# Design and Construction of a Shell & Tube Heat Exchanger

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# APPROVAL

This is to certify that the project on "**Design and Construction of a Shell & Tube Heat Exchanger**" by Md. Habibur Rahman (BME-1903019083), Md. Arifuzzaman (BME1903019084), Milon Hossain (BME-1903019130) and Sabbir Hossain Talukder (BME-1903019064) has been carried out under our supervision. The project has been carried out on partial fulfillment of the requirements of the degree of Bachelor of Science (B.Sc.) in Mechanical Engineering of years of 2023 and has been approved as to its style and contents.

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# DECLARATION

We, hereby, declare that the work presented in this project is the outcome of the investigation and research work performed by us under the supervision of **Md. Istiaque Zahur**, Lecturer, Department of Mechanical Engineering, Sonargoan University. We also declare that no part of this project and thesis has been or is being submitted elsewhere for the award of any degree.

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# ABSTRACT

In this equipment the objective is to study the heat transfer is shell and tube heat exchanger at various conditions to calculate the LMTD.

This heat exchanger is operated with heated water as hot water flows through the inner copper tube while the cold fluid flowing through the shell side.

The temperature inlet for cold fluid are lower than temperature outlet and temperature inlet for hot water are much higher than temperature outlet. This proven that there is heat exchanger process happened during the experiment.

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# CHAPTER 1

## Introduction

## General

Usually a heat exchanger is a heat-transfer device that is used for transfer of internal thermal energy between two or more fluid (such as liquids, vapors or gases) which is separated by a heat-transfer surface at different temperatures. It provides a large heat transfer area economically and practically.

Heat exchangers are used in both cooling and heating processes. They are widely used in the process, power, petroleum, transportation, air conditioning, refrigeration, cryogenic, heat recovery, alternate fuels, space heating, chemical plants, natural gas processing, sewage treatment and other industries.

Common examples of heat exchangers familiar to us in day- to- day use are automobiles radiators, condensers, evaporators, air pre-heaters and oil coolers.

There are several different types of heat exchanger including Shell-and-Tube, double-pipe, plate-and-frame types and many more.

The project we have designed is a one pass shell-and-tube counter flow type heat exchanger. It consists of a cylindrical steel shell containing several copper tubes. One fluid passes through a bunch of copper tubes, while the other circulating via the surrounding steel shell.

## Contribution of the Project:

Ninety percent Heat Exchangers use in industry are tube-and- shell type heat exchanger. So, they have huge applications.

This tube-and-shell heat exchanger's project will be helped on future development of design according to the process desired temperature, pressure, mass flow rate, overall heat transferred coefficient.

# Project Objective:

Objective of the project and thesis:

1. To design (according to the TEMA specifications) and construction of a one-pass shell-and-tube counter flow type heat exchanger depending on process parameters (temperature, pressure, velocity, flow etc.).

2. To select the material on the basis of structural strength for shell and thermal conductivity for the tube for designing a very robust heat exchanger without compromising the overall efficiency.

3. To operate the heat exchanger by the different working fluids.

# CHAPTER 2

# Methodology

## 2.1 Project Design:

The choice of material for construction in heat exchanger is usually influenced by the process fluids and operating condition such as temperature and pressure.

Moreover, shell and tube heat exchanger's design pressure lots of depend on tube properties. In this heat exchanger inner and outer surface of tube face both cold and hot fluids pressure and temperature. Tube must withstand against their internal and external pressure. So, we designed heat exchanger on the basic of tube strength.

### 2.1.1 Thermal Design

#### 2.1.1.1 Copper tube:

Important properties of copper tube-

- High thermal conductivity.
- Excellent resistant to corrosion and scaling.
- High mechanical strength.
- High temperature and pressure resistance.
- Economical and light weight.

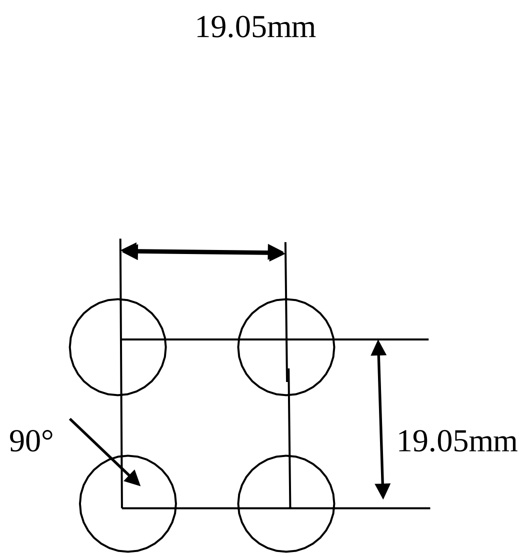
In this project using ½’’ (12.67mm) copper tube which Birmingham wire gauge (BWG) thickness number is 21 (thickness 0.89mm) and can withstand approx. 40bar pressure at 200°c temperature.

### 2.1.1.2 Tube pitch:

Center to center distance between two adjacent tubes 1.50 times the outside diameter of the tube.

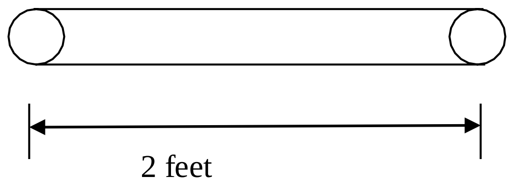
Tube pitch = (12.67*1.50) mm

= 19.05mm




### 2.1.1.3 Tube length:

Generally the most economical shell and tube heat exchangers have a small shell diameter and long tube length. The tube length of 6, 8, 12, 16, 20 and 24 feet are preferably used. Here the length of tube is 2 feet.




#### 2.1.1.4 Tube layout:

Generally the tube layout can be categorized into four patterns.

- Triangular pattern (30°)
- Square pattern (90°)
- Rotated triangular pattern (60°)
- Plotted square pattern (45°)

The tube layout Square pattern (90°)is selected by considering heat transfer, pressure drop and fouling.

## 2.1.1.5 Baffles design:

Baffle is a device to direct the shell side fluid across the tubes bundle to obtain higher co-efficient.

1. **The number of baffles ($N_b$):**

$N_b = (L_{t1}/L_{bc})-1$ here,

$N_b$= baffles number

$L_{bc}$=Central baffle spacing which is equal to the shell diameter=6inch

$L_{t1}$=tube length

$$= \frac{24}{6} - 1$$

$$=4-1$$

$$=3$$

So, total baffle is 3. Distance between adjacent baffles is almost 6 inch. The distance between adjacent baffles is called baffle spacing. So, here baffle spacing is 6 inch.

