfer can be divided into:

1. Conduction

   Is a heat transfer that occurs because the molecules in the substance intersect, where the amount of heat transfer speed:

$$Q = k.A.\frac{\Delta T}{\Delta x} \tag{2.2}$$

With,

Q = speed of heat transfer by conduction (Btu / hr)

A = heat transfer area (ft^2)

k = conductivity (Btu/ft.hr.)°F

T = temperature difference between hot and cold surfaces (°F)

x = thickness of the material through which the heat passes (ft)

Based on Fourier's law, the amount of Q depends on:

- The size of the conductivity (k)
- Directly proportional to the temperature difference (Δ T)
- Inversely proportional to thickness ($\Delta\chi$)

2. Convection

Is a heat transfer caused by the movement of atoms / molecules of a fluid in contact with the surface. Can be calculated by the equation:

$$Q = h.A.(Ts - Tv) \quad (2.3)$$

With,

Q = convection heat transfer rate (Btu/hr)

h = convection heat transfer coefficient (Btu/ft^2.hr.)°F

A = heat transfer area (ft^2)

Ts = rod surface temperature (°F)

Tv = solubility temperature (°F)

3. Radiation

Is a heat transfer wave due to temperature differences and takes place in electromagnetic waves without intermediaries.

Can be calculated by the equation:

$$Q = \varepsilon.\sigma.A.\left(T_1{}^4 - T_2{}^4\right) = 0{,}171\left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right] \quad (2.4)$$

With,

Q = radiant heat transfer energy (Btu/hr)

σ = Stefan Boltzmann constant (1.714 x 10^{-9}Btu/$ft^{(2)}$ hr.°F^4)

ε = material emissivity

A = field area (ft^2)

T_1 = absolute temperature (°F)

T_2 = absolute temperature (°F)

2.3. Black's Principle

Black's principle is a principle in thermodynamics proposed by Joseph Black. This principle describes:

- If two objects of different temperatures are mixed, the hot object gives heat to the cold object so that the final temperature is the same.
- The amount of heat absorbed by the cold object is equal to the amount of heat released by the hot object.
- A cooled object releases the same amount of heat as it absorbs when heated.

Black's Principle reads as follows: "When two substances are mixed, the amount of heat received by the higher temperature substance is equal to the amount of heat released by the lower temperature substance." Formulated:

$$Qh = mh.Cph.(Th_1 - Th_2) \tag{2.5}$$

$$Qc = mc.Cpc.(Tc_2 - Tc_1) \tag{2.6}$$

With,

Qh = hot fluid heat transfer rate (Btu/hr)

Qc = cold fluid heat transfer rate (Btu/hr)

mh = hot fluid mass flow rate (kg/s)

mc = cold fluid mass flow rate (kg/s)

Th_1, Th_2 = inlet temperature and outlet temperature of hot fluid (°C)

Tc_1, Tc_2 = inlet temperature and outlet temperature of cold fluid (°C)

2.4. Overall Heat Transfer Coefficient (U)

A very important thing to analyze a heat exchanger is the overall heat transfer coefficient (U). This coefficient is a measure of the heat exchanger in terms of moving heat. For a large U price, the heat transfer speed will be large, but on the contrary, if U is small, the heat transfer speed is small.

If in a heat exchanger the two fluids are separated in a flat plane then U can be expressed in the form:

$$U = \frac{1}{\frac{1}{h_h} + \frac{x}{k} + \frac{1}{h_c}} \tag{2.7}$$

With,

h_h = convection heat transfer coefficient on the hot fluid side (Btu/ft^2.hr.)°F

h_c= convection heat transfer coefficient on the cold fluid side (Btu/ft^2.hr.)°F

x = wall thickness (ft)

k = heat conductivity of wall material (Btu/ft.hr.)°F

The price of U depends on:

1. Thickness of the wall, the thicker the wall the smaller the U price and the smaller the heat transferred.
2. Heat conductivity.

3. Temperature difference, the greater the temperature difference, the greater U.
4. Area of hot surface area.

2.5. Resistance of Dirt

Resistance of Dirt is a condition where a heat exchanger device has impurities that can interfere with the performance of the heat exchanger. This impurity can affect the amount of heat transferred in the heat exchanger, so it needs to be cleaned regularly. The most common type of Dirt Resistance is fouling.

