Eastern Mediterranean University

Department of Mechanical Engineering

Introduction to Capstone Design
MENG 411

Name of Project: *Multi pass Shell and Tube Heat Exchanger*

Group Name: *Triple A's*

Group Members:

143107 ALI MOHAMED ALI ABDALLAH

147180 AMMAR RAFAT AMMAR

137802 AKRAM TAKRORI

Supervisor: *Assist. Prof. Dr. Murat Ozdenefe*

Coordinator: *Assist. Prof. Dr. Mohammed Asmael*

Semester: *Fall 2018/2019*

Submission Date: *21/12/2018*

JURY MEMBERS

NAME	SIGNATURE
Prof. Dr. UĞUR ATİKOL	
Assist. Prof. Dr. MURAT ÖZDENEFE	
Assist. Prof. Dr. DEVRİM AYDIN	

ABSTRACT

The aim of the project is to design and manufacture a multi pass shell and tube heat exchanger, which is a common type used ranging from power plants to oil industries to remove excess heat from the desired fluid by using another fluid without mixing them.

Heat exchangers mainly include two main parts; the tube with cold fluid and the shell with the hot fluid, by this technique the heat transfer occur during the process without the two fluids mix.

Heat exchanger have advantages such as being able to deal with high temperature and pressure. The main objectives of our project is to build a heat exchanger which can cool down engine oil from 70℃ to 50℃ in the shortest time possible, with water at an initial temperature of 18 ℃, he estimate final temperature is around 28℃ for the cooling water. It is sought to design a cost effective heat exchanger.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

- P_r = Prandtl Number (Dimensionless)
- D= Diameter (mm)
- $V_{avg.}$ = Average velocity (m/s)
- C_P =Specific heat capacity (J/kg K)
- n= number of tubes (Dimensionless)
- As= Surface Area (m^2)
- NTU= Number of transfer Units (Dimensionless)
- E= Effectiveness (Dimensionless)
- $\dot{Q}max$= Maximum Heat transfer (Watts)
- $\dot{Q}$ = Heat transfer (Watts)
- C_c= heat capacity rate of hot fluid (W/K)
- C_h= heat capacity rate of hot fluid (W/K)
- U= Overall Heat Transfer coefficient (W/ m^2.K)
- A_o= Outside Area (m^2)
- A_i= Internal Area (m^2)
- L_T, turbulent = Entrance length turbulent Region (m)
- D_i= internal Diameter (m)
- h_i = Internal heat transfer coefficient (W/ m^2.K)
- h_o= External Heat transfer coefficient (W/ m^2.K)
- Nu= Nusselt Number (Dimensionless)
- Re= Reynolds Number (Dimensionless)
- $A_{external}$ =Area External (m^2)
- k= Thermal Conductivity (W/m.K)

CHAPTER1 – INTRODUCTION

1.1. Detailed definition of the project

Our heat exchanger is a device that enables thermal energy from a fluid to pass to the second fluid without mixing the two fluids. In another words, the essential principle of our project (a heat exchanger) is a device which transfers heat from one medium to another medium, a hydraulic oil cooler for example will remove heat from hot oil by using air or cold water-room temperature as will be used in our project (Multi Pass Shell and Tube Heat Exchanger). As a matter of fact, heat is transferred by the conduction process through the exchanger materials which separate the mediums being used [1].

Shell and tube heat exchanger passes fluids over and through the tubes. Basically, conduction is the process in which energy is transferred from one molecule to another molecule through direct contact; the molecules themselves do not need to change position, but it just simply vibrate less or more quickly against each other. It can be seen that heat exchangers are in in all kinds of places, usually working to cool down or to heat up buildings or helping engines and machines to work more efficiently and effectively. Actually, all heat exchangers have the same function, however they work in various ways. The two most common kinds of heat exchanger are the shell-and-tube (the one that was designed and produced by our capstone team members) and the plate/fin. In shell and tube heat exchangers, one fluid flows through a set of metal tubes made of a specified material which is copper in our case, while the second fluid passes through a sealed iron shell that encompass or in another words surround them.

The two fluids can flow either in the same direction which is basically called as parallel flow, in opposite directions known as counter flow or counter-current, or at right angles which is often called cross flow. [2]

In fact, Boilers in steam locomotives work this way. Plate/fin heat exchangers have many thin metal plates/ fins with a huge surface area because that exchanges more heat more rapidly. There are many types of Heat Exchangers including shell and tube heat exchangers, plate heat exchanger, regenerative heat exchangers, adiabatic wheel heat exchangers , plate fin heat exchangers, dynamic scraped surface heat exchangers and many more. The heat transfer coefficient of tube side and shell side fluid is vitally important and the individual heat transfer coefficients must be high enough to attain high overall heat transfer coefficient. As the shell would be huge as compared to the tubes, the velocity and the turbulence of the shell side fluid is vitally important as well. [3]

Shell-and-tube heat exchangers can be basically used in almost all process heat transfer applications. There it may be required to increase the area to have the desired heat exchange for this low heat transfer coefficient. The area may be increased by increasing the length of the tube. However, the tube length requirement may be impractical for a given situation. Thus the number of tubes should be increased without increased the tube length.

The increased number of tubes would also provide the increased velocity in the shell side resulting in the higher heat transfer coefficient. Therefore, multi-pass construction is needed, which would permit to use the practical and standard tube lengths. [4]

However, the disadvantages are that the construction of the exchangers become complex, parallel flow cannot be avoided, additional friction losses may occur.

In addition to this, it should be noted that generally even number of tube passes are used in the multi-pass heat-exchanger. There are a variety of materials used in the design of shell and tube heat exchangers, including carbon steel, copper stainless steel, brass, bronze, titanium and various alloys like aluminum bass and copper nickel alloys. In addition to capacity and flow ratings, shell and tube heat exchangers are identified by the number of times the fluid passes through the inner tubes. Exchanger diameter and length are also important to keep in mind, especially where space is a factor. [5]

The shell-and-tube heat exchanger is one of the most common type of heat exchanger used in Marine/ Chemical industry and many more. Design temperatures range from -250^{o}C to 800^{o}C. The shell-and-tube heat exchanger will function poorly with any temperature crosses unless multiple units in series are employed. [6]

1.2 Significance of the project

The significance of this project can be basically described by the fact that the shell and tube heat exchangers are the most common type of heat exchanger in the industry.

In fact, they have applications in a wide type of industries ranging from chemical industries to power plants. In addition to this, without shell and tube heat exchangers all these type application where there is the presence of high pressure and velocity fluids have to be heated or cooled would be quite complex to handle.

The significance and the goal of the project is to cool down a ship engine oil using multi-pass heat exchanger using room temperature water in the least time possible and to illustrate the working of this beneficial heat exchanger and how it functions effectively. Shell and tube heat exchangers can have wide variety of designs depending on the application where it will be used. Not only that, but also the pressures of the fluid that will be present/desired and whether these fluids are to be heated up or cooled down. However in our project our aim is to cool down the oil as mentioned earlier. The detailed design process will also be shown later in the report.

1.3. Detailed Project Objectives

The objective of this project is to build a compact multi pass shell and tube heat exchanger to cool down viscous oil (Ship Engine Oil) with room temperature water in the least time possible in a safe way. The hot oil flows inside the shell side while the cold one is on the tube side. Noting that, shell and tube heat exchangers vary in size from hundreds meters to a few meters. The main objective of this project is to design and build a compact and an economical one to achieve the desired result. Another objective of this project is to achieve the maximum amount of heat transfer area and to achieve a certain flow type in a compact size.

The temperature of the hot oil which flows on the shell side will be reduced from 70°C to 50°C with the help of cold water on the tube side which will be at an initial temperature of 18-21°C. The team members agreed to use water since this fluid is one of the liquids with low viscosity and high heat transfer coefficient, so it will extensively help us achieve our goal. The materials that will be chosen to build the heat exchanger are great for the heat transfer application as they have high thermal conductivities. [8]

1.4 Detailed Project Constraints

The capacious project constraint is its size. The heat exchanger design has to be in certain limits of length and diameter according to TEMA standards (Tubular Exchanger Manufacturers Association). Standards sizes have to be not just any sizes can be chosen. Economical constrains have to be considered too, the cost for the project should not exceed a certain limit in order to be cost effective for a senior year project , so the sizes of the pipe for the fluid have to be kept in check, and within these limits the required heat transfer area has to be achieved. [9]

Lastly, health and safety is another constraint that should be checked properly according to the Health and Safety Standards (OSHA). The design should be very safe in order to avoid any unexpected harms or injuries to the group members or any individual who is going to use the project later on. For instance, the shell and tube heat exchanger should not have any leaks in order to avoid any flammable incidents which could be very problematic and could be quite difficult to-resolve. [10]

1.5 Report Organization

- Chapter 1, discusses the definition of Multi Pass Shell and Tube Heat Exchangers, the importance and the significance of the project, goals and objectives of the activity and lastly the limitations (constraints).

- Chapter 2, includes the background information about manufacturing processes and the steps needed to design and produce the heat exchanger and the concurrent solutions for different types of heat exchangers.

- Chapter 3, discusses more about the design and analysis which includes the selected design where all members agreed to work on, engineering standards followed during the activity, design mathematical calculations and finally the cost analysis.

- Chapter 4, includes the discussion about manufacturing process selection and the detailed manufacturing process

- Chapter 5, discusses the Verification plan of the objectives of the project and Verification plan of the applied engineering standards

- Chapter 6, discusses the simulation and testing of the shell and tube heat exchanger.

CHAPTER 2 - LITERATURE REVIEW

2.1 Background information

Heat exchangers are generally used to transfer heat energy from one fluid to another fluid in order to control the temperature of a system. Heat exchangers usually contain two fluids where one is hot while the other one is cold; they are separated by a thermally conductive tube or plate unless the fluids are immiscible. The two streams are directed such that one transfers the thermal energy to the other. In addition to this, according to the heat transfer process, the heat exchanger may use a direct contact or in direct contact heat transfer method. Indeed, in direct contact heat exchangers, the fluids are immiscible (e.g. gas and liquid) and therefore, do not require physical separation when transferring heat.

However, in indirect contact heat transfer, the fluids in the system are separated by a thermally conductive boundary layer which allows heat energy to flow, but prevents mixing. There are several ways leads to the classification of Heat exchangers for example according to flow arrangements, the heat exchanger may be either single pass or multi-pass. It may incorporate cross-flow, counter-flow, or co-current flow. Generally, heat exchangers combines these flow patterns to enhance thermal efficiency. Fluids in multi-pass heat exchangers are looped back to flow by each other multiple times. [11]

The Four arrangements which a fluid can flow through a heat exchanger are:

- **Counter flow:** In this type of flow the two fluids in the heat exchanger flow parallel but opposite in direction. This is the most efficient type of flow since it allows the largest heat transfer.
- **Concurrent Flow:** In this both the fluids flow together in parallel and same direction. This is less efficient than the counter flow arrangement.
- **Cross Flow:** In Counter flow one fluid is flowing vertically and the second one is flowing horizontally across each other .The efficiency of this type of flow arrangement is in between the counter and parallel flow. This can be more efficient than the other 2 arrangements if the flow rate of one fluid is less than the flow rate of the other fluid.

For our heat exchanger we have picked the cross flow arrangement since it is quite efficient.

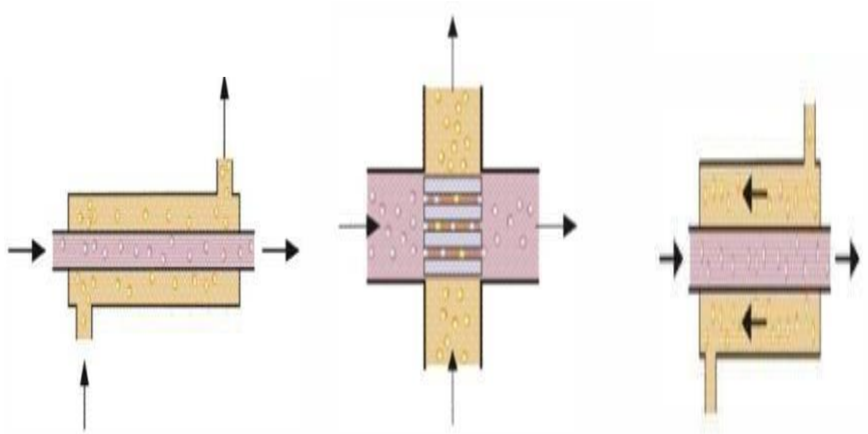

Figure 1 Counter, Parallel, Cross Flow Arrangement [5]

The very basic design of shell and tube exchangers was made in the early 1900s to fill the needs in power plants for large heat exchanger surfaces like feed waters heaters and condensers in order to be able to operate under extensively high pressures industry which popularized the use of shell and tube heat exchanger and made it a very popular product was the oil industry. This revolution also started around 1900s. The shell and tube heat exchangers became popular in this industry because of the high temperatures and pressure which the shell and tube heat exchanger can basically handle better than all the other types of heat exchangers. Shell and tube heat exchangers are also very good with impure liquids that have high viscosities. Shell and tube heat exchangers are used in the oil industry as boilers, condensers, oil heaters etc. Another advantage of shell and tube heat exchangers is that it is easy to get rid of the dirt that accumulates over time.

The most serious problems in these early stages of shell-and-tube heat exchanger development was the material strength calculations for the various components, mainly the tube sheets. Other problems included were the assembly of the components. Putting the components together was a difficult procedure and sophisticated manufacturing had to be used. All of these problems were eliminated during the 1920s because of the great development in this field. [12] .

During the 1920s shell-and-tube manufacturing technology became fairly well developed, mainly because of the efforts of relatively few major manufacturers. Units up to 500 m^2

that is, approximately 750-mm diameter and 6-m length were manufactured for the rapidly growing oil industry. [12]

In the 1930s, the shell-and-tube heat exchanger designers established many sound design principles from intuition and data emerging on ideal tube banks. Viscous flow was one of the most difficult problems for shell-side flow and was poorly understood until the 1960s.

2.2 Concurrent solutions

This section describes the different types of heat exchangers used in industry for variety of purposes.

Nowadays, several types of heat exchangers are used in different filed, there are various types of heat exchangers. As most common types of heat exchangers and the application that is used to is the ‘’Shell and Tube Heat Exchangers” which are comprised of four main parts.

First part is the front end; basically it is the entrance of the fluid which flows in the tubes. Second, the back end which is the exit of the fluid is flows in the tubes .Third, the tube bundle consists of the number of tubes inside the heat exchanger, to hold this tubes we use baffles, tie rods etc. Fourth, the shell this is the outer part of the heat exchanger which is basically the casing of tube bundle.

The number of tubes and their arrangements inside the shell depends on the fluid and the heat transfer required or the desired application. Normally the hot fluid flows and moves inside the shell and the cold fluid flows inside the tubes, and the heat transfer takes place across the surface of the tubes. The number of times the fluid passes through the shell is known as a shell pass and the number of times passes through the tubes is known as the tube pass. [12]

The tube pass is normally an even number because with the odd number unwanted stresses are produced inside the tubes.

Overall the shell and tube heat exchanger have three main types as shown below which is:

- The Fixed Tube Sheet heat exchanger is the mostly used type of heat exchangers in all of the industries field because of the ability to be used in higher temperature and higher-pressure applications. [13]

- The Floating Head Heat Exchanger In this type of heat exchanger; tube sheet which is in the back Header end is not welded or attached without moving to the shell but allowed to float or move. The Tube sheet at the Front Header has a larger diameter than the shell, those specifications make the floating head heat exchanger used and recommended in place of fixed plate heat exchanger for high pressure and temperature operation is required.