## *2.* Baffle layout type:

There are different types of baffles.

a) Cut-segmental baffle.

b) Disc and doughnut baffle.

c) Orifice baffle.

Cut segment baffle used in baffles design. Baffles cuts from 15% to 45% are normally used. Here, Baffle cut is 30%.

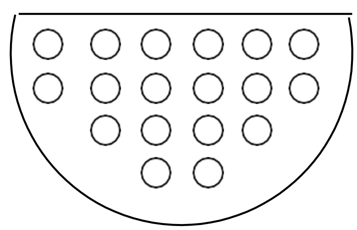


Fig: Baffle design

### 2.1.1.6 Bundle to Shell clearance:

The bundle to shell clearance is calculated based upon there equations:

For a fixed tube sheet heat exchanger

$L_{bb}$ =12.00+0.005*D*

=12.72mm

Tube sheet thickness = 0.2*D*mm

=29 mm

here,

12.00+0.005*145

*D*=145 mm

### 2.1.1.7 The number of baffles ($N_b$):

$N_b$= ($L_{t1}$/$L_{bc}$)-1

$$= \frac{24}{6} - 1$$

=4-1

=3

here,

$N_b$= baffles number

$L_{bc}$=Central baffle spacing which is equal to the shell diameter=6inch

$L_{t1}$=tube length=24 inch

### 2.1.2 Mechanical Design:

After finishing essential dimensions of the thermal design of heat exchanger, the next work was to design the different mechanical parts of the heat exchanger.

Different mechanical part of the heat exchanger (Shell thickness, shell cover design, tube sheet thickness, bolts, flanges, nozzle, tie rods, saddle support, gasket etc) was designed according to the TEMA (Tubular Exchanger Manufacturers Association) specification. As this was done, the whole design of the shell and tube exchanger was prepared for manufacture.

### 2.1.3 Fouling Factor:

In shell and tube heat exchanger fouling is the formation of undesired deposits (could by impurities in the fluid, chemical reaction between the fluid & wall material and rust) on heat transfer surfaces which impede the heat transfer and increase the resistance to fluid flow, resulting in higher pressure drop. Fouling can be happened internal and external surface of the pipes or tubes.

Fouling factor is denoted as $\mathbf{R_f}$

$\mathbf{R_f}$ = 0 for new heat exchanger

$\mathbf{R_f}$ $\boldsymbol{\alpha}$ time is use

$\mathbf{R_f}$ $\boldsymbol{\alpha}$ temperature

$$\mathbf{R_f} = \frac{1}{velocity\ of\ flow}$$

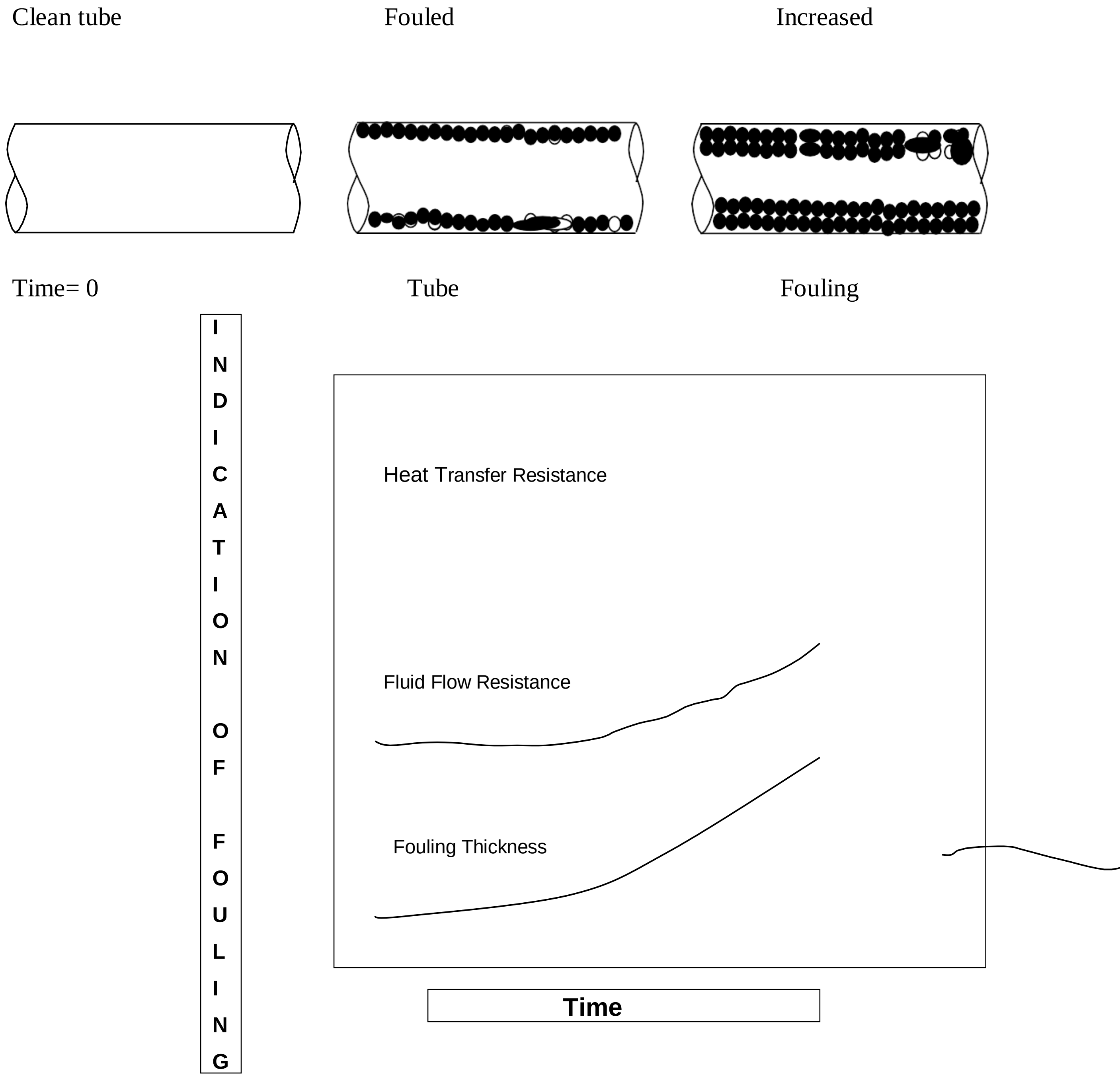



**Fig: 1** (Effect of Fouling)

There is an increase of the roughness, thus increasing frictional resistance to flow, and fouling blocks flow passages; due to these effects, the pressure drop across the heat exchanger increases.