Fouling is the accumulation of unwanted solids on the surface of the heat exchanger in contact with the working fluid, including the surface of the heat exchanger. These events are deposition, scaling, corrosion, polymerization and biological processes. This fouling factor greatly affects heat transfer in heat exchangers. This fouling can occur due to deposits from the flowing fluid, or caused by corrosion of the components of the heat exchanger due to the influence of the type of fluid flowing. As long as this heat exchanger is operated, the influence of fouling will definitely occur. The occurrence of fouling can interfere with or affect the temperature of the flowing fluid and can also reduce or affect the overall heat transfer coefficient of the fluid.

Causes of fouling:

- The presence of heavy impurities, namely scale derived from corrosion or coke.
- Porous fouling is soft scale derived from the decomposition of hard scale.

As a result of fouling:

- Leads to an increase in heat transfer resistance, thus increasing costs, both investment, operation and maintenance.
- The size of the heat exchanger becomes larger, energy loss increases, shutdown time is longer and maintenance costs increase.

2.6. Types of Plate and Frame Heat Exchanger

1. Gasketed Plate Heat Exchanger

Gasketed plate heat exchanger is one type of heat exchanger that is commonly used in condensation and evaporation systems. The plates are arranged and connected with bolts for easy removal for maintenance. Hydraulic or mechanical machines are needed to close the plates before they are connected using bolts. Gaskets on the plate are used to prevent fluid flow from leaking, maintain fluid pressure, and direct the flow of hot fluid to not mix.

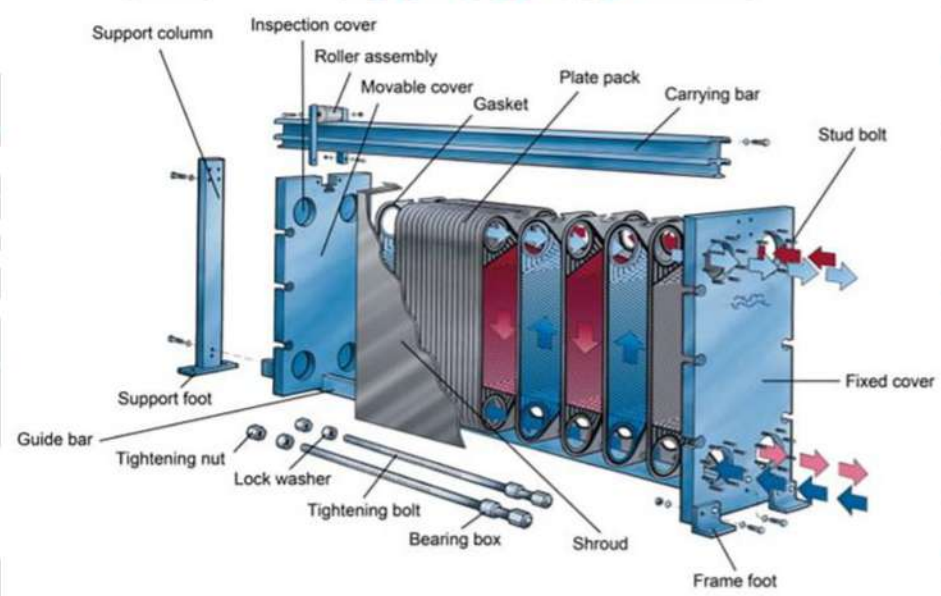

Figure 2.1 Gasketed plate heat exchanger

2. Brazed Plate Heat Exchanger

Brazed Plate Heat Exchanger has the same geometry as Gasketed Plate Heat Exchanger, the difference is in the gasket which is completely removed. The plates are connected by brazing using copper or nickel alloy and the heat exchanger is sealed tightly to prevent leakage. The heat exchanger can be used in the temperature range of -160ºC to 190ºC and pressure up to 30 bar. Applications of using brazed plate heat exchangers, namely in district heaters, heat pumps, gas boilers, and air dryers.

Figure 2.2 Brazed plate heat exchanger

3. Welded Plate Heat Exchanger

Welded plate heat exchanger consists of many plates that are connected by a welding system to form cassettes for fluid flow to operate in the heat transfer system. Cassetes are covered by a layer to form a square. The advantages of using this type are that there is no leakage, it takes up little space, and is more efficient.