- The last type of multi pass shell and tube heat exchanger is the U-tube heat exchanger in this type both the tube bundle and the shell side can be inspected and cleaned mechanically the application that used such as Water heating with steam , Refrigeration , Cooling tower trim cooling, Condensate cooling and Preheating boiler feed water.

However, as the desired applications or projects get more complicated, the recommended systems usually required to combine techniques` or method to reach the desired objective. For defining the required shell and tube heat exchanger or any other type of heat exchanger to choose for desired application, the using of heat exchanger configuration is required.

There are several ways of classification. The classification according to flow arrangements, such as single and multi-pass; as flow classification there is four basic flow configurations for the shell and tube heat exchangers; Counter Flow, Concurrent Flow, Cross flow and Hybrids such as Cross Counter flow and Multi Pass Flow There are other ways of classification that the heat exchangers are differ in; such as the classification according to the transfer process, in the direct and the indirect contact type.

- *Indirect Heat Exchangers*

In this type of heat exchangers the fluids are separated by a wall which is made up of a metal usually, the most indirect contact type heat exchangers are tubular heat exchangers and plate heat exchangers.

Tubular heat exchangers are well known for their enhanced flexibility in its design. The flexible parameters include wide range of pressures and temperatures.

Tubular can further be subdivided into shell and tube heat exchangers and plate heat exchangers as shown below.

- *Shell and Tube Heat Exchangers*

This is the most common type of heat exchanger as discussed before it consists of outer cylindrical shell in which the tubes are placed. Fluids within the heat exchanger can exchange heat, as one fluid passes through the shell or outside of the tubes and the other flows inside the tubes. The tubes can be arranged in the shell in 3 distinct ways: as U-tube, Straight tubes with two pass and Straight Tube Heat Exchanger with one pass.

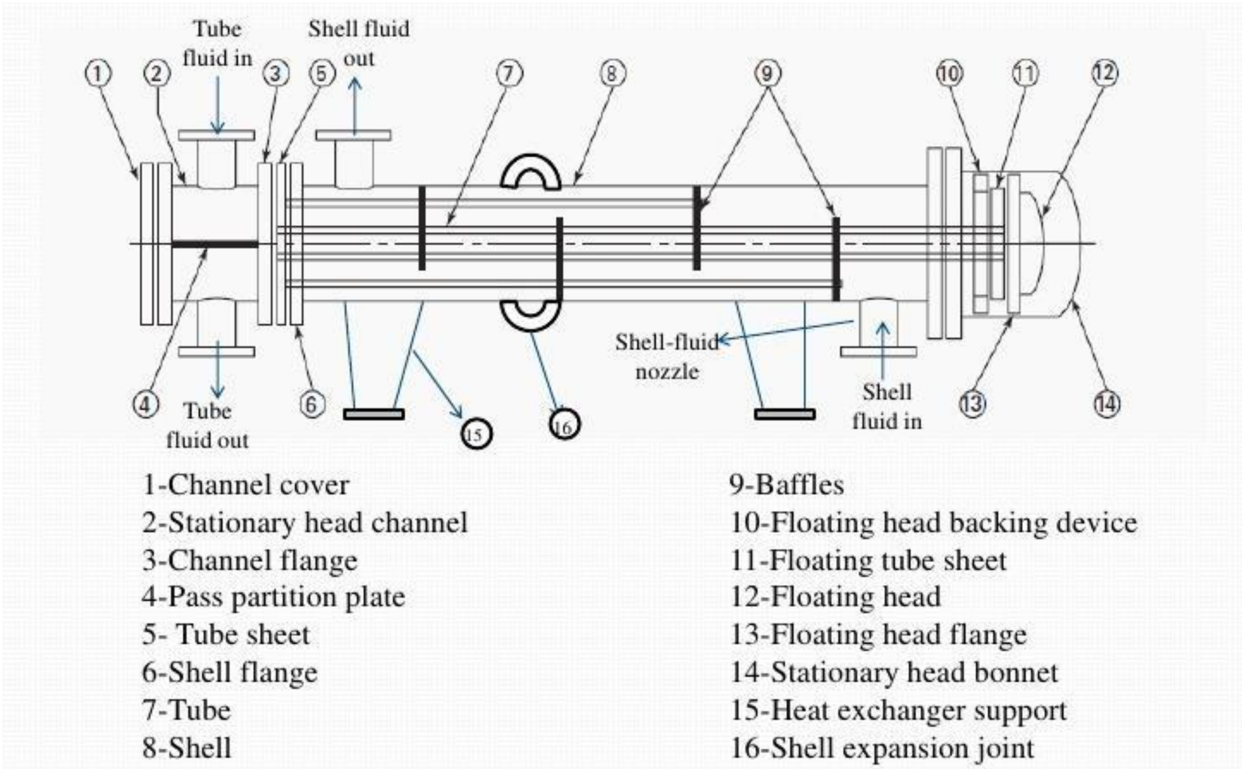

Figure 2 Components of shell and tube heat exchanger [7]

- <u>*Plate and Frame Heat Exchanger*</u>

This type of heat exchanger includes a couple of rectangular end members which clutch together a number of embossed rectangular plates, which consist of holes on the corners which allow the fluid to flow though. Gaskets are used to separate the plates, seal them and also arrange the flow of the fluid. This class of heat exchangers has applications in food industry since they are easy to clean.

In the direct contact type or "Direct Type Heat Exchangers" the heat transfer surface is absent, due to this it cost less than the indirect type heat exchanger however the limitation of this heat exchanger is that the fluids must be immiscible or there must be phase change when a single fluid is used. Generally we found that immiscible, gas-fluid, and liquid vapor fluids are used in this types.

Other ways of classification is the classification due to the construction and the heat transfer mechanism. According to that classification which can define other type of heat exchanger not just for shell and tube types, further types of heat exchanger is shown below:

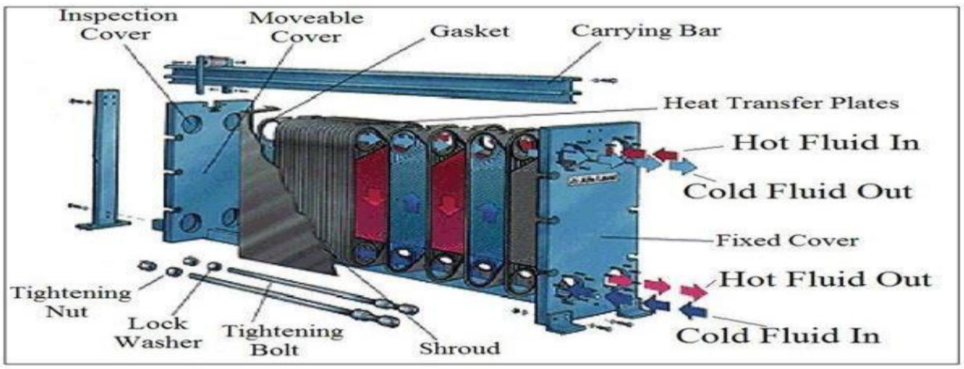

Figure 3 Plate and Frame heat exchanger parts [5]

- *<u>Regenerative Heat Exchangers</u>*

This type of heat exchanger, the flow consists of a matrix shape component, which is initially heated when the hot fluid passes through it which is known as the hot blow. This heat is later transferred to the cold fluid when it flows through the matrix which is called cold blow. Applications of regenerative heat exchangers included “gas to gas” heat recovery applications in power stations.

- *Recuperative Heat Exchangers*

This kind of heat exchangers can be divided into two categories which consist of indirect contact and direct contact heat exchanger.

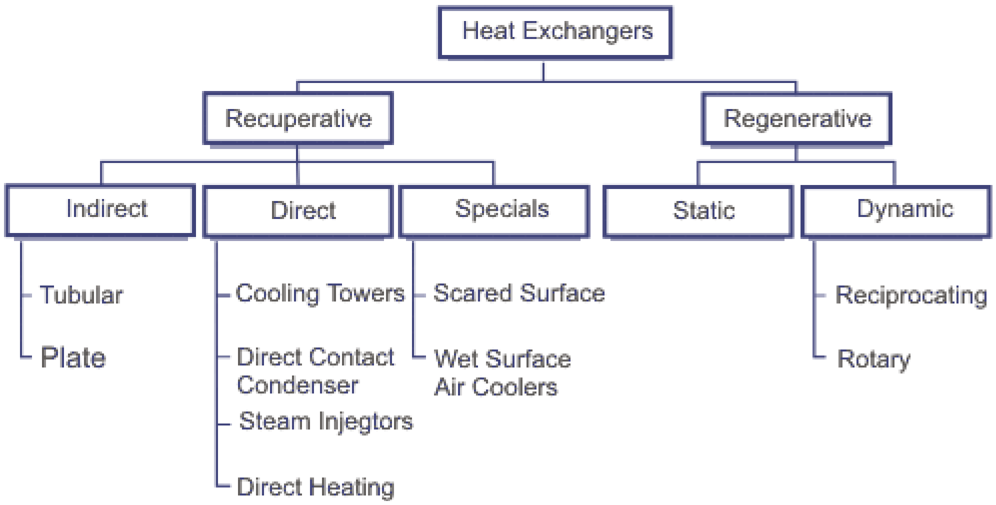

Figure 4 Recuperative and Regenerative subtypes

2.3 Comparisons of the concurrent solutions

In this section comparison of the existing solutions of heat exchangers will be discussed and their benefits, drawbacks and applications will be discussed.

Heat exchanger type	Advantage (s)	Disadvantage (s)
Plate Heat Exchangers	• High value for overall heat transfer coefficient • Easy cleaning and maintenance	•High pressure drop •Does not work very effectively with very high fluid temperatures •Potential for leakage
Shell and tube Heat Exchangers	•Less expensive compared to the Plate type •Used in systems with higher operating pressures and temperatures •Less pressure drop across a tube cooler •Tube leaks are easily located	•Heat transfer efficiency is less compared to plate type cooler. •Cleaning is quite difficult •Capacity of tube cooler cannot be increased. •Requires more space.
Finned tube heat exchanger	•Use to handle low heat transfer coefficient fluids •Used for cooling and heating of a vast quantity of gases	•Slurry fluids cannot be handled •Deposition of the particle at fin corner •Cleaning difficulty •High-pressure drop
Tubular heat Exchangers	•Slurry fluids cannot be handled •Deposition of the particle at fin corner •High-pressure drop	•Leakage corners which is not preferable •Takes a lot of time to do its maintenance •Occupy more floor space (areas) compared to Others

Table 1 Advantages and Disadvantages of different types of heat exchangers

2.4 Engineering standards of the concurrent solutions

Standards should be present in every industry. They are used to have a uniform design, methods and processes across the world. Each industry have certain standard they follow and adhere there product according to it. . There are many standards that cover heat exchangers, a few of the famous ones will be mentioned in the next paragraph. [11]

- TEMA: "Tubular Exchange Manufacturer's Associations" .TEMA standards are for shell and tube heat exchangers and include their design, construction, placement and how to use them and their maintenance after they have been installed. TEMA have sub-standards to cover wide variety of shell and tube heat exchangers. Engineering standards for concurrent solutions or the types of heat exchanger that we have is basically based on the Typical TEMA code for each kind there are several codes. For every different type of heat exchanger we have different" Type of codes" to be used as shown below :
- The fixed tube sheets have typical TEMA codes as BEM, AEM which meant to the following instruction and limitations; "Shell side is completely welded up, however, the bonnets are removable. Chemical, mechanical, and water blast cleaning of the tubes is possible, and you do not have access to the shell. You should avoid using Steam cleaning on a fixed tube sheet unit unless the unit has a shell side expansion joint. The steam will cause the tubes to expand and pull out of the Tube Sheet causing failure at startup". [11]

- The Floating head typical codes we have AEW, BEW, BEP, AEP" These are straight tube units with one inside packed floating head and one stationary head. The floating head is generally sealed with packing. These units are most often used as intercoolers and after coolers with the gas on the tube side. They are also the most common style for oxygen service exchangers. These units have been used in services with tube side design pressures in excess of 2000 PSIG [11]

- For the U-Tube code types we have BEU and AEU, which mean "U Bundle Exchangers are generally the most cost effective design style of removable bundle exchanger. Tubes may be water blasted, steam or chemically cleaned. These units must have an even number of tube passes, sometimes limiting their applicability to a service (e.g. they generally cannot be used when a temperature cross occurs) .

- HEI: Stands for "Heat Exchange Institute". This is the leading standard for the design and development of heat exchangers and covers variety of their types such as feed water heaters, shell and tube heat exchangers and plate heat exchangers.

- ASME: The "American Society of Mechanical Engineers standards" covers variety of heat exchangers. In fact, the standards define the geometry and provide security regulations. In addition to this, it basically covers the cost of making the equipment at a reasonable cost. [23]

CHAPTER 3 - DESIGN and ANALYSIS

3.1 Proposed/Selected design

In this section of report the design of the heat exchangers will be purposed and the configuration will be decided. The figure below shows the schematic of basic shell and tube heat exchanger with the fluid inlets and outlets, tank, oil pump, flow meter and heating coils.

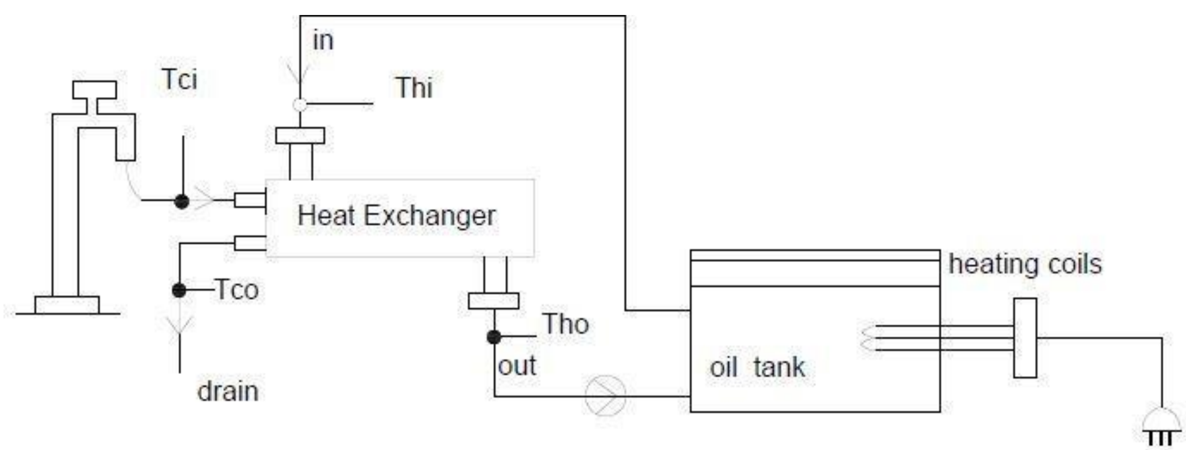

Figure 5 Schematic Diagram of the system

Symbols

Tci = Inlet Temperature of cold fluid
Thi= Inlet Temperature of hot fluid
Tco= Outlet Temperature of cold fluid
Tho= Outlet temperature of hot fluid

3.1.2 “The components of the “Shell and Tube Heat Exchanger”

- **Tubes/Pipes*:*** These are metal pipes present inside the shell through which the other fluid flows. The fluid in the tube is normally the hot one. The number of tubes depends on the applications.