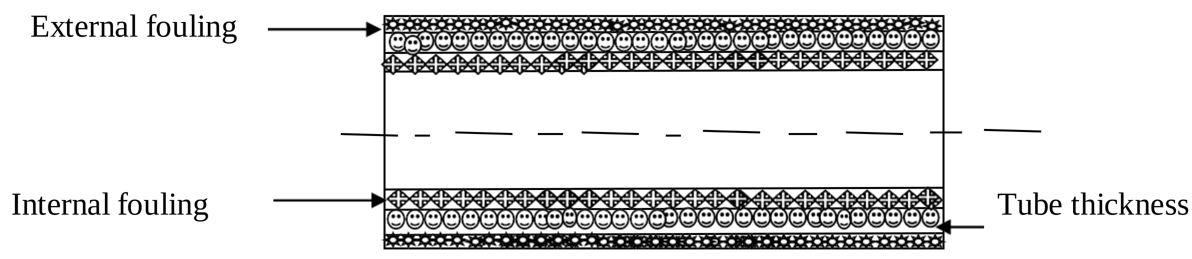



**Fig: 2** (Fouling deposit build up on heat transfer surface)

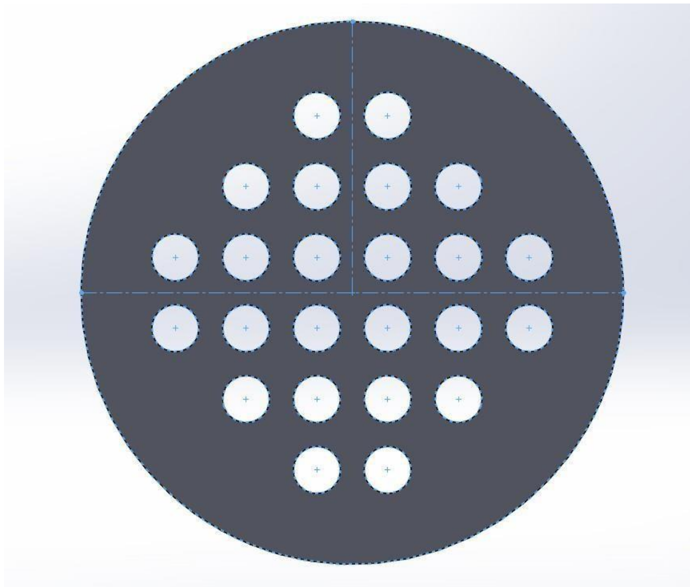
Mathematically total fouling (internal and external fouling) equation is,

$R_{total} = (1/h_iA_i) + (R_{fi}/A_i) + (In(D_o/D_1)/2\pi kL) + (R_{f.o}/A_o) + (1/h_oA_o)$

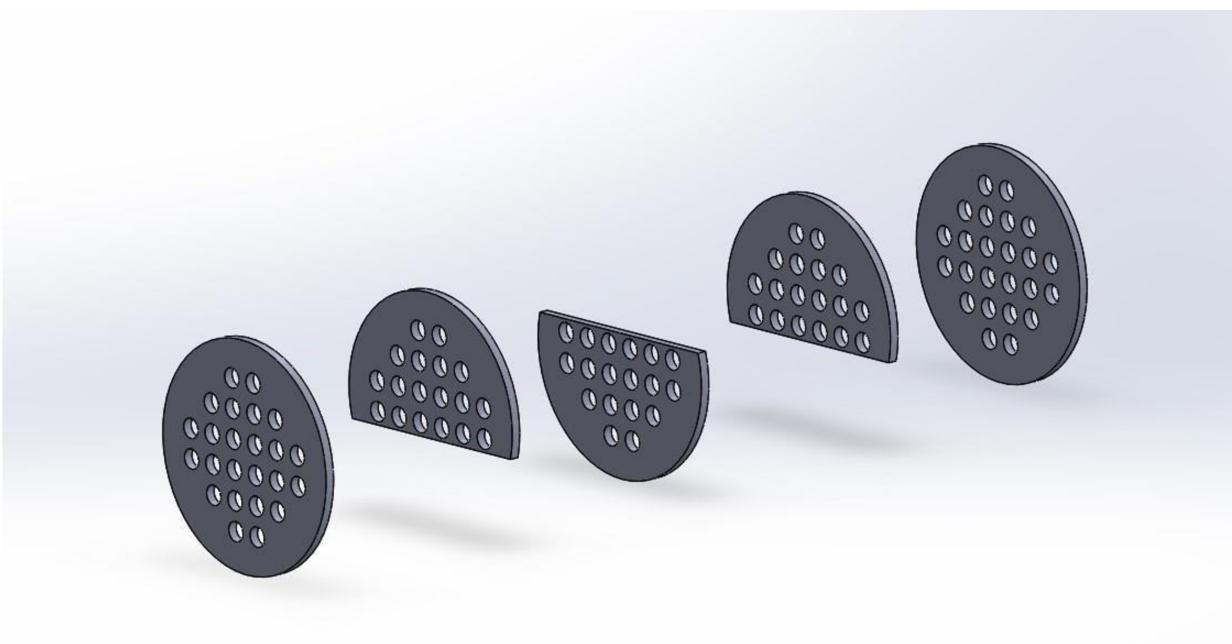
The unit of fouling factor is $\frac{m^2k}{w}$