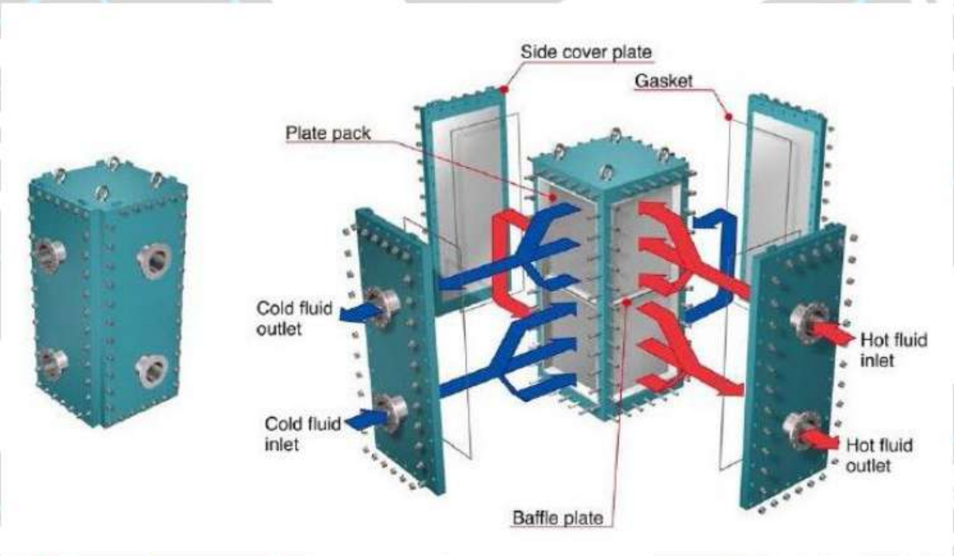

Figure 2.3 Welded plate heat exchanger

4. Semi Welded Plate Heat Exchanger

Semi welded plate heat exchanger consists of plates arranged one to another and welding is done on the sealing groove which is used later for gasket installation. This heat exchanger is often used in evaporators, condensers, desuperheaters, cascade duties, and economizers.

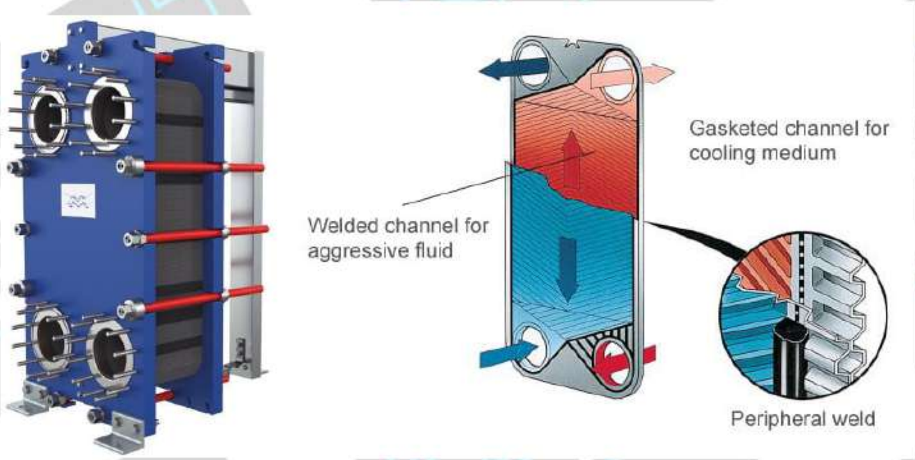

Figure 2.4 Semi welded plate heat exchanger

2.7. Explanation of LMTD Formula

To design a heat exchanger and estimate the ability of the heat exchanger, the relationship between the total heat transferred and other quantities such as the entry temperature and exit temperature of the two fluids, the price of the overall heat transfer coefficient U and the heat transfer area of the heat exchanger must be shown.