- **Shell:** This is the enclosure or the casing of the shell and tube heat exchanger and one of the fluids flows though this part. It is made up of a metal pipe and is normally of a cylindrical shape. Its material and the size depend on the application. The fluid inside the shell is normally the cold one.

- **Flanges:** These are the sections through which the tube and the shell side fluid enter and leave the heat exchanger**.** Following the DIN standards

- **Tube Sheets**: are plates or forgings drilled to provide holes through which tubes are inserted. Tubes are appropriately secured to the tube sheet so that the fluid on the shell side is prevented from mixing with the fluid on the tube side. Holes are drilled in the tube sheet normally in either of two patterns, triangular or square.

- **Baffles:** The baffles are the walls that regulate the flow of the fluid inside according to the flow arrangement. It also helps the fluid flow over the tubes properly so that the contact area is maximized.

3.1.2 Equations Governing the Analysis of Heat Exchangers

GOVERNING EQUATIONS

Mass flow rate

$$\dot{m} = A_{external} \times \rho \times V_{avg.} \qquad (3.1)$$

$\rho = Density$

$V_{avg.} = Average\ Velocity$

Reynolds Number (3.2)

$$Re = \frac{\rho V_{avg.}\ D}{\mu}$$

Re= Reynolds Number

$\mu = Dynamic\ Vicscoity$

$D = Diamerter$

$h = Heat\ Transfer\ Coefficient$

$Pr = Prandlt\ Number$

$$Nu_D\left(D_h, L_t, Re_D, Pr\right) := \begin{cases} \left(\frac{f\left(Re_D\right)}{2}\right) \cdot \frac{\left(Re_D - 1000\right) \cdot Pr}{1 + 12.7 \cdot \left(\frac{f\left(Re_D\right)}{2}\right)^{0.5} \cdot \left(Pr^{\frac{2}{3}} - 1\right)} & \text{if } Re_D > 2300 \\ 1.86\left(\frac{D_h \cdot Re_D \cdot Pr}{L_t}\right)^{\frac{1}{3}} & \text{otherwise} \end{cases} \qquad (3.3)$$

Bulk mean fluid temperature $T_b = \frac{T_i+T_e}{2}$ (3.4)

T_b = $Bulk\ Temperature$

T_i=$Temperature\ Inlet$, T_e=$Temperature\ Exit$

To check the flow fully developed of still developing

$$L_{t,Turbulent} \approx L_{h,turbulent} = 10D \quad (3.5)$$

$$L_{t,laminar} = 0.05 \text{ Re Pr D} = \text{Pr} L_{h,laminar} \quad (3.6)$$

Heat gain by the cold fluid is equal to heat loss by the hot fluid

$$\dot{Q} = \dot{m}_c c_{pc}(T_{c,out} - T_{c,in}) \quad (3.7)$$

$$\dot{Q} = \dot{m}_h c_{ph}(T_{h,in} - T_{h,out}) \quad (3.8)$$

Where:

$\dot{m}_h$, $\dot{m}_c$= mass flow rates of the hot and cold fluid

c_{pc}, c_{ph} = specific heats

$T_{c,out}$, $T_{h,out}$ = outlet temperature of the fluids

$T_{c,in}$, $T_{h,in}$= inlet temperatures of the fluids

The Overall heat transfer coefficient U calculated by the following equation

$$\frac{1}{UA_s} = \frac{1}{UA_i} = \frac{1}{UA_o} = \text{R} = \frac{1}{h_i A_i} + \frac{1}{h_o A_o} + R_{wall} \quad (3.9)$$

Some Ranges of U for heat exchangers are given in the table below

The total heat transfer areas for both fluids are obtained as follows:

$$Ai := \pi \cdot di \cdot Lt \cdot Nt$$

$$Ao := \pi \cdot do \cdot Lt \cdot Nt \tag{3.10}$$

Type of heat exchanger	U, W/m^2 · °C*
Water-to-water	850–1700
Water-to-oil	100–350
Water-to-gasoline or kerosene	300–1000
Feedwater heaters	1000–8500
Steam-to-light fuel oil	200–400
Steam-to-heavy fuel oil	50–200
Steam condenser	1000–6000
Freon condenser (water cooled)	300–1000
Ammonia condenser (water cooled)	800–1400
Alcohol condensers (water cooled)	250–700
Gas-to-gas	10–40
Water-to-air in finned tubes (water in tubes)	30–60†
	400–850†
Steam-to-air in finned tubes (steam in tubes)	30–300†
	400–4000‡

Table 2 typical values of heat transfer coefficient. [7]

Heat exchanger type	Effectiveness relation
1 *Double pipe:*	
Parallel-flow	$\varepsilon = \dfrac{1 - \exp[-NTU(1+c)]}{1+c}$
Counter-flow	$\varepsilon = \dfrac{1 - \exp[-NTU(1-c)]}{1 - c\exp[-NTU(1-c)]}$
2 *Shell and tube:*	
One-shell pass 2, 4, . . . tube passes	$\varepsilon = 2\left\{1 + c + \sqrt{1+c^2}\,\dfrac{1 + \exp[-NTU\sqrt{1+c^2}]}{1 - \exp[-NTU\sqrt{1+c^2}]}\right\}^{-1}$
3 *Cross-flow (single-pass)*	
Both fluids unmixed	$\varepsilon = 1 - \exp\left\{\dfrac{NTU^{0.22}}{c}[\exp(-c\,NTU^{0.78}) - 1]\right\}$
C_{max} mixed, C_{min} unmixed	$\varepsilon = \frac{1}{c}(1 - \exp\{1 - c[1 - \exp(-NTU)]\})$
C_{min} mixed, C_{max} unmixed	$\varepsilon = 1 - \exp\left\{-\frac{1}{c}[1 - \exp(-c\,NTU)]\right\}$
4 *All heat exchangers with $c = 0$*	$\varepsilon = 1 - \exp(-NTU)$

Table 3 Effectiveness relation of different types of heat exchangers [7]

For the effectiveness, relation is given below

$$\varepsilon = \frac{\dot{Q}}{\dot{Q}_{max}} = \frac{\text{Actual heattransfer}}{\text{Maximum possible Heat transfer}} \tag{3.11}$$

$$\dot{Q} = C_c(T_{c,out} - T_{c,in}) = C_h(T_{h,in} - T_{h,out}) \tag{3.12}$$

$$\Delta T_{max} = T_{h,in} - T_{c,in} \tag{3.13}$$

$$\dot{Q}_{max} = C_{min}\Delta T_{max} \tag{3.14}$$

Where C_{min} is the smaller of $C_h$and C_c

Effectiveness equation can be selected according to the design.

Where c is capacity ratio

$$c = \frac{C_{min}}{C_{max}} \tag{3.15}$$

$$C_h = \dot{m}\, C_P \tag{3.16}$$

3.2 Engineering Standards

We have followed the TEMA (Tubular Exchanger Manufacturer Association) standards which have comprehensive detail on the design and manufacturing of shell and tube heat exchangers. They include a lot of configurations of which we have picked one. The materials of the pipes are also according to the standard. The diameter of the pipes are according to the size but the length isn't because in standard the length is quite which contradicts with our design objective of the heat exchanger being compact. The figure different shapes of TEMA design

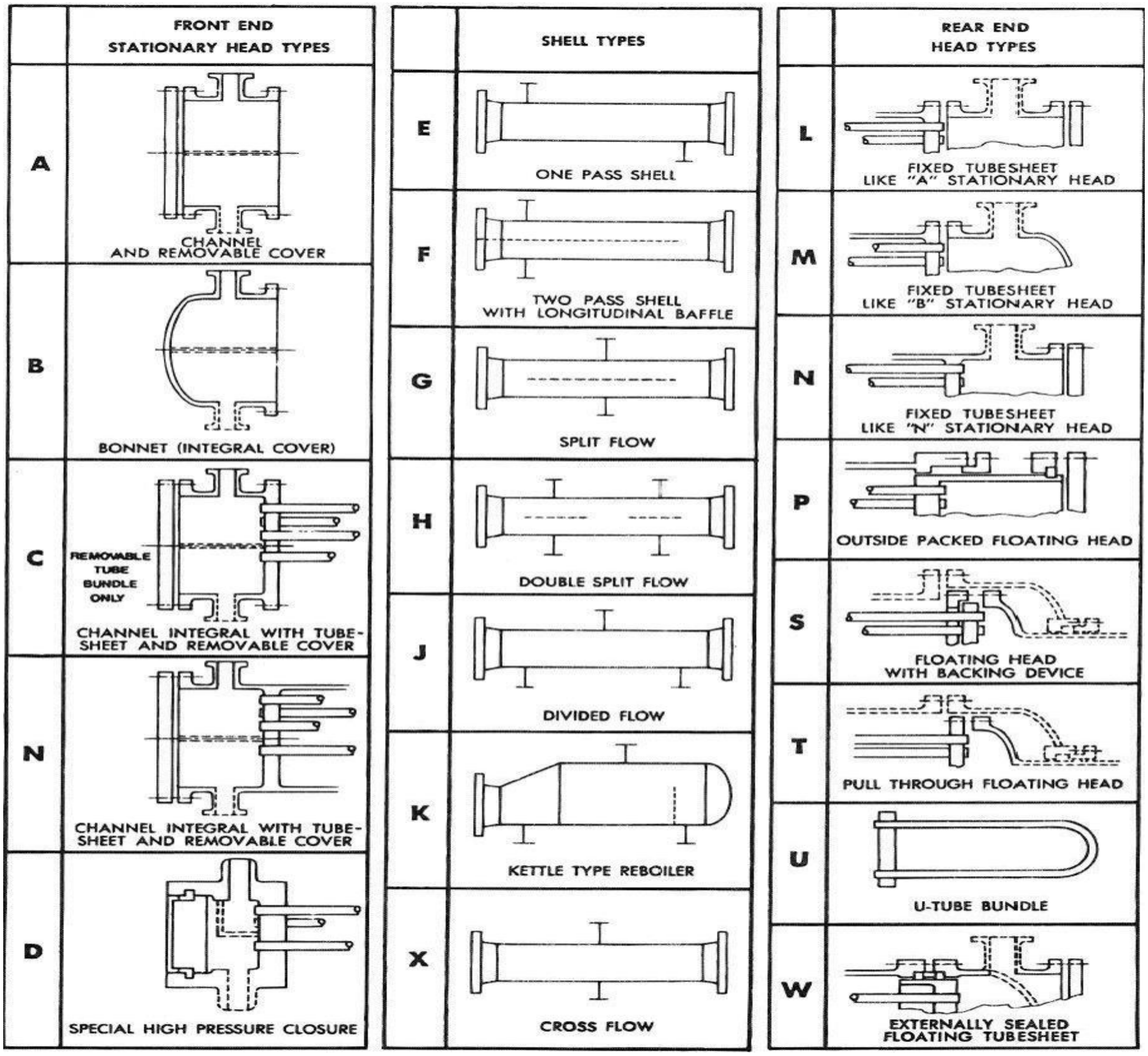

Figure 6 TEMA standards for different configuration [9]

3.3 Calculations

Assumptions made:

- Lt = Tube length = 600 mm
- Nt = Number of tube = 4 Tubes
- Np = Number of passes = 2
- Ds = Shell inside diameter = 132 mm
- Nb = Number of baffles
- B = Baffle spacing
- B = $\frac{Lt}{Nb+1}$ = $\frac{600}{4}$ = 150 mm
- Ct = Tube clearance
- De = Equivalent Diameter for square pitch layout

De = $\frac{4Pt^2 - \pi * do^2/4}{\pi * do}$

De= $\frac{4(29^2 - \pi * 21 * 10^{-3})/ 4)}{\pi * (21*10-3)}$ = 0.0299 m = 29.9 mm

The cross-flow area of the shell Ac is defined as

Ac = $\frac{Ds*Ct*B}{Pt}$

Ac= $\frac{132mm*8mm*150mm}{29\ mm}$ = 5.462 * $10^{-3}\ m^2$

The tube pitch ratio Pr is defined by

Pr $= \frac{Pt}{d0} = \frac{29mm}{21mm} = 1.4$ (dimensionless)

Ct = Pt – do = 29mm-21mm = 8 mm

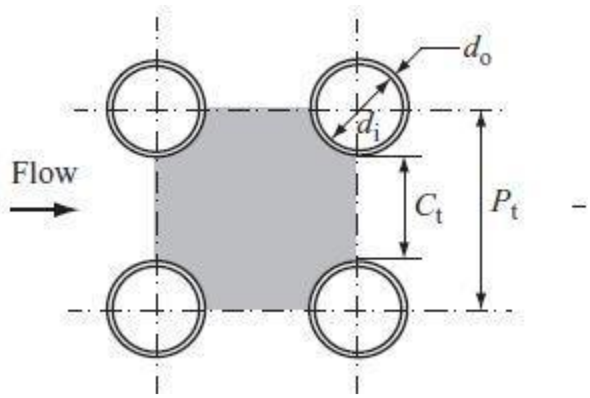

Figure 7 Square Pitch Layout [23]

Engine oil - shell side at 60 ℃

Q Oil = $\dot{m}$ cp (Tf-Ti) (for oil)= 0.216) (2047) (35) then Q= 15475.32 W

$T_b = \frac{T_i + T_e}{2}$

$T_b = \frac{70+35}{2} = 52.5℃$

$\rho 1 := 864 \frac{kg}{m^3}$ k

$\mu 1 := 39.071 * 10^{-3} \frac{kg}{m*sec}$

Specific Heat Cp1: = 2047 $\frac{kJ}{Kg*K}$

Thermal Conductivity k1: = 0.14 $\frac{W}{m*K}$

Pr1: = 1050

$\dot{m}$ = 0.216kg/sec

<u>Water – tube side at 32.75℃</u>

Q water $=\dot{m}$ cp (Tf-Ti) = 0.14 (4178) (44.5-18) =15500.38 W

$T_b = \frac{T_i + T_e 2}{}$

$T_b = \frac{18+44.5}{2} = 32.75℃$

ρ,2: = 996 $\frac{kg}{m^3}$. k

μ,2: = 0.798 * 10^{-3} $\frac{Kg}{m*sec}$

Specific Heat Cp2: = 4178 $\frac{kJ}{Kg*K}$

Thermal Conductivity k2: = 0.615 $\frac{W}{m*K}$

Pr,2: = 5.42

$\dot{m}$ = 0.14 kg/s

The inlet temperatures are given as

T,1 i (oil):= 70 ◦ C

T,2 i (water):= 18 ◦ C

The mass flow rates are given as

$\dot{m}$ (oil) := 0.216 kg /s

$\dot{m}$ (water) := 0.14 kg/ s

Design Parameters

Ds = 132 mm (Shell inside diameter)

Lt = 600 mm (Tube length)

do = 21 mm (Tube outside diameter)

Tube Side (Water)

The cross-flow area, velocity, and Reynolds number are defined as follows:

Ac ,1: $=\frac{\pi \cdot di^2}{4}\ (\frac{Nt}{Np})$

Ac,1 = 6.346 × 10−4 m^2

$\dot{m}=A_c \times \rho \times V_{avg.}$ (3.1)