Range is 0.0001 to 0.0009

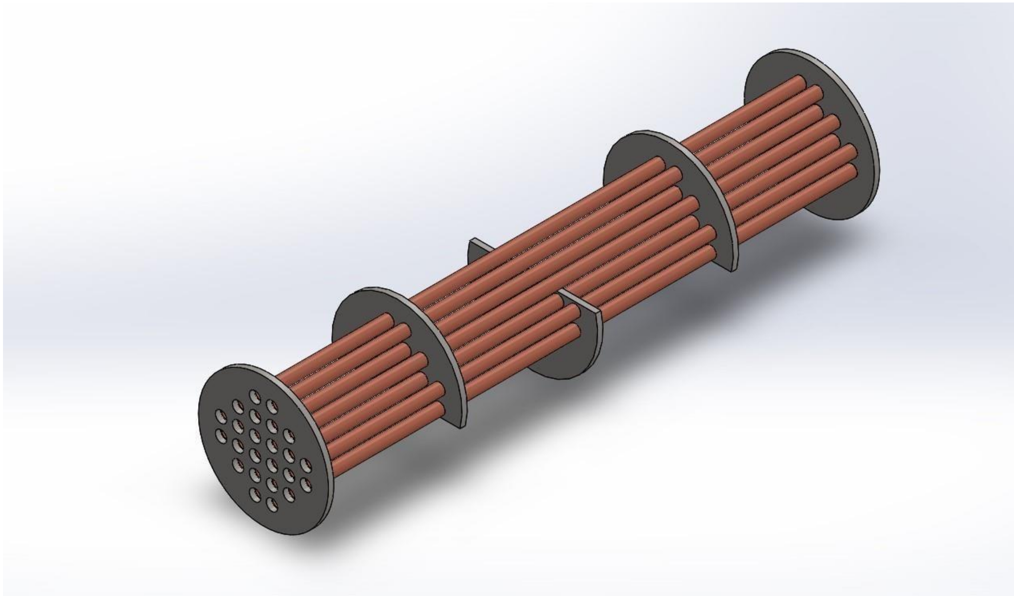
## 2.1.4 Three-dimensional design:



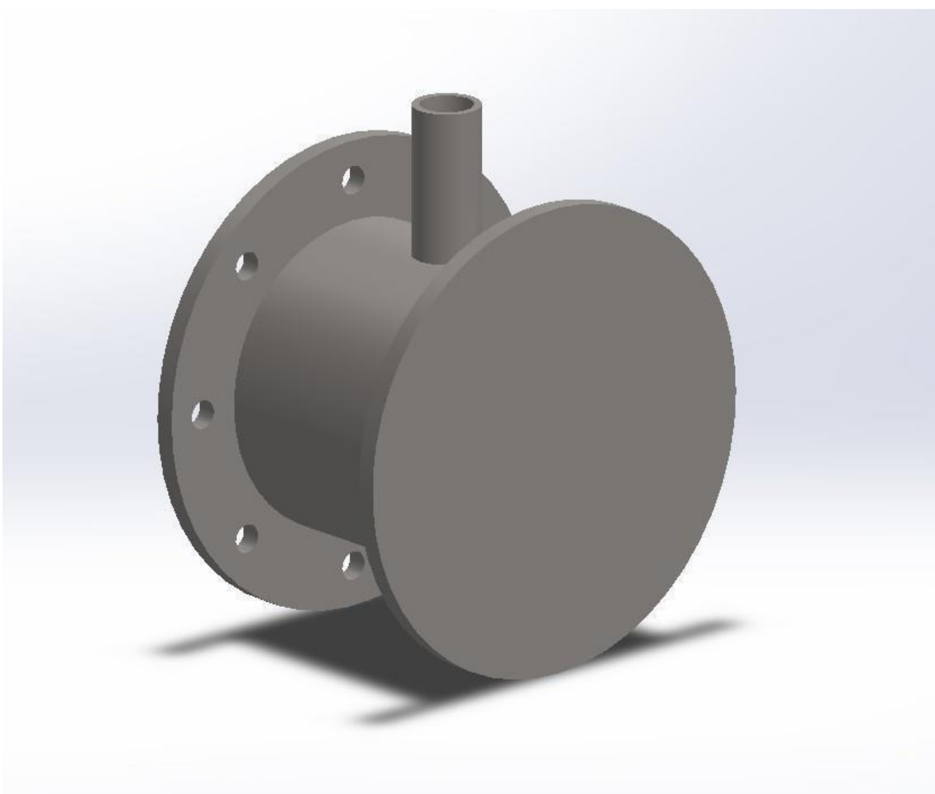
Tube layout



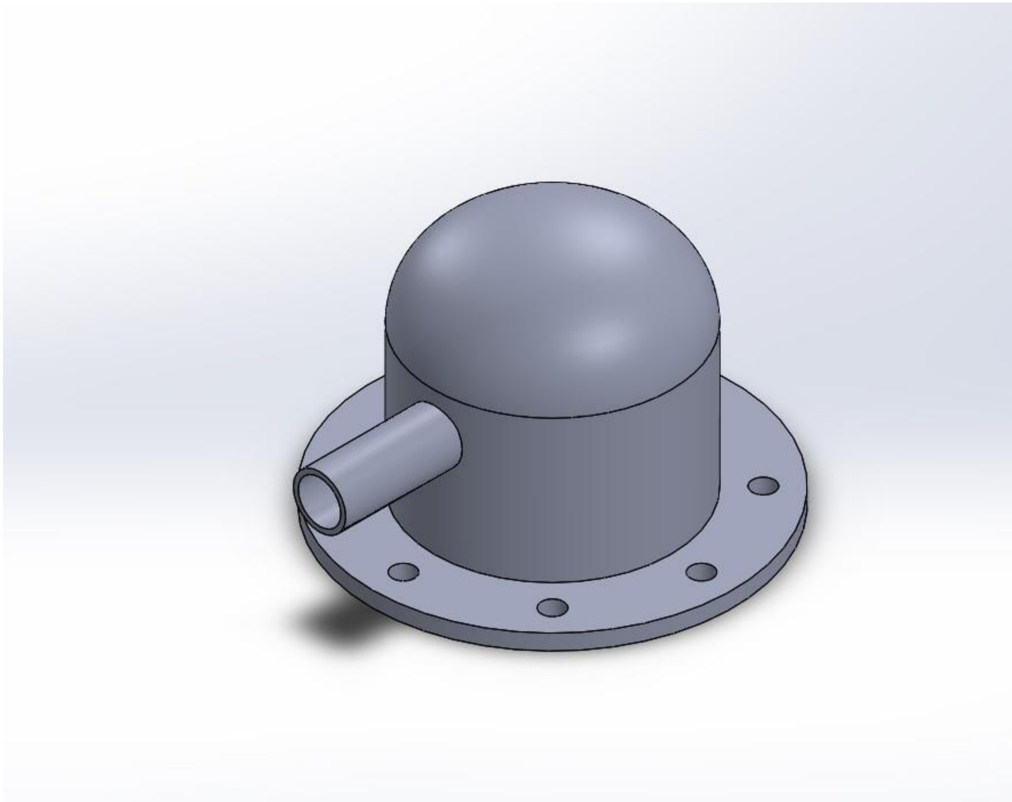
Baffle Plate design



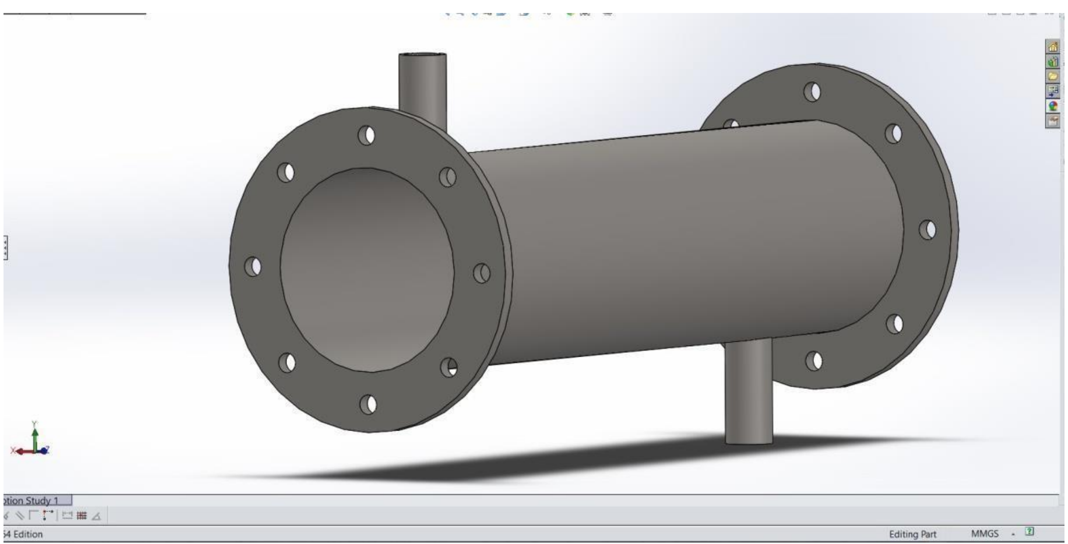
Tube bundle



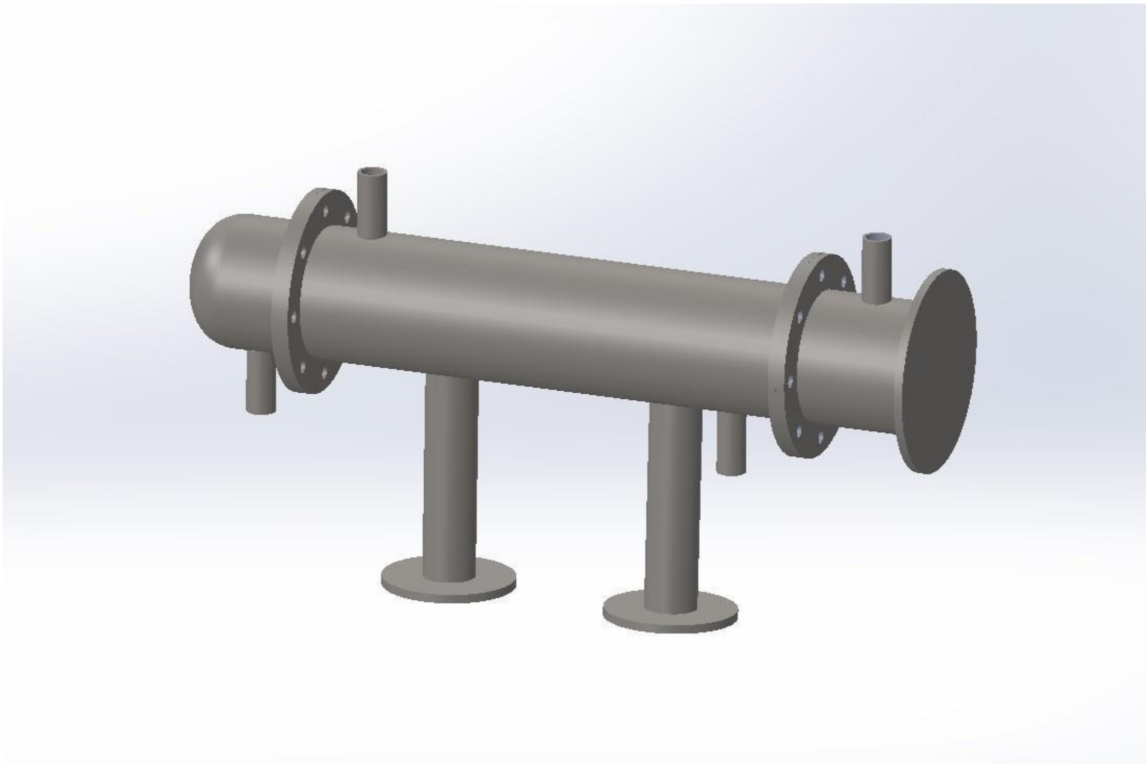
Front End Stationary Head



Rear End Head




Shell Side Cover



Main Product

All **3D drawing** were be done by using **Solidworks-2014**

### 2.1.5 TEMA

Tubular Exchanger Manufacture's Association (TEMA) is the most widely used 'design code'. This is a US code and is used together with ASME Selection VIII (for the design of unfired pressure vessels). The TEMA code specifies the mechanical design procedure, tolerances allowed and the dimensions of the various parts of an exchanger.

ASME – American Society of Mechanical Engineers.

## 2.2 Main Body & Production

The main body was constructed in Mechanical workshop with accurate project's design. The main body was made using mild steel material.