The heat released by the hot fluid can be written in the form of an equation:

$$Q = mh.cph.(Th_i - Th_o) \tag{2.8}$$

The heat is entirely received by the cold fluid which can be expressed in the form of an equation:

$$Qc = mc.Cpc.(tc_o - tc_i) \tag{2.9}$$

The heat released by the hot fluid and received by the cold fluid can occur due to the temperature difference ΔT = Th-tc which is called the local temperature difference between the hot fluid and the cold fluid at a certain point or locally, where from the input end to the output end the price ΔT always changes. By using the energy balance, it can be formulated as follows.

$$Dq = mh.Cph.\Delta Th = -Ch.\Delta Th \tag{2.10}$$

Where

$$Mh.Cph = Ch \tag{2.11}$$

Heat transfer through area dA can be expressed as:

$$Dq = U.\Delta T.dA \tag{2.12}$$

Where

$$\Delta T = Th - tc \tag{2.13}$$

$$D(\Delta T) = dTh - dtc \tag{2.14}$$

$$Dq = -Ch.\Delta Th \rightarrow dTh = \frac{dq}{Ch} \tag{2.15}$$

$$Dq = Cc.dtc \rightarrow dtc = \frac{dq}{Cc} \tag{2.16}$$

Then

$$D(\Delta T) = dTh - dtc = -dq\left(\frac{1}{Ch} + \frac{1}{Cc}\right) \tag{2.17}$$

$$D(\Delta T) = -dq\left(\frac{1}{Ch} + \frac{1}{Cc}\right) \tag{2.18}$$

Substitute $dq = U.A.\Delta T$, then it will be obtained:

$$D(\Delta T) = -U.\Delta T.dA\left(\frac{1}{Ch} + \frac{1}{Cc}\right) \tag{2.19}$$

$$\frac{\mathrm{D(\Delta T)}}{\Delta \mathrm{T}} = -\mathrm{U}\left(\frac{1}{\mathrm{Ch}} + \frac{1}{\mathrm{Cc}}\right)\mathrm{dA} \tag{2.20}$$

Integralized along the heat exchanger is obtained:

$$\int_1^2 \frac{\mathrm{d(\Delta T)}}{\Delta \mathrm{T}} = -\mathrm{U}\left(\frac{1}{\mathrm{Ch}} + \frac{1}{\mathrm{Cc}}\right)\int_1^2 \mathrm{dA} \tag{2.21}$$

$$\mathrm{Ln}\frac{(\Delta \mathrm{T}_1)}{(\Delta \mathrm{T}_2)} = -\mathrm{U.A.}\left(\frac{1}{\mathrm{Ch}} + \frac{1}{\mathrm{Cc}}\right) \tag{2.22}$$

Substitution

$$Ch = \frac{q}{Thi-Tho} \text{ dan } Ch = \frac{q}{Tco-Tci} \quad (2.23)$$

$$Ln\frac{(\Delta T_1)}{(\Delta T_2)} = -U.A.\left(\frac{Thi-Tho}{q} + \frac{Tco-Tci}{q}\right) \quad (2.24)$$

$$Ln\frac{(\Delta T_1)}{(\Delta T_2)} = \frac{-U.A.}{q}(Thi - Tho + Tco - Tci) \quad (2.25)$$

Where $\Delta T = Thi - tci$ and $\Delta T_2 = Tho - tco$

Then we get

$$Q = U.A.\frac{\Delta T_1 - \Delta T_2}{l(\Delta T_2 \Delta T_1)} \quad (2.26)$$

So that

$$\Delta Tm = \Delta T_{LMTD} = \frac{\Delta T_2\text{-}\Delta T_1}{\ln\left(\frac{\Delta T_2}{\Delta T_1}\right)} = \frac{\Delta T_1\text{-}\Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} \quad (2.27)$$

Heat transfer from hot fluid to cold fluid depends on the logarithmic mean temperature difference (LMTD), heat transfer surface area (A), and overall heat transfer coefficient (U). $q = U.A.\Delta T_{LMTD}$. This equation is only valid for the following condition:

1. The fluid is in steady state and the flow velocity is constant.
2. U and A are constant.
3. Cp is constant even if the temperature changes.
4. Heat lost in the surroundings is ignored.
5. Applicable to co-current and counter-current.
6. Not applicable for cross flow.
7. There is no phase difference in the system.

2.8. Pros and Cons of Co-Current and Counter-Current Flow

1. Co-current

   Pros:

   - Commonly used in 1 phase in multiphase heat exchangers.
   - Can limit the maximum temperature of the cold fluid.
   - Can change one of the fluids quickly.

   Disadvantages:

   - The heat generated is smaller than counter current.
   - Rarely used in single pass heat exchangers.
   - It is not possible to get one of the exiting fluids close to the entry temperature of the other fluid.

2. Counter-current

   Pros:

   - Heat generated is quite large compared to co-current.