$V_{avg.} = \frac{\dot{m}}{\rho A_c} = \frac{0.14\ kg/sec}{996\frac{kg}{m^3}\times 6.346 * 10^{-4}\ m^2} = 0.222\ \frac{m}{s}$

After calculating average velocity we need to find the Reynolds Number to determine the nature of the flow is it Turbulent or Laminar for this purpose we use the equation (3.2)

$$\text{Re} = \frac{(996)\frac{kg}{m^3} * (0.222)\frac{m}{s} * (0.021)m}{(0.798 * 10^{-3})kg/m.sec} = 5818 \qquad (3.2)$$

Re > 2300

So its turbulent flow

After determining the nature of the flow which is turbulent, to calculate Nusslet Number use equation (3.3)

For factor of friction we have that:

F = $(1.58 * \ln(ReD) - 3.28)^2$ if ReD > 2300 F

$F = 9.471 \times 10^{-3}$

And for Nu:

$$Nu_D(D_h, L_t, Re_D, Pr) := \begin{cases} \left(\frac{f(Re_D)}{2}\right) \cdot \frac{(Re_D - 1000) \cdot Pr}{1 + 12.7 \cdot \left(\frac{f(Re_D)}{2}\right)^{0.5} \cdot \left(Pr^{\frac{2}{3}} - 1\right)} & \text{if } Re_D > 2300 \\ 1.86\left(\frac{D_h \cdot Re_D \cdot Pr}{L_t}\right)^{\frac{1}{3}} & \text{otherwise} \end{cases} \tag{3.3}$$

Nu = 31.641

And after finding the Nusselt number calculate the heat transfer coefficient for the flow

Then we have that

$Nu = \frac{h\,D}{k}$

$h = \frac{Nu * k}{D}$

$h = \frac{31.641 * 0.615}{0.021} = 926.63 \quad \frac{W}{m^2 * K}$

For oil in shell side

Shell Side (engine oil)

The cross-flow area, velocity, and Reynolds number are defined as follows:

Ac ,2: $= \frac{(\mathrm{Ds} \cdot \mathrm{Ct} \cdot \mathrm{B})}{\mathrm{Pt}} = \frac{(132 \cdot 8 \cdot 150)}{29} = 5.462 * 10^{-3}$

Ac,2: = $5.462 * 10^{-3}\, m^2$

v,2: $= \frac{\dot{m}}{\rho 2 \cdot \mathrm{Ac2}} = \frac{0.216}{864 * 5.462 * 10^{-3}}$

v,2 $= 0.0457 \frac{m}{s}$

$\dot{m} = A_c \times \rho \times V_{avg.}$ (3.1)

$V_{avg.} = \frac{\dot{m}}{\rho A_c} = \frac{0.216\ \mathrm{kg/sec}}{864 \frac{kg}{m^3} \times 5.462 * 10^{\wedge}{-3} m^2} = 0.0457 \frac{m}{s}$

After calculating average velocity we need to find the Reynolds Number to determine the nature of the flow is it Turbulent or Laminar for this purpose we use the equation (3.2)

Re $= \frac{(864)\frac{kg}{m^3} * (0.0457)\mathrm{m/sec} * (0.021)\mathrm{m}}{(39.071 * 10^{-3})\, \boldsymbol{kg/m.sec}} = 21.229$

So its laminar flow

After determining the nature of the flow which is turbulent, to calculate Nusstel Number use equation (3.3)

For finding Nu :

$$Nu_D(D_h, L_t, Re_D, Pr) := \begin{cases} \left(\frac{f(Re_D)}{2}\right) \cdot \frac{(Re_D - 1000)\cdot Pr}{1 + 12.7 \cdot \left(\frac{f(Re_D)}{2}\right)^{0.5} \cdot \left(Pr^{\frac{2}{3}} - 1\right)} & \text{if } Re_D > 2300 \\ 1.86\left(\frac{D_h \cdot Re_D \cdot Pr}{L_t}\right)^{\frac{1}{3}} & \text{otherwise} \end{cases} \tag{3.3}$$

Using the second equation we have that

$$1.86\left(\frac{0.012*21.22*1050}{600*10^{-3}}\right)^{1/3} = 14.2$$

And after finding the Nusselt number calculate the heat transfer coefficient for internal flow

Finding h for the engine oil

$$Nu = \frac{h\,D}{k} \Rightarrow h = \frac{Nu.k}{De} = \frac{14.2*0.14}{0.0299} = 66.52\ \frac{W}{m^2}$$

Nu = 14.2

$$U = \frac{1}{\frac{1}{h_i} + \frac{1}{h_o}}$$

$$U = \frac{1}{\frac{1}{926.63} + \frac{1}{66.52}} = 61.7\ \frac{W}{m^2 * K} \tag{3.9}$$

To calculate heat capacity rate C_h use equation

$$C_h = \dot{m}\, C_P \tag{3.16}$$

$$C_h = \dot{m}_h C_P = 0.216 \times 2048 = 442.368 \frac{W}{K}$$

$$C_c = \dot{m}_c C_P = 0.14 \times 4178 = 584.92 \frac{W}{K}$$

$C_{min} = C_{h(oil)} = 442.368$ W/K

Heat capacity ratio using equation

$$c=\frac{C_{min}}{C_{max}} \tag{3.14}$$

$$c = \frac{C_{min}}{C_{max}} = \frac{442.368}{584.92} = 0.7561$$

Calculate maximum heat transfer rate; use equation

$\dot{Q}_{max} = C_{min}\Delta T_{max}$

$Q\ max = C_{min}(T_{h\ in} - T_{c\ in}) = 442.368\ (70\text{-}18) = 23003.136$ W

To calculate actual heat transfer rate use the equation

$$\dot{Q}=C_c(T_{c,out}-T_{c,in})= C_h(T_{h,in}-T_{h,out}) \tag{3.12}$$

$Q = C_h(T_{h\ in} - T_{h\ out}) = 532.48\ (70\text{-}35) = 18636.8$ W

After calculating maximum heat transfer rate and actual heat transfer rate we can calculate the effectiveness by using the equation below:

$$\varepsilon = \frac{\dot{Q}}{\dot{Q}_{max}} = \frac{\text{Actual heattransfer}}{\text{Maximum possible Heat transfer}} \tag{3.11}$$

$$\varepsilon = \frac{Q}{Q\ max} = \frac{18636.8}{23003.136} = 0.79 \text{ (dimension less)}$$

3.3 Bill Of Materials

Part Name	Quantity	Weight (Kg)	Price (TL)	Shipping Cost (TL)	Source (Company)
Steel Pipe	1	1.5	75	25	X
Steel Shell	1	15	420	100	X
Copper Pipers	8	1.6	350	X	Uc Yildiz
Flanges	4	14	1000	85	X
Bolts and Nuts	16	1.5	50	N/A	Yar Plus
Baffles	3	1.5	400	85	X
Shell Cover	2	4	250	85	X
Steel Sheets	2	2	250	85	X
Engine Oil	4-5	5	75	N/A	Castrol
Oil Pump	1	10	400	N/A	Department of Mechanical Engineering
Tank	1	N/A	300	N/A	Department of Mechanical Engineering
Heating Coils	1	N/A	120	N/A	Department of Mechanical Engineering
Total	44	41 Kg	3,690	550	

Table 4 Bill of Materials

Chapter 4 – MANUFACTURING

4.1.1 Manufacturing Process Selection

Manufacturing processes are the steps taken through which materials are transformed into product by mechanical processes and then assemble them in the last steps.

The manufacturing process begins with the creation of the materials from which the design is made.

These material are usually modified through manufacturing processes to reach the desired part.

In fact, selection of manufacturing processes depends on many constraints, but the most important four are:

- The selection of materials
- Cost of manufacturing processes
- Availability and Manufacturability
- Safety (Leakage of hot fluid should be avoided) and reliability

4.1.2 The selection of materials

A general procedure for that could be used for identifying the most appropriate material for specific shell and tube heat exchanger application would consist of the following steps:

1) Define the heat exchanger requirements

2) Establish a strategy for evaluating candidate materials

3) Identify candidate materials

4) Evaluate materials in depth

5) Selecting the optimal material

For the first step, the team members must consider the normal operating parameters (eg: nature of the fluids on both the tube and shell side, flow rate, temperature and pressure), startup and shutdown conditions, upset conditions, hazardous effects of intermixing of shell and tube side fluids, and associated maintenance, etc. The safety regulations must also be considered. [25]

While establishing the strategy for evaluating the materials, the main factors to be considered are cost and reliability. The minimum cost strategy would mean use of less expensive materials and rectifying the problems as they show up. Maximum reliability strategy would mean going for the most reliable regardless of its cost. [26]

In identifying candidate materials, it is desirable to narrow the field to a comparatively small number of materials for more extensive evaluation. There is no hard and fast rule as to how many candidate materials should be selected for detailed study. The initial identification and selection procedure, if done properly, will eliminate those materials which are unsuitable and those which are excessively expensive. This calls for use of operating experience, use of handbook data and literature on advanced materials under development, and judgement. Special considerations which affect materials selection include: [27]

.

Corrosion Resistance

- Low corrosion rate to minimize the corrosion allowance.
- Resistance to corrosion from off normal chemistry resulting from leak in upstream heat exchanger or failure in the chemistry control - Tolerance to chemistry resulting from mix up of shell and tube fluids.

Manufacture

Ease of fabrication is an important aspect for selection of materials. The usual manufacturing steps involved for heat exchangers are bending of tubes, joining of tube to tube sheet by welding, forming of shell geometry and welding of shell plates and shell to nozzle and the heat treatments associated with the welding steps.

Criteria for making the final selection will include an assessment of each of the following:

- Initial cost
- Maintenance cost, including consideration of how frequently the equipment will need to be inspected for corrosion
- Cost of loss in production
- Consequences of failure. Is failure likely to create unsafe conditions or cause discharge of an undesirable chemical into the environment or serious repercussions to an emerging technology.

Generally materials selection is based on qualitative comparisons of the candidate materials. However, it is worthwhile to make the assessment based on financial parameters**.**

COMPONENTS	MATERIAL(S)
• Pipes/ Tubes	• Copper
• Flanges	• Steel
• Tube Sheets	• Steel
• Baffles	• Steel
• Shell	• Steel
• Shell Cover	• Steel
• Support	• Iron

Table 5 Components and Materials used in the design

4.2 Detailed manufacturing process

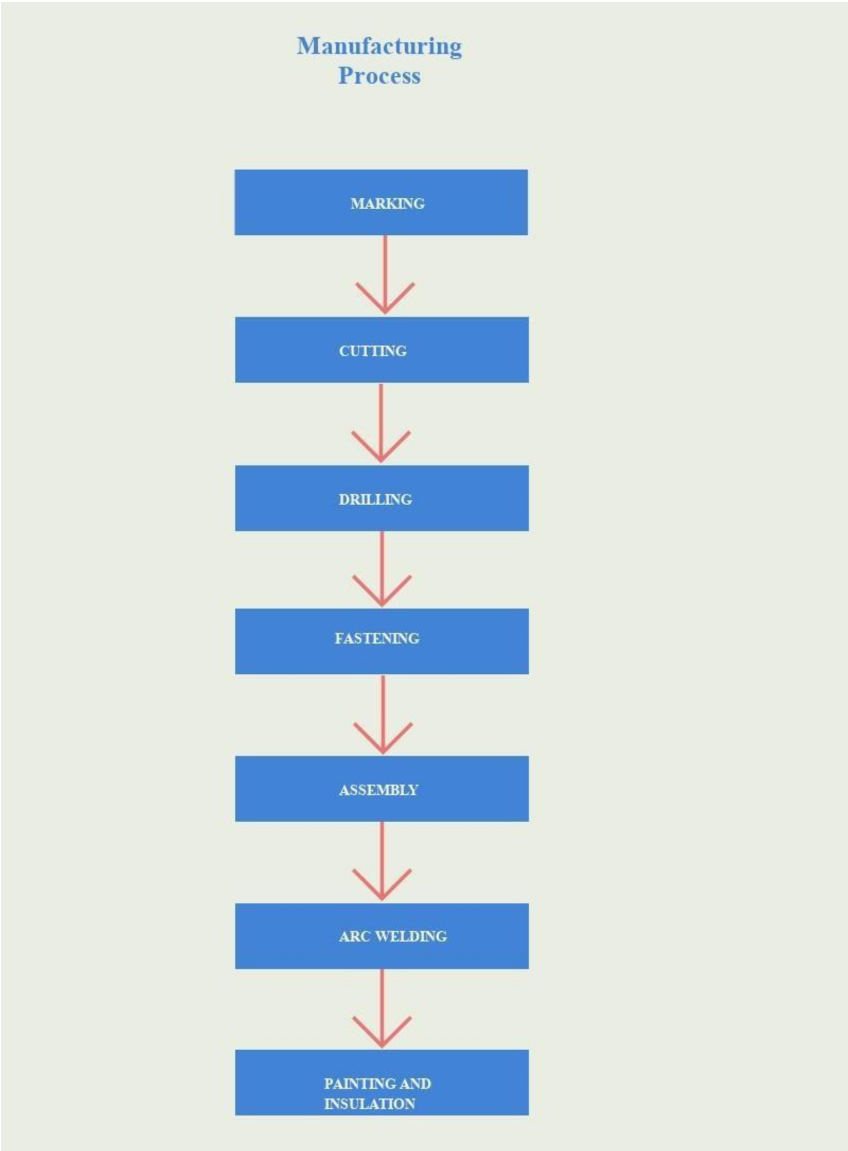

Figure 8 Flowchart of the manufacturing process

For constructing a heat exchanger there are some manufacturing process.to be done by team members. ts construction depends on its design. In our case we will built a multi pass shell and tube heat exchanger which cools down the oil from 70℃ to 50℃ in the least time possible as mentioned earlier

Marking

Copper pipes, Steel Shell, Tube Sheets and Baffles are delivered from the factory ready to be marked. High Speed Steel Scribers are used to mark the parts

- Sections to be cut, for example the length of copper pipes were a bit long, so we had to cut the extra portion.
- Holes for drilling of shell, tube sheets and baffles.
- Weld markings were made for ease of assembly.

MATERIAL	HACKSAW BLADE TEETH PER INCH (PITCH)
SHEET METAL	14
SOLID STOCK: 1	
ALUMINUM	4
BRASS	10
BRONZE	4
CAST IRON	4
COPPER	4
STEEL, ALLOY	6
STEEL, HIGH-SPEED	6
STEEL, MACHINE	4
STEEL, STAINLESS	6
STEEL, TOOL (ANNEALED)	6
STEEL, TOOL (UNANNEALED)	4
TUBING, THIN	14
TUBING, HEAVY	10

Table 6 Different pitch for blades of different materials. [7]

Cutting

- After marking step is done, parts are moved for cutting. The copper pipes and steel pipe was cut by the power hacksaw machine available in our workshop.
- According to standard we used the 4 pitch blade for cutting the steel and copper pipes

Drilling

- Drilling circle marks were already placed on shell as we had two holes for the (Flanges) inlet and outlet of the hot fluid (engine oil), another circle marks were made on the tube sheets and the baffles for the copper pipes to go inside them. The Radial Drilling machine will be used to drill the required parts mentioned earlier.