The still photographs of the project during construction

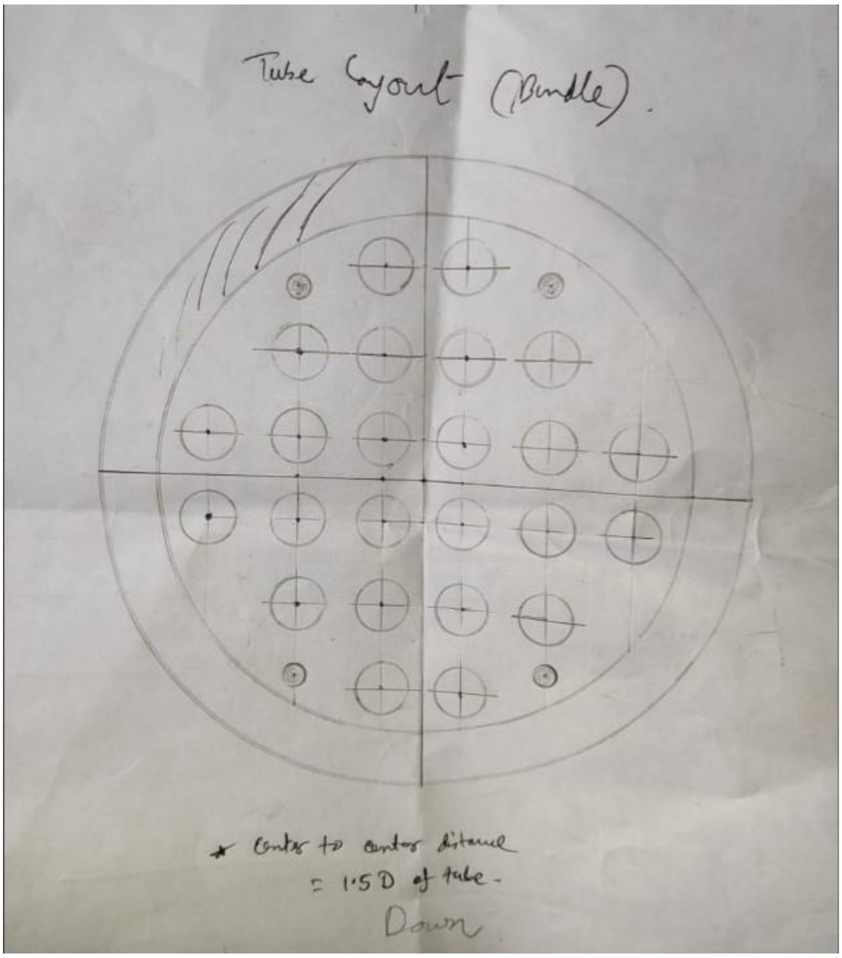



**Fig: 1**(Tube layout of hand drawing)

**Fig: 2** (Copper tubes)

**Fig: 3** (tube layout according to design)

**Fig: 4** (Copper tube and tie rod)

**Fig: 5** (Copper tubes are fixed with tube sheet)

**Fig: 6** (tube bundle including tube-sheet, baffle and copper tube)

**Fig:** 7 (Shell cover and tube side)

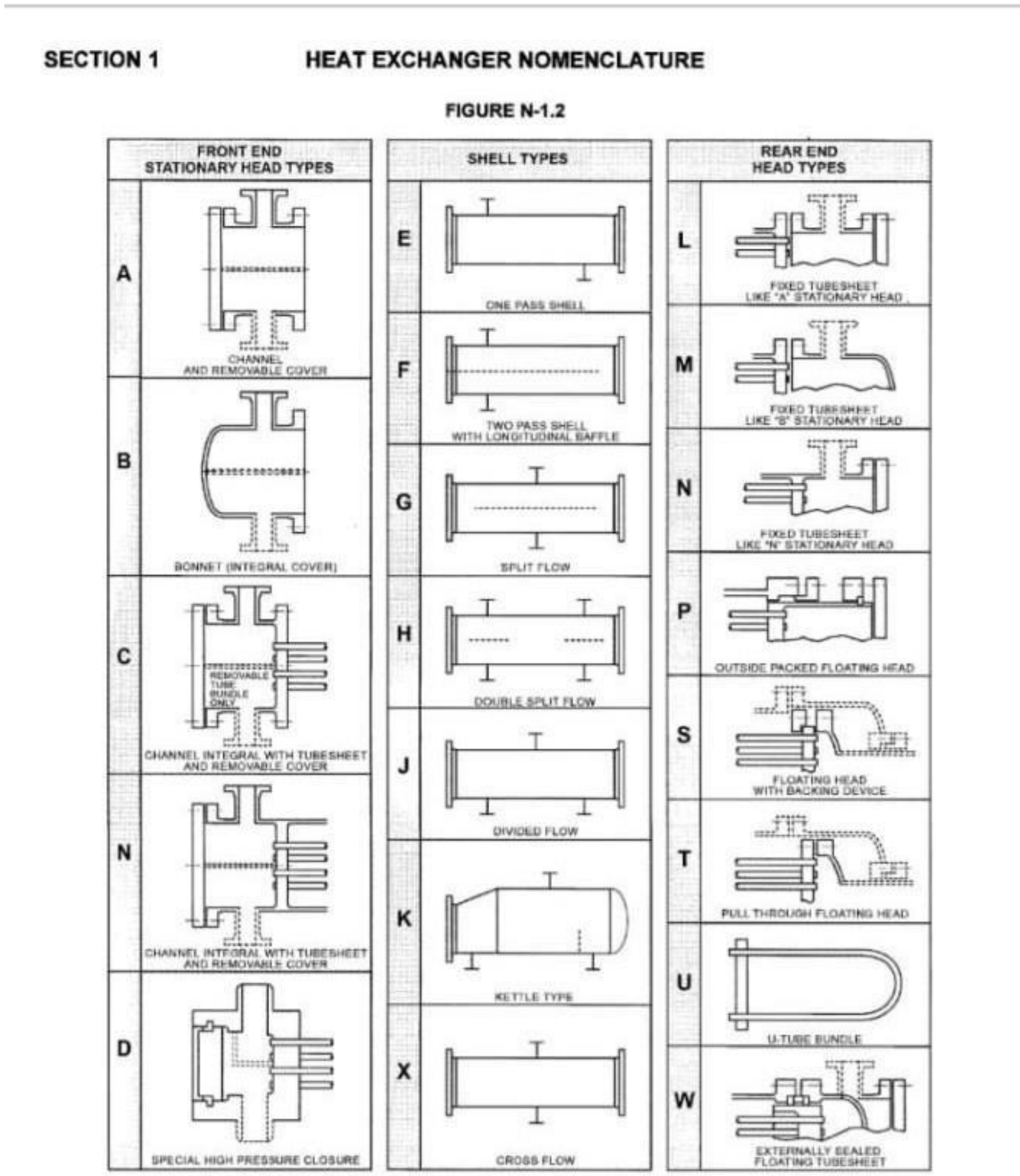



**Fig: 8** (TEMA Design)

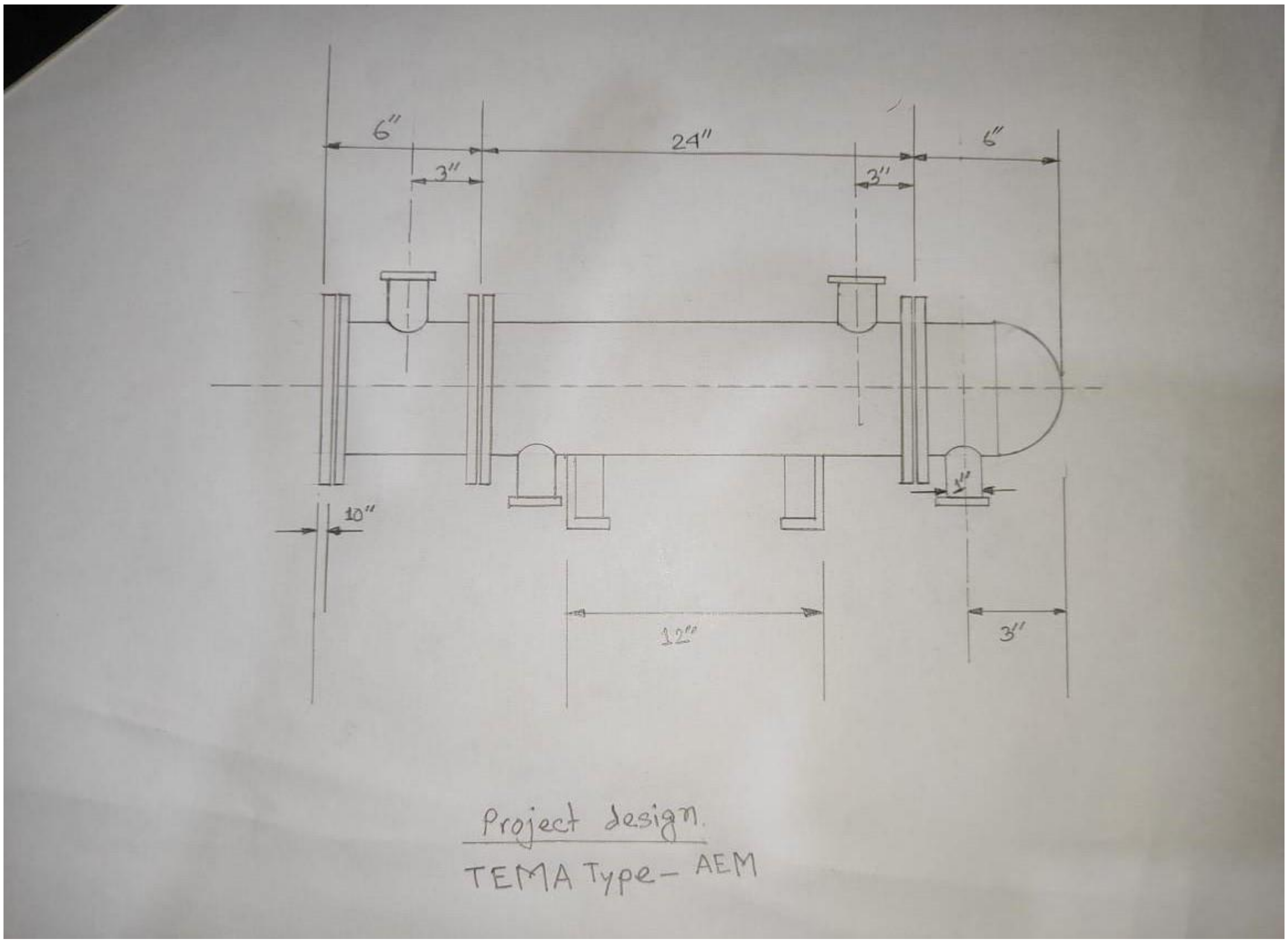



**Fig: 9** (Project design, **TEMA type-AEM**)

**Fig: 10** (front end head cover)

**Fig: 11** (Rear end head cover)

**Fig: 12** (Shell cover)

**Fig: 13** (Insert tube bundle into the shell)

**Fig:14** (Temperature Indicator-TI fittings)

**Fig: 15** (Product with TI)

**Fig: 16** (Final product with painting)

# Chapter 3

# Results

## 3.1 Thermal & Hydraulic Results

## Test 1:

<u>Hydraulic oil (Castor 46) and Hot water</u>

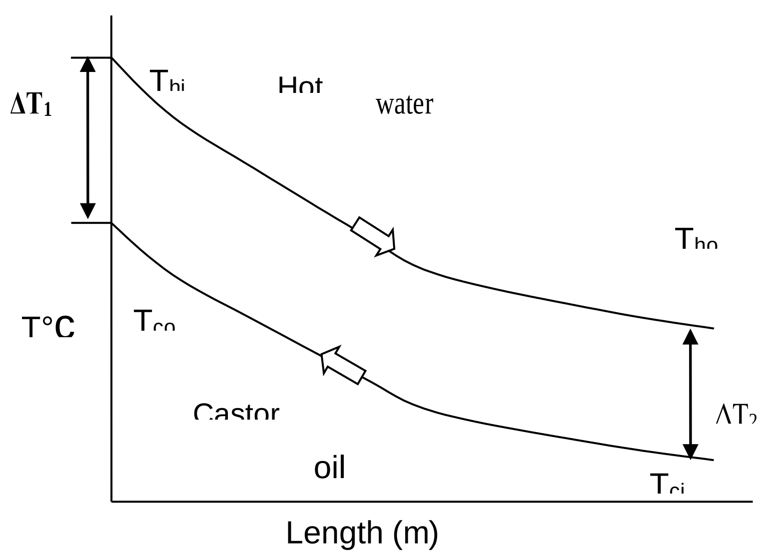
| Fluid allocation | Tube side | Shell side |
|---|---|---|
| Fluid name | Hot water | Hydraulic oil (Castor 46) |
| Fluid condition | Flowing | Non-flowing |
| Temperature (in/out) | 77°c/59°c | 32°c/47°c |

LMTD (counter flow):

$\Delta T_1$ = (77-47)°c = 30°c , $\Delta T_2$ = (59-32)°c = 27°,

LMTD = ( $\Delta T_1$- $\Delta T_2$ )/ln($\Delta T_1$/$\Delta T_2$)=(30-27)/ln(30/27)