- The exit temperature of one fluid can be close to the inlet temperature of the other fluid.
- Construction materials are more durable because the thermal stress is small.

Disadvantages:

- Cannot be used to change fluid temperature quickly.
- Less efficient if used to raise the temperature of cold fluid for a certain limit.

CHAPTER III

PRACTICAL METHOD

3.1 Experimental Design

1. Fixed variable:
   - Flowrate of cold fluid
   - Initial temperature of cold fluid
   - Counter-current flow type
2. Independent variable:
   - Hot fluid initial temperature
   - Hot fluid flowrate

3.2 Materials and Equiipment Used

3.2.1 Materials

1. Aquadest

3.2.2 Equipment

1. Brazed plate heat exchanger
2. Thermometer

3.3 Equipment Diagram

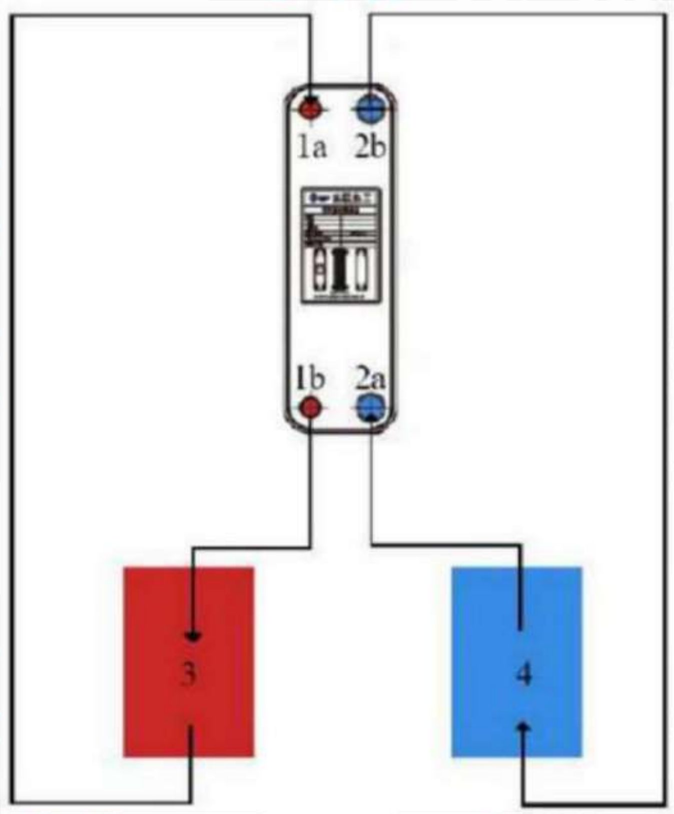

Figure 3.2 Main equipment of counter-current flow

Picture description:

1. Hot Fluid
    a. Inlet flow
    b. Outlet flow
2. Cold Fluid
    a. Inlet flow
    b. Outlet flow
3. Hot Tank
4. Cold Tank

3.4 Response

1. Inlet and outlet hot fluid temperature difference.
2. Inlet and outlet cold fluid temperature difference.

3.5 Required Data

1. Hot fluid flow rate
2. Flow rate cold fluid
3. Hot fluid initial temperature
4. Cold fluid initial temperature
5. Temperature change at a certain flow rate, either hot or cold fluid every 1 minute for 10 minutes (T_{hi}, T_{ho}, T_{ci}, T_{co}).
6. Calculate the amount of LMTD, U based on the data above and then draw a graph of the relationship with the initial temperature and flow rate of hot fluid.

3.6 Practicum Procedure

1. Turn on the heat exchanger switch, then turn on the power cold and hot fluid.
2. Turn on the thermostat on the hot fluid and cold fluid.
3. Set the temperature on the hot tank via the thermostat.
4. Calibrate the temperature on the hot tank thermostat using a thermometer.
5. Once the temperature in the hot tank is reached, turn on the hot and cold pumps.
6. With the flow rate control valve, adjust the flow of hot fluid and the flow of cold fluid entering according to the variables.

7. After the flow rate is appropriate, the operation starts and record the temperature change data every 1 minute for 10 minutes.
8. The variables used in this experiment are:
    a. Hot fluid initial temperature
    b. Hot fluid flowrate
9. When the experiment is complete, turn off both pumps, the thermostat, and the refrigeration unit.

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