Figure 9 Radial Drilling Machine

Figure 10 Drilled baffles

Figure 11 Drilled Shell

Figure 12 Drilled Tube Sheet

Welding

- Arc welding and gas welding operations were used widely in welding the flanges to the shell, tube sheets to the shell and also we welded the copper pipes in the tube sheets and the baffles to keep them in fixed position. For stainless steel, arc welding was the most suitable form to us as it is available in our workshop In addition to this, it is easy to use since we have good experience in using it in manufacturing and workshop courses. It is a type of *welding* that uses a *welding* power supply to create an electric *arc* between an electrode and the base material to melt the metals at the *welding* point. They can use either direct (DC) or alternating (AC) current, and consumable or non-consumable electrodes.

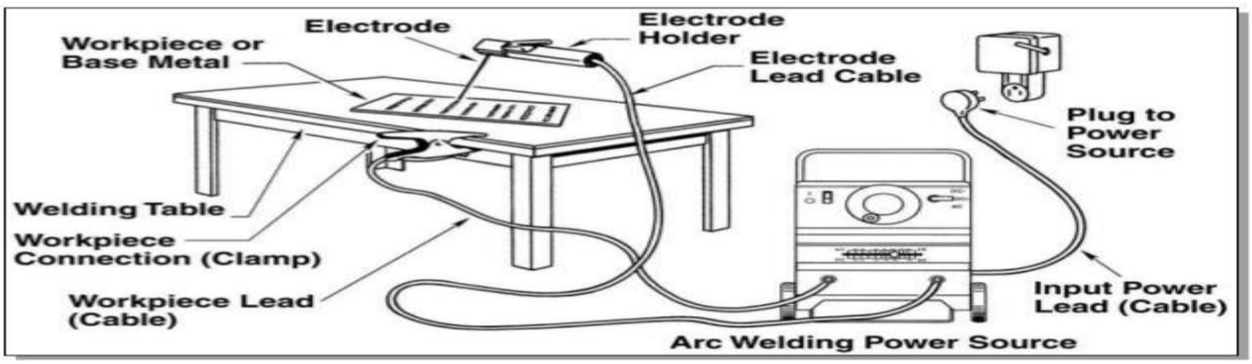

Figure 13 Arc Welding Setup [25]

For welding the copper pipes to the tube sheet we have used gas welding because it is made of copper and the tube sheet was made of steel.

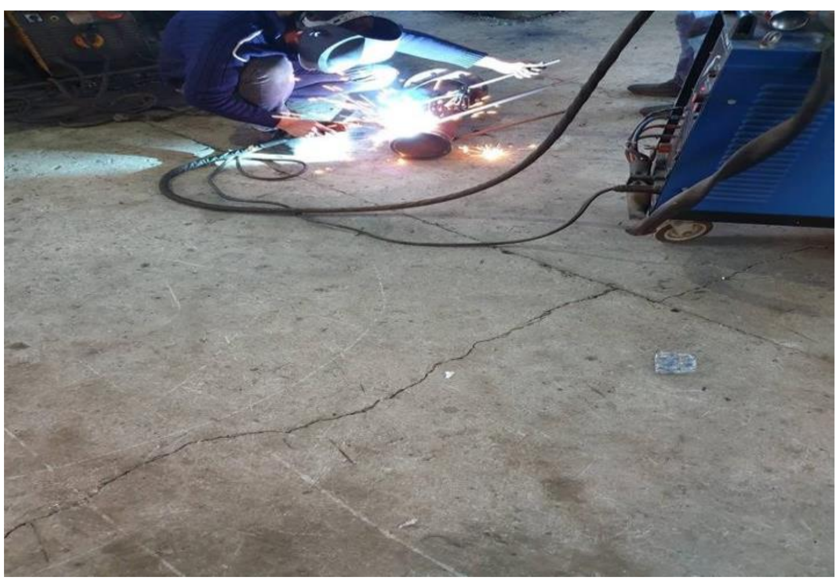

Figure 14 Gas Welding Process

Figure 15 Copper tubes welded to both tube sheets and baffles

Fastening

For fastening purposes, ISO M grade threads and fasteners will used. Fastening processes uses 3 types for threads and fasteners

- A Screw is a headed and threaded bolt used without a nut. It is inserted into an internally tapped hole and tension is induced by rotation of the screw head.
- A Stud is a fastener with no head but it has threads at both ends of the shank. It, like a screw, has one end that screws into a tapped hole. A nut is used on the other end to create tension.
- If a stud is threaded its entire shank length and a nut used on both ends to create tension, it serves the function of a bolt and is then classified as a Stud Bolt.

Figure 16 Fasteners

Painting

- Painting is done on the outer side of the shell to provide a better appealing eye catching clean design and to prevent corrosion due to humid and wet environment.

Assembly

- Assembly operations as mentioned before are composed of 2 processes discussed above. Which are welding and fastening using bolts and nuts.

Figure 17 Painting of the shell and tube heat exchanger

CHAPTER 5- PRODUCT TESTING

5.1 Verification plan of the objectives of the project

Verification process is done during implementation before validation. Integration consists of assembly and fabrication process. Validation process occurs after integration. In our Capstone 1 project we only carried out verification plans and integration and validation processes will be done in Capstone 2.

5.2 Verification of the Applied Engineering Standard

We have followed the TEMA standards for the shell and tube heat exchanger, according to TEMA standard we picked the pipes diameter, our material which is copper for the tube sides and the stainless steel for the shell. For manufacturing we will used different processes, including welding. In welding standards we must perform an X-ray test to check the cracks in the welded part, which is impossible to replicate in our work shop, so we will check the leakage just by inspection. The pressure drop is not significantly high so the shell and tube will not have any safety issues mostly. So our design adheres to safety standard.

FMEA (Failure Modes and Effect Analysis)								
Product: Shell and Tube Heat Exchanger								
#	Function	Causes	Potential Failure Effect	Frequency	Consequences	Recommended Actions	Responsible Person (s)	
1	Tube/Pipe Failure	Corrosion from fluids (shell side)	Leakage	Rare	Two fluids will mix	Replace Copper Pipes	All team members	
2	Tube Sheet Failure	See tube failure.	Leakage and Vibrations	Rare	Two fluids will mix	Replace tube sheets	All team members	
3	Erosion of Tubes	High velocity of cooling water	Heat Loss	Rare	Decrease effectiveness	Reduce the velocity of cooling water	All team members	
4	Corrosion (Tube/Pipe Side)	Incorrect process composition	Leakage Heat loss	Frequent	Decrease effectiveness	Replace Copper Pipes	All team members	
5	Baffles Swinging	Poor Assembly and/or High speed of hot fluid	Vibrations	Rare	Decrease effectiveness	Proper Assembly	All team members	
Team member: All team							Prepared by: Ali Mohamed	
							Checked by: Assist. Prof.Dr. Murat	Approved by: Assist. Prof.Dr. Murat

Table 7: The FMEA analysis of the Heat Exchanger

CHAPTER 6 - RESULTS and DISCUSSIONS

6.1 The Results

The result of CFD simulation is a mathematical model that describes the state variables and changes in these variables in the heat exchanger. We are able to observe state changes in whole exchanger volume, or in any part or section. Heat exchanger design for hot oil engine sets wide range of specifications. As first step was defined the working conditions of whole unit and the required temperatures for each part of this device. The basic dimensions of heat exchanger were set using criterion formula. With this calculation was verified the inlet and outlet temperatures of the heat exchanger.

- Properties used in the simulation using the Autodesk CFD software was the same like in the formulas used above in the calculations section.

Properties for Water (fixed)
Environment: 101325 Pa, 19.85 Celsius (from scenario)

Property	Value	Units	Underlying variation
Density	998.2	kg/m3	Piecewise Linear
Viscosity	0.00089	Pa-s	Constant
Conductivity	0.6	W/m-K	Constant
Specific heat	4178	J/kg-K	Constant
Bulk modulus	2.18565e+09	Pa	Constant
Emissivity	1	none	Constant
Wall roughness	0	meter	Constant
Phase	0		Linked Vapor Material

Table 8 Cold Fluid Properties used in CFD Autodesk Simulation

Properties for SAE 40W (fixed)
Environment: 101325 Pa, 19.85 Celsius (from scenario)

Property	Value	Units	Underlying variation
Density	864	kg/m3	Constant
Viscosity	0.266878	Pa-s	Piecewise Linear
Conductivity	0.145	W/m-K	Constant
Specific heat	1879.4	J/kg-K	Piecewise Linear
Bulk modulus	1.38019e+09	Pa	Constant
Emissivity	1	none	Constant
Wall roughness	0	meter	Constant
Phase	0		Vapor Pressure

Table 9 Hot Fluid Properties used in CFD Autodesk Simulation

Properties for Copper (fixed)
Environment: 19.85 Celsius (from scenario)

Property	Value	Units	Underlying variation
X-Conductivity	385.696	W/m-K	Piecewise Linear
Conductivity			Same as X-dir.
Conductivity			Same as X-dir.
Density	8939.58	kg/m3	Constant
Specific heat	384.4	J/kg-K	Constant
Emissivity	0.6	none	Constant
Transmissivity	0	none	Constant
Electrical resistivity	1.7e-08	ohm-m	Constant
Wall roughness	0	meter	Constant

Table 10 Copper Properties used in CFD Autodesk Simulation

Properties for Steel (fixed)
Environment: 19.85 Celsius (from scenario)

Property	Value	Units	Underlying variation
X-Conductivity	54.4	W/m-K	Piecewise Linear
Conductivity			Same as X-dir.
Conductivity			Same as X-dir.
Density	7833	kg/m3	Constant
Specific heat	465	J/kg-K	Constant
Emissivity	0.3	none	Constant
Transmissivity	0	none	Constant
Electrical resistivity	1.7e-07	ohm-m	Constant
Wall roughness	0	meter	Constant

Table 11 Steel Properties used in CFD Autodesk Simulation

The figures below show the simulation of the heat exchanger for both hot and cold fluid and after putting the properties mentioned above into the simulation software we successfully achieved results similar to the one we calculated using the formals. it can also be seen from the figure below that the red color shows the high temperature of the oil when its enter the heat exchanger and then decreases gradually to the desired temperature by looking at the color scale shown on the left-side red color means the highest temperature and blue is the room temperature that we assigned previously in the CFD software [14]

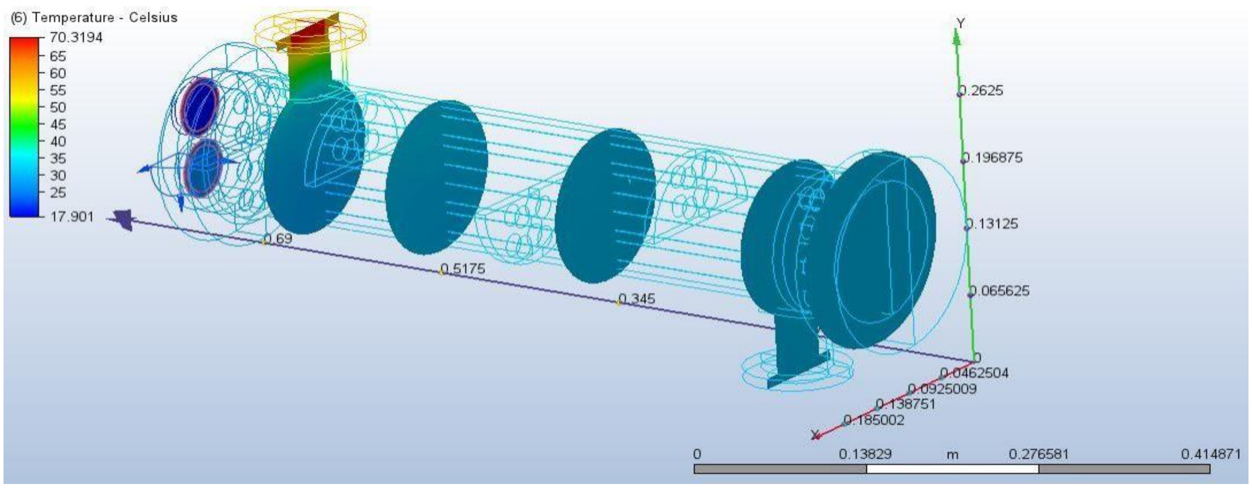

Figure 18 Temperature simulation of inlets and outlets

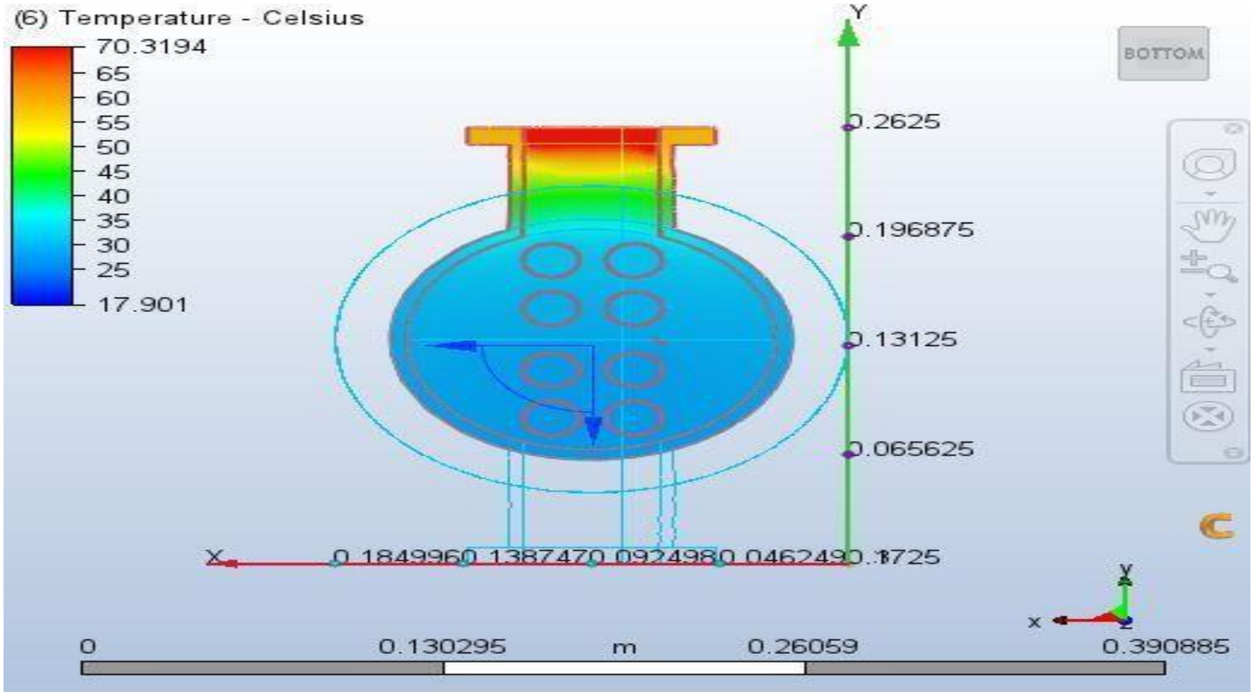

Figure 19 Temperature simulation

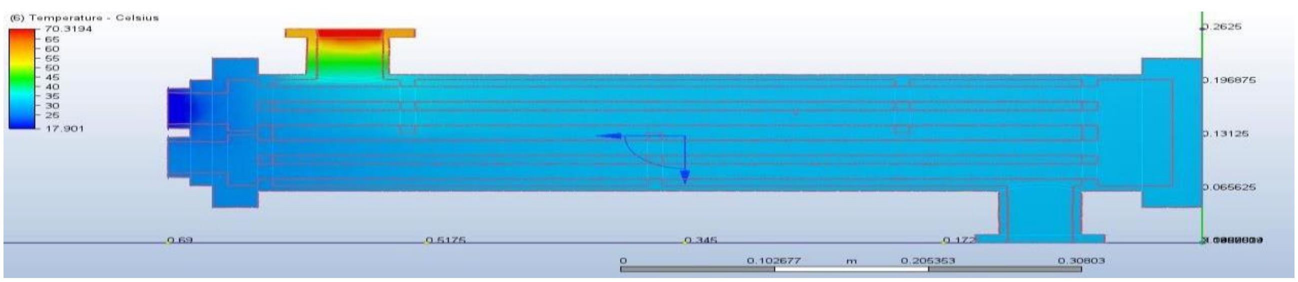

Figure 20 Temperature simulation

The velocity boundary condition is used to define the velocity magnitude and direction of the oil and water at the hot and cold inlets of the heat exchangers. The inlet temperature is also required at this boundary. The pressure outlet condition is used to model the flow conditions at the outlets of the heat exchanger. Tests were conducted to verify the grid independency of the results. Simulations were performed for different grids size, until the results were consistent. [26]

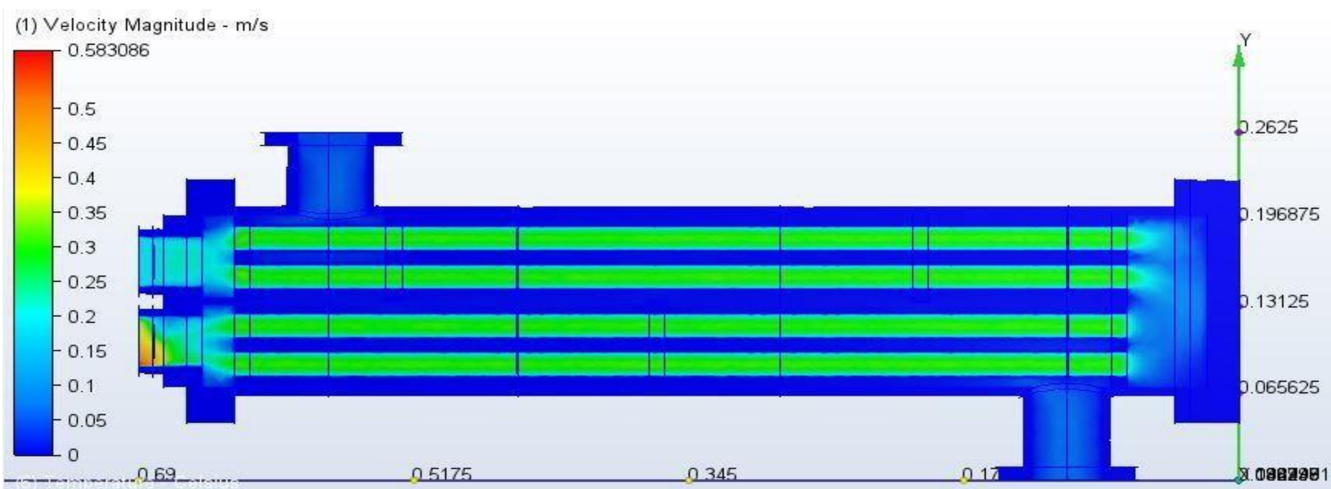

Figure 21 Velocity Simulation

6.2 Constraints

Economical*:*

- Design can be used by the public
- The total cost should be less than $600

Environmental

- This design does not result in any leakage of the hot fluid that is why we used seals to be harmful free and is an environmentally friendly invention.

Manufacturability

- The tolerances are not kept so tight during the design manufacturing.
- The baffles are made from stainless steel and are relatively stiff to minimize vibrational effects.
- Availability of chosen material is an important design constraint.
- The shell is sprayed with anti-corrosion paint/zinc.
- This design can be manufactured in the Mechanical Engineering workshop.
- This design is adhered to certain engineering standards.

Health and safety

- The health and safety rules of the workshop should be followed to avoid any unwanted injuries to the user.
- It is still advisable to wear the safety goggles and gloves while working the shell and tube heat exchanger

- The hot fluid will be heated using the heating coils up to 70 Celsius and not above this temperature for health and safety consideration.

Ethical

- This design is a revolutionary invention and all the references are provided in the end of the report.
- This design does not involve the usage of any radioactive material.

Sustainability

- There is a minimal use of machinery in the design assuring that the vibrational effects are properly suppressed.
- Our design is both reliable and durable.
- The system including the shell and tube heat exchanger and the oil pump was tested in real life to get an idea about the reliability and the durability of the system under different conditions.

Legality

- Our design uses concepts that are secured by patents.

	YES	NO
Economic	✓	
Environmental	✓	
Manufacturability	✓	
Health and Safety	✓	
Ethical	✓	
Sustainability	✓	
Legality	✓	

Table 12 Constraints

Chapter 7

CHAPTER 7 - CONCLUSIONS and FUTURE WORKS

7.1 The Conclusion

This project has been about the construction of shell and tube heat exchanger, to cool oil with water and successfully we achieved the delta T (Temperature). In another words after the real life testing and the computer simulation we cooled down the engine oil from 70-40 Celsius.

The report shows all the chapters from introduction, literature, design and calculation, simulation/testing, results and conclusion.

The heat exchanger has been designed with certain parameters in mind which includes cost, size, availability of materials, manufacturing process, etc. The heat exchanger changer cools down the oil close to the specification requirement, but certain modification and better manufacturing would have made it achieve better results.

7.2 Future Works

The built heat exchanger can be improved in a variety of way including:

- Better manufacturing processes to make the product more professional
- Increase number of pipes to increase heat transfer rate and effectiveness
- Add fins to the pipes to increase the heat transfer rate

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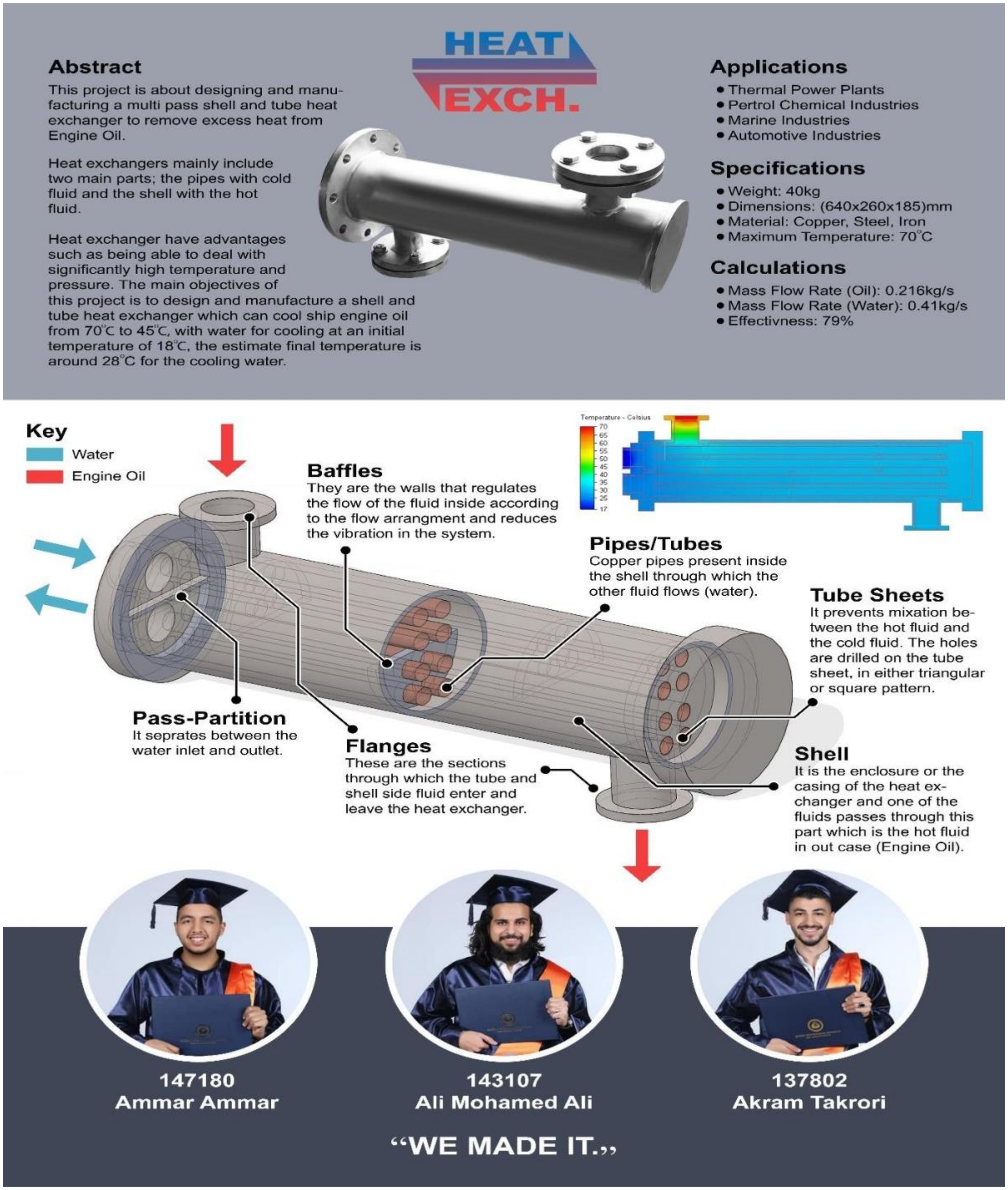
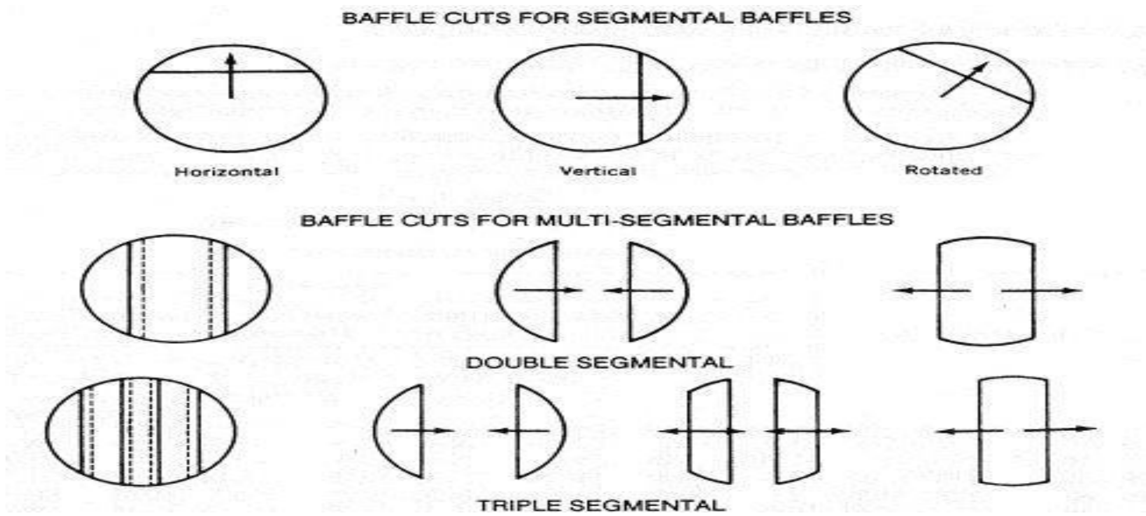
APPENDIX A: Electronic Media

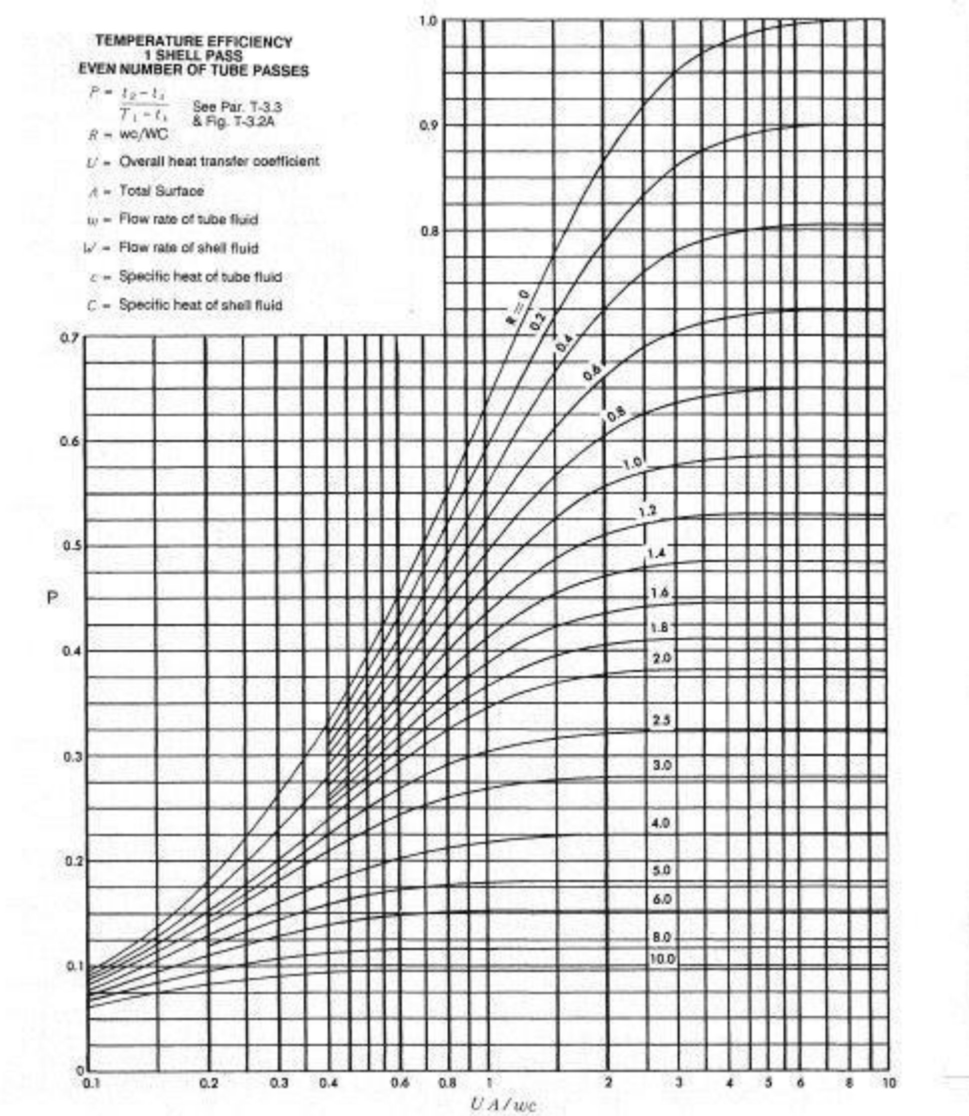


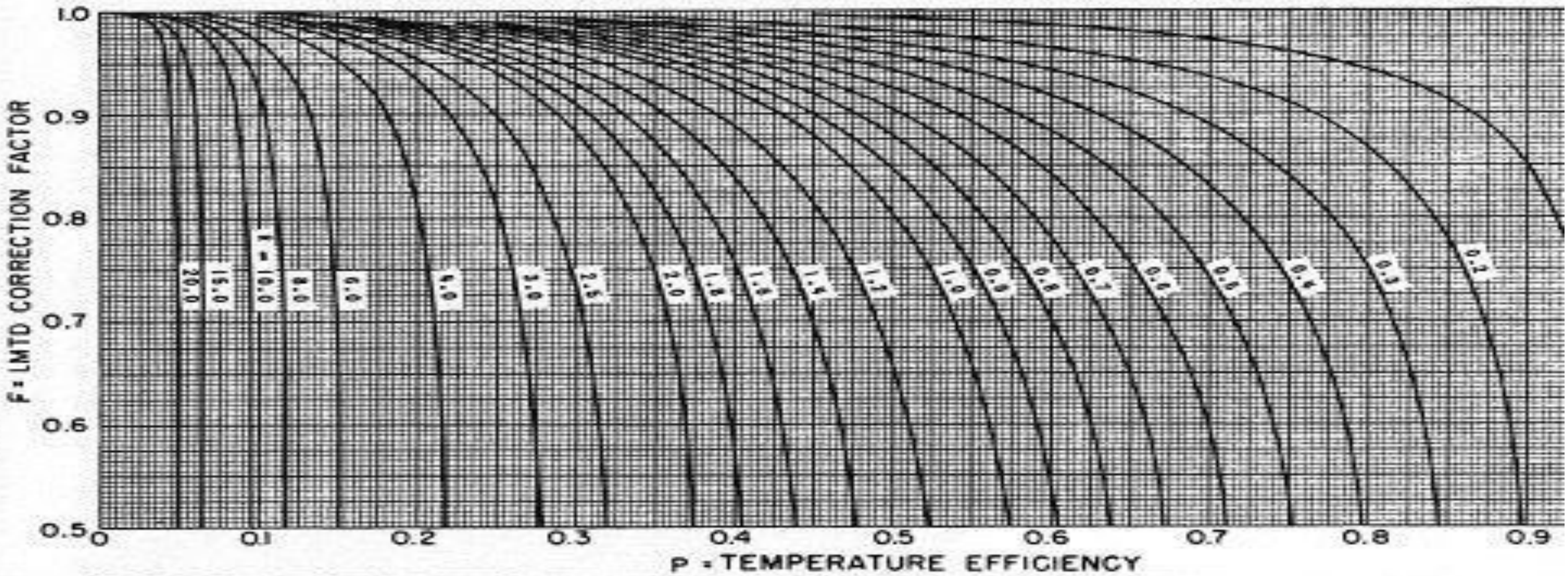
APPENDIX B: Standards

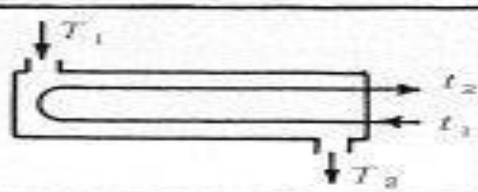


MINIMUM SHELL THICKNESS
Dimensions In Inches (mm)

Nominal Shell Diameter		Minimum Thickness				
		Carbon Steel			Alloy *	
		Pipe	Plate			
6	(152)	SCH. 40	-		1/8	(3.2)
8 - 12	(203-305)	SCH. 30	-		1/8	(3.2)
13 - 29	(330-737)	SCH. STD	3/8	(9.5)	3/16	(4.8)
30 - 39	(762-991)	-	7/16	(11.1)	1/4	(6.4)
40 - 60	(1016-1524)	-	1/2	(12.7)	5/16	(7.9)
61 - 80	(1549-2032)	-	1/2	(12.7)	5/16	(7.9)
81 - 100	(2057-2540)	-	1/2	(12.7)	3/8	(9.5)


TEMPERATURE EFFICIENCY
1 SHELL PASS
EVEN NUMBER OF TUBE PASSES
$P = \frac{t_2 - t_1}{T_1 - t_1}$
See Par. T-3.3 & Fig. T-3.2A
R = wc/WC
U = Overall heat transfer coefficient
A = Total Surface
w = Flow rate of tube fluid
W = Flow rate of shell fluid
c = Specific heat of tube fluid
C = Specific heat of shell fluid
P
UA/wc
R = 0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.5
3.0
4.0
5.0
6.0
8.0
10.0





LMTD CORRECTION FACTOR

1 SHELL PASS EVEN NUMBER OF TUBE PASSE

$P = \frac{t_2 - t_1}{T_1 - t_1}$ $R = \frac{T_1 - T_2}{t_2 - t_1}$

THERMAL CONDUCTIVITY OF METALS

MATERIAL \ TEMP. DEG C	W/M DEG. C															
	21.1	37.8	93.3	148.9	204.4	260.0	315.6	371.1	426.7	482.2	537.8	593.3	648.9	704.4	760.0	815.6
CARBON STEEL	51.9	51.7	50.5	49.2	47.8	46.0	44.3	42.6	40.7	38.9	37.0	35.0	32.9	30.5	28.0	27.0
C-1/2 MOLY STEEL	42.9	43.3	43.6	43.4	42.9	42.1	41.0	39.8	38.4	37.0	35.3	33.7	31.8	28.9	26.5	26.0
1 CR-1/2 MO & 1-1/4 CR-1/2 MO	36.9	37.2	37.9	38.1	37.9	37.6	36.9	36.0	35.0	34.1	33.1	32.0	30.6	28.6	26.0	25.6
2-1/4 CR-1 MO	36.2	36.3	36.9	37.2	37.2	37.0	36.5	35.8	35.0	34.1	33.1	32.0	31.2	29.8	27.0	26.5
5 CR-1/2 MO	29.2	29.9	31.3	32.4	33.1	33.2	33.2	32.9	32.4	31.8	31.2	30.5	29.6	28.7	27.7	27.3
7 CR-1/2 MO	24.4	24.9	26.5	27.7	28.6	29.2	29.6	29.8	29.9	29.8	29.6	29.1	28.7	28.0	27.0	26.8
9 CR-1 MO	22.2	22.7	24.2	25.4	26.3	27.0	27.5	27.7	27.9	27.9	27.9	27.7	27.3	27.0	26.3	26.0
3-1/2 NICKEL	39.6	40.2	41.2	41.7	41.4	40.5	39.6	38.6	37.4	36.2	34.8	33.2	31.5	29.2	26.8	26.5
12 CR & 13 CR	26.3	26.5	26.8	27.0	27.3	27.3	27.5	27.5	27.5	27.5	27.3	27.0	26.5	26.1	26.0	26.1
15 CR	24.6	24.6	24.9	25.1	25.3	25.4	25.4	25.6	25.6	25.6	25.6	25.5	25.6	25.6	25.6	25.6
17 CR	21.8	22.0	22.2	22.5	22.7	22.8	23.0	23.2	23.4	23.5	23.7	23.9	24.1	24.4	24.7	25.1
17-19 CR (TP 439)			24.2													
TP 304 STN STL	14.9	15.1	16.1	17.0	18.0	18.9	19.6	20.4	21.1	22.0	22.8	23.5	24.2	25.1	25.8	26.5
TP 316 & 317 STN STL	13.3	13.7	14.5	15.6	16.4	17.3	18.2	19.0	19.9	20.6	21.5	22.3	23.0	23.9	24.6	25.3
TP 321 & 347 STN STL	14.0	14.5	15.2	16.3	17.1	18.0	18.9	19.7	20.6	21.3	22.2	23.0	23.7	24.4	25.3	26.0
TP 310 STN STL	12.6	13.0	13.8	14.9	15.7	16.6	17.5	18.4	19.2	20.1	20.9	21.8	22.7	23.5	24.4	25.1
2205 (S31803)	13.8	14.7	15.6	16.4	17.3	18.2	19.0	19.9	20.8							
3RE60 (S31500)	14.5	14.7	15.6	16.3	17.0	17.7	18.3	19.0	19.6							
NICKEL 200			67.2	64.4	61.3	59.0	56.2	55.0	56.2	57.3	58.5					
NI-CU (N04400)	21.8	22.3	24.1	26.0	27.9	29.4	31.0	32.7	34.3	36.2	38.1					
NI-CR-FE (N06600)	14.9	15.1	15.7	16.6	17.5	18.4	19.2	20.1	20.9	21.8	22.8	23.9	24.7	25.8	26.8	27.7
NI-FE-CR (N08800)	11.6	11.8	12.8	13.8	14.9	15.7	16.6	17.5	18.4	19.2	20.1	20.9	22.0	22.8	23.9	25.1
NI-FE-CR-MO-CU (N08825)			12.3	13.2	14.0	14.9	15.7	16.6	17.3	18.0	18.9	19.7	20.4	21.5	22.3	23.5
NI-MO ALLOY B		10.6	11.1	11.6	12.1	12.8	13.3	14.2	15.1	16.1	17.3	18.5				
NI-MO-CR ALLOY C-276 (N10276)		10.2	11.1	12.1	13.0	14.0	15.1	15.9	17.0	18.0	19.0	19.9	20.9			
ALUMINUM ALLOY 3003	177.1	177.9	180.3	182.1	183.6											
ALUMINUM ALLOY 6061	166.3	167.7	171.3	174.1	176.4											
TITANIUM (GRADES 1,2,3 & 7)	22.0	21.6	20.8	20.2	19.9	19.6	19.4	19.4	19.4	19.6	19.7	20.1				
ADMIRALTY			121.1	129.8	136.7	145.4	154.0									
NAVAL BRASS			122.9	128.1	133.3	138.5	143.6									
COPPER			389.4	389.4	387.7	387.7	385.9									
90-10 CU-NI			51.9	53.7	58.8	64.0	72.7	81.3	84.8	88.3	91.7					
70-30 CU-NI (C71500)			31.2	32.9	36.3	39.8	43.3	46.7	51.9	57.1	64.0					
7 MO (S32900)		15.2	16.1	17.0	17.8	18.7	19.6									
7 MO PLUS (S32950)		14.9	16.3	17.7	19.2	20.4	22.0									
MUNTZ			122.9													
ZIRCONIUM			20.8													
CR-MO ALLOY XM-27			19.6													
CR-NI-FE-MO-CU-CB (ALLOY 20CB)			13.2													
NI-CR-MO-CB (ALLOY 625)	9.9	10.0	10.7	11.8	12.5	13.3	14.2	14.9	15.7	16.6	17.5	18.3	19.0	19.9	20.8	21.8
AL 29-4-2	15.2					19.0										
SEA-CURE	16.3	16.6	17.8	18.9	20.1	21.3	22.3	23.7								
AL-6XN (N08367)			13.7													

APPENDIX C : Logbook

Ali Mohamed Ali-143107

Date	Brief Description of the performed work
01/10/2018	Meeting with Assist. Prof. Dr. Murat Özdenefe to discuss about the capstone project
03/10/2018	Meeting with group members to discuss the manufacturing process
05/10/2018	Meeting with Assist. Prof. Dr. Devirm Aydin to recheck the capstone 1 report
08/10/2018	Modify some CAD parts on the project report
11/10/2018	Meeting with Sr. Instr. Cafer Kizilors
15/10/2018	Searching from where to get the materials and components
05/11/2018	Receiving some parts from the company located in Ankara
08/11/2018	Meeting with the group members
12/11/2018	Meeting with Sr. Instr. Cafer Kizilors to discuss the manufacturing process
19/11/2018	Receiving the remaining parts from the company
03/12/2018	Cutting the 2 inch steel pipe in the work shop for the flanges
04/12/2018	Drilling the shell pipe
10/12/2018	Drilling the tube sheet
11/12/2018	Created Quality function development
12/12/2018	Final checking of the calculations
13/12/2018	Created FMEA (Analysis)
13/12/2018	Meeting with group members for Reviewing the whole report
14/12/2018	Meeting with Assist. Prof. Dr. Murat Özdenefe to finalize the report
16/12/2018	Painting/Insulating the shell
18/12/2018	Simulating and Testing the Design
19/12/218	Create Poster/Electronic Media
20/12/2018	Reviewing the whole report and finalizing it with the group
21/12/2018	Submission of the report to supervisor

APPENDIX : Logbook

Ammar Ammar-147180

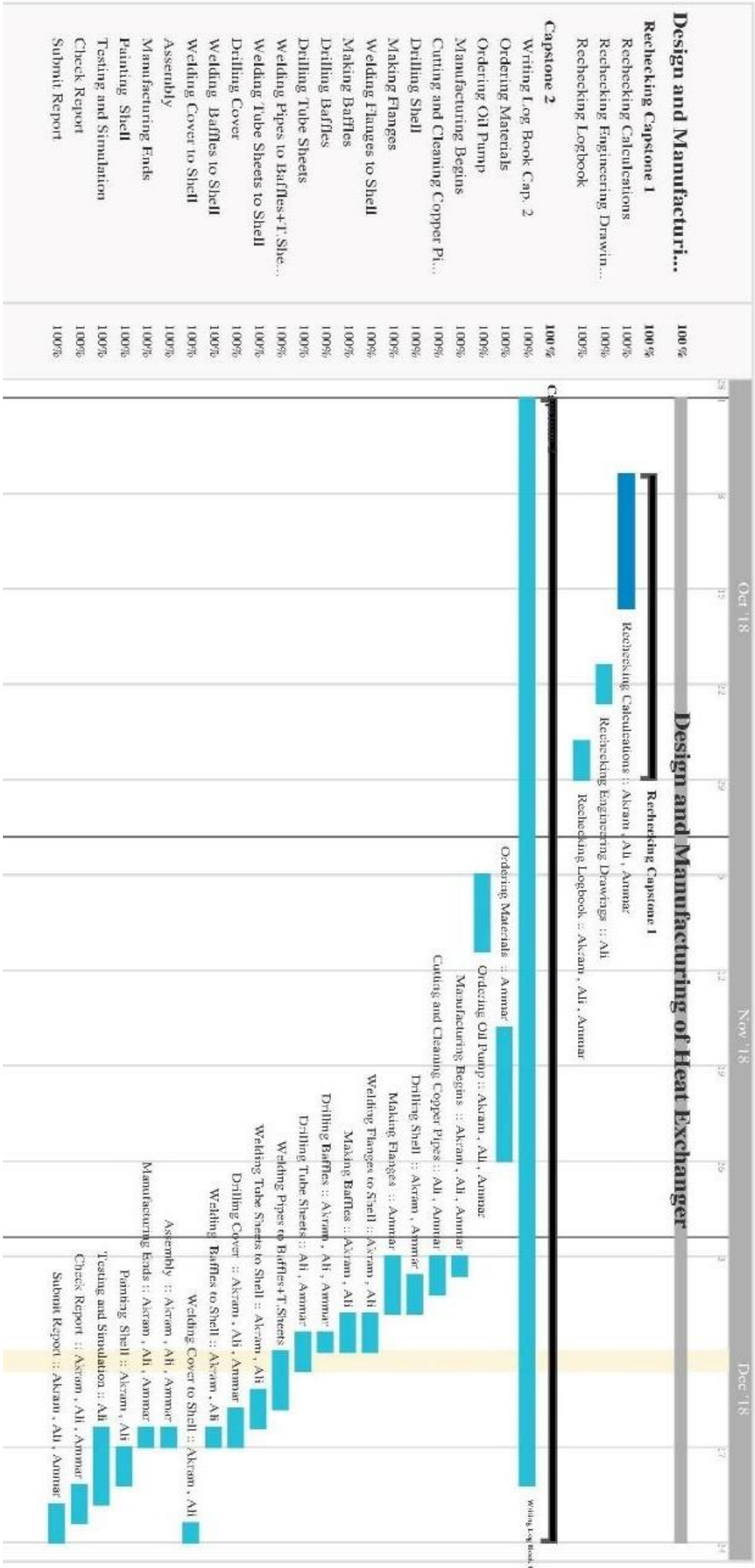
Date	Brief Description of the performed work
01/10/2018	Meeting with Assist. Prof. Dr. Murat Özdenefe to discuss the capstone project
03/10/2018	Meeting with group members to discuss the manufacturing process
05/10/2018	Meeting with Assist. Prof. Dr. Devirm Aydin to check the capstone 1 report
15/10/2018	Searching from where to get the materials and components
17/10/2018	Order the materials/components from the company located in Ankara
05/11/2018	Receiving some materials/components from the company
08/11/2018	Meeting with the group members
12/11/2018	Meeting with Sr. Instr. Cafer Kizilors to discuss the manufacturing process
19/11/2018	Receiving some materials/components from the company
03/12/2018	Filing and reduce the diameter of the 2 inch steel pipe in the work shop for the flanges
10/12/2018	Drilling the baffles
12/12/2018	Gantt chart making for capstone 2
13/12/2018	Meeting with group members for Reviewing the whole report
14/12/2018	Drilling the cover for the inlet and outlet cold fluid
15/12/2018	Assembly process continues
16/12/2018	Painting/Insulating the shell
18/12/2018	Simulating and Testing the Design
19/12/2018	Finalized the report and poster
20/12/2018	Reviewing the whole report and finalizing it with the group
21/12/2018	Submission of the report to supervisor

APPENDIX : Logbook

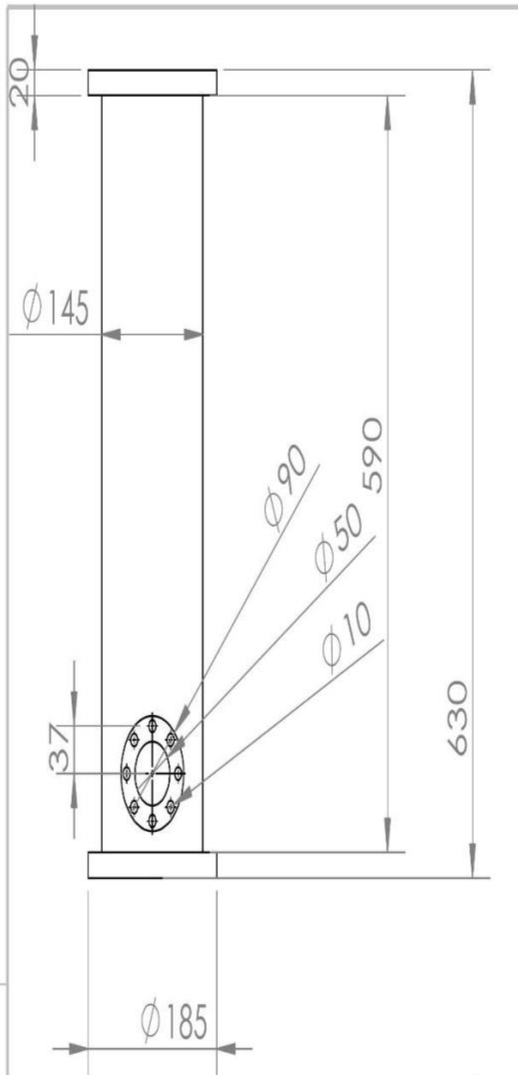
Akram Takrori - 137802

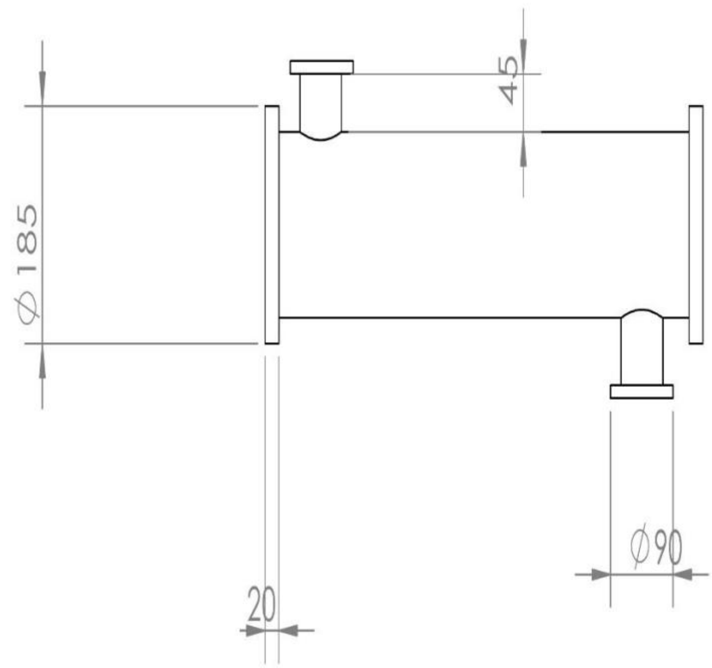
Date	Brief Description of the performed work
01/10/2018	Meeting with Assist. Prof. Dr. Murat Özdenefe to discuss the capstone project
03/10/2018	Meeting with group members to discuss the manufacturing process
08/10/2018	Modify some CAD parts on the project report
11/10/2018	Meeting with Sr. Instr. Cafer Kizilors
05/11/2018	Receiving some materials/components from the company
08/11/2018	Meeting with the group members
12/11/2018	Meeting with Sr. Instr. Cafer Kizilors to discuss the manufacturing process
19/11/2018	Receiving some materials/components from the company
03/12/2018	Welding the 2 inch tube with the flanges
10/12/2018	Reduce the diameter of the tube sheet
11/12/2018	Welding the cooper tubes with the tube sheet and the baffles
12/12/2018	Welding the tube sheet with the shell
13/12/2018	Meeting with group members for Reviewing the whole report
14/12/2018	Drilling the cover for the inlet and outlet cold fluid
15/12/2018	Assembly process
16/12/2018	Painting/Insulating the shell
19/12/2018	Create a Website
20/12/2018	Reviewing the whole report and finalizing it with the group
21/12/2018	Submission of the report to supervisor

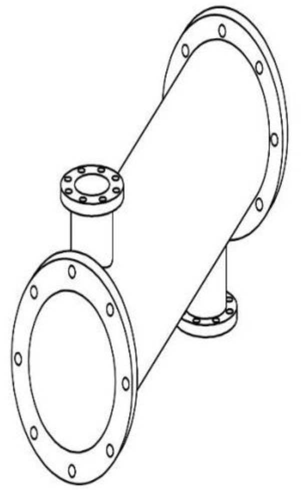
APPENDIX D: GANTT CHART

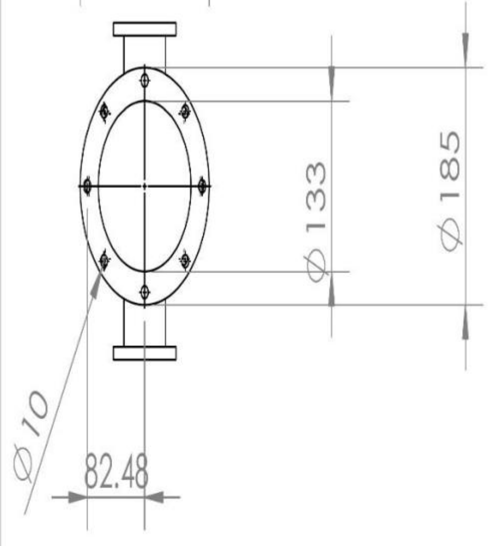


APPENDIX E: ENGINEERING DRAWINGS

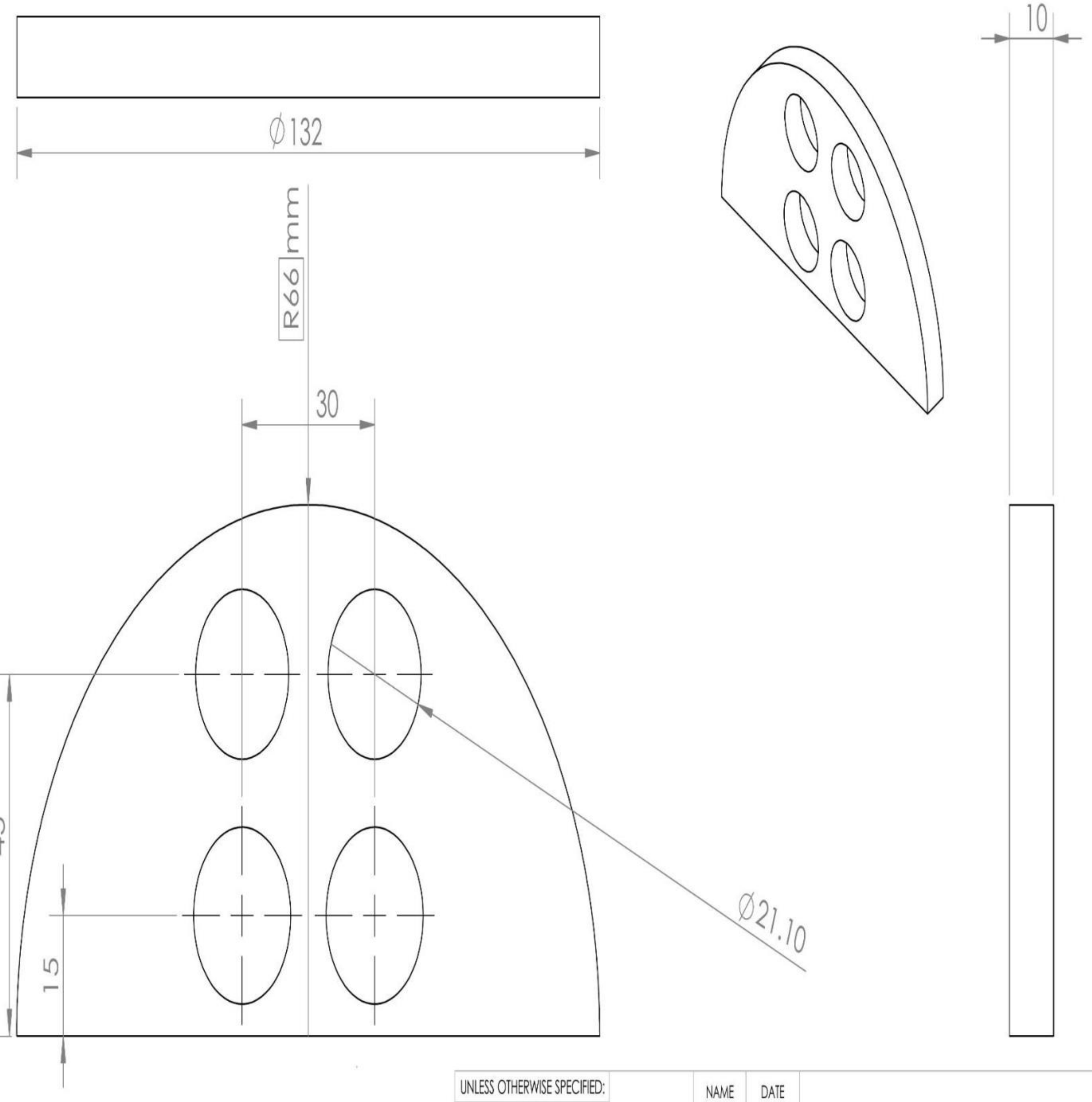




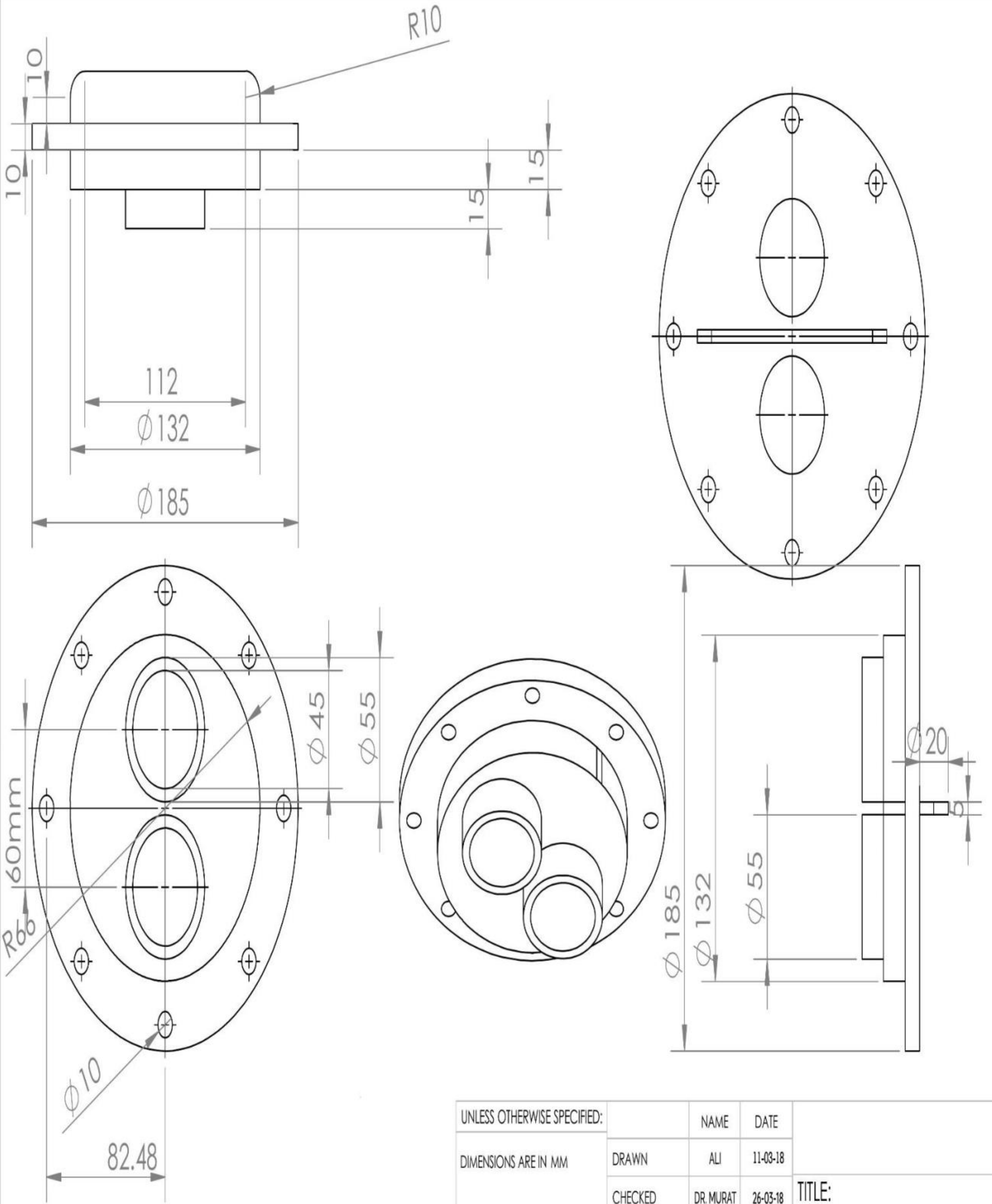