=28.47%



## Test 2:

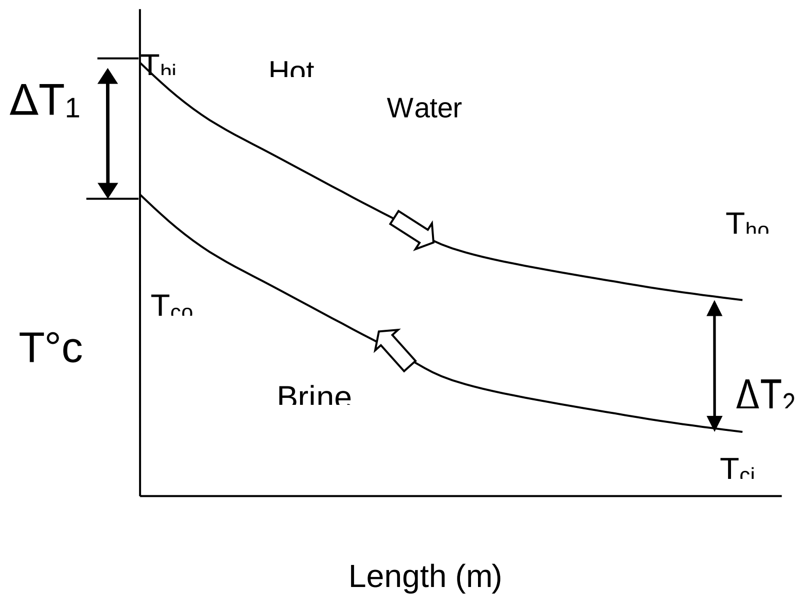
<u>Brine solution 20% concentration & hot water</u>

| Fluid allocation | Tube side | Shell side |
|---|---|---|
| Fluid name | Hot water | Brine solution |
| Fluid condition | Flowing | Non-flowing |
| Temperature (in/out) | 80°c / 62.5°c | 31°c / 46°c |

LMTD (counter flow):

$\Delta T_1$ = (80-46)°c = 34°c, $\Delta T_2$ = (62.5-31)°c = 31.5°c

LMTD = ( $\Delta T_1$- $\Delta T_2$ )/ln($\Delta T_1/\Delta T_2$) = (34-31.5)/ln(34/31.5) = 32.73%



## Test 3:

<u>Geo thermal water & Normal water</u>

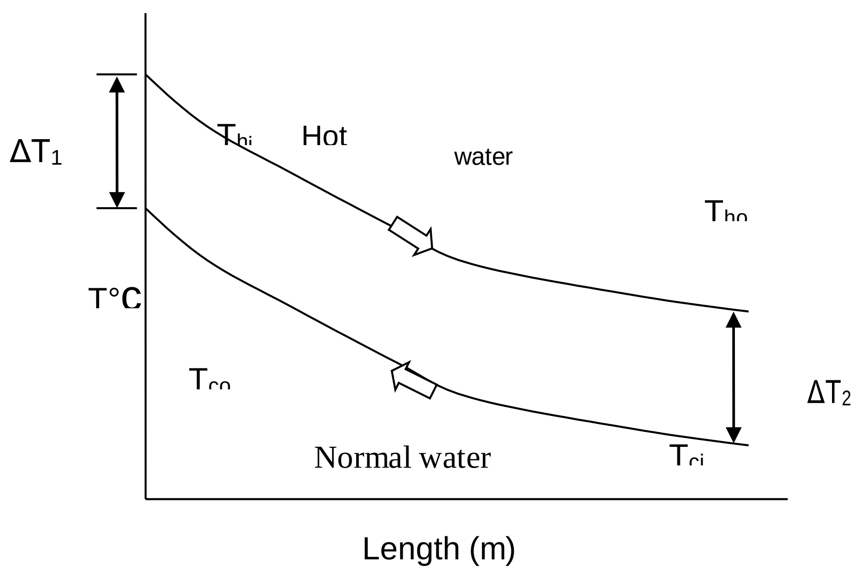
| Fluid allocation | Tube side | Shell side |
|---|---|---|
| Fluid name | Hot water | Normal water |
| Fluid condition | Flowing | Flowing |
| Temperature (in/out) | 75°c / 65°c | 32°c / 39.5°c |

LMTD (counter flow):

$\Delta T_1 = (75\text{-}39.5)°c = 36.5°c$

$\Delta T_2 = (65\text{-}32.5)°c = 32.5°c$

LMTD = $(\Delta T_1 - \Delta T_2)/\ln(\Delta T_1/\Delta T_2)$ = (36.5-32.5)/ln(36.5/32.5) = 34.46%



# CHAPTER 4

# Problems

## 4.1 Problem Analysis:

Since heat exchanger is complicated design as well as rare equipment for workshops. It is not available constructed in local engineering workshops. So, it is very difficult to find proper engineering workshop with experience and skilled man power to fabricate according to the TEMA's design.

To overcome this problem, we have also participated to construct the project.

Due to lack of available proper materials for heat exchanger, it is not easy to find accurate materials for front heat, back head, shell cover and tube.

# CHAPTER 5

# Discussions and Conclusion

## Discussions:

The project has been made is not only a model heat exchanger but also usable in appropriate process.

We faced some limitations for testing. Because of the insufficient Hydraulic oil (Castor 46) and Brine solution.

We could not provide flow of oil and brine in the heat exchanger during testing period. For this reasons the showing temperature of inlet and outlet of TI both shell side and tube side might be a little error.

Moreover, we could not measure mass fluid rate of fluids.

## Total costing of the project

| Item no | Item name | Cost (in taka) |
|---|---|---|
| 1. | Pipe 2ft length and 6” diameter | 1500 |
| 2. | Copper tube ½ ”diameter(24piece) | 6500 |
| 3. | 6” flange (5 piece) | 2000 |
| 4. | 6” flange (closed-1 piece) | 500 |
| 5. | Tube sheet (2 piece) | 1200 |
| 6. | Baffle plate (3 piece) | 1500 |
| 7. | Gasket | 200 |
| 8. | Temperature Indicator (4 piece) | 10000 |
| 9. | Miscellaneous (bolt, nut, wrench, saddle, welding and painting) | 3500 |
| 10. | Labor cost | 15000 |
| | **Total cost** | 41900 |

## Further design and recommendation:

By changing TEMA type, thermal design (tube, materials, tube length, tube diameter, tube layout, tube pass arrangement, baffle design, baffle layout type, baffle to shell clearance), mechanical design (shell length, shell thickness, shell diameter, shell materials, front heat design, back head design, bolts, nuts, flanges, gasket), further design and construction can be done.

## Conclusion:

The constructed one pass shell and tube heat exchanger as stated in TEMA specifications is tested with different fluids.

The LMTD result of those test are very much optimistic. But more development is possible by changing certain parameters. Based on economic, thermal design, mechanical design, more optimization will be done.

# References:


1. TEMA- 10th Edition-2019, Richard C. Byrne
2. Heat Exchanger Design Handbook, T. Kuppan.
3. Copper Tube Handbook, Copper Development Association.
4. Heat and Mass Transfer-Fundamentals and Applications.

   Y.A. Cengel, A.J Ghajar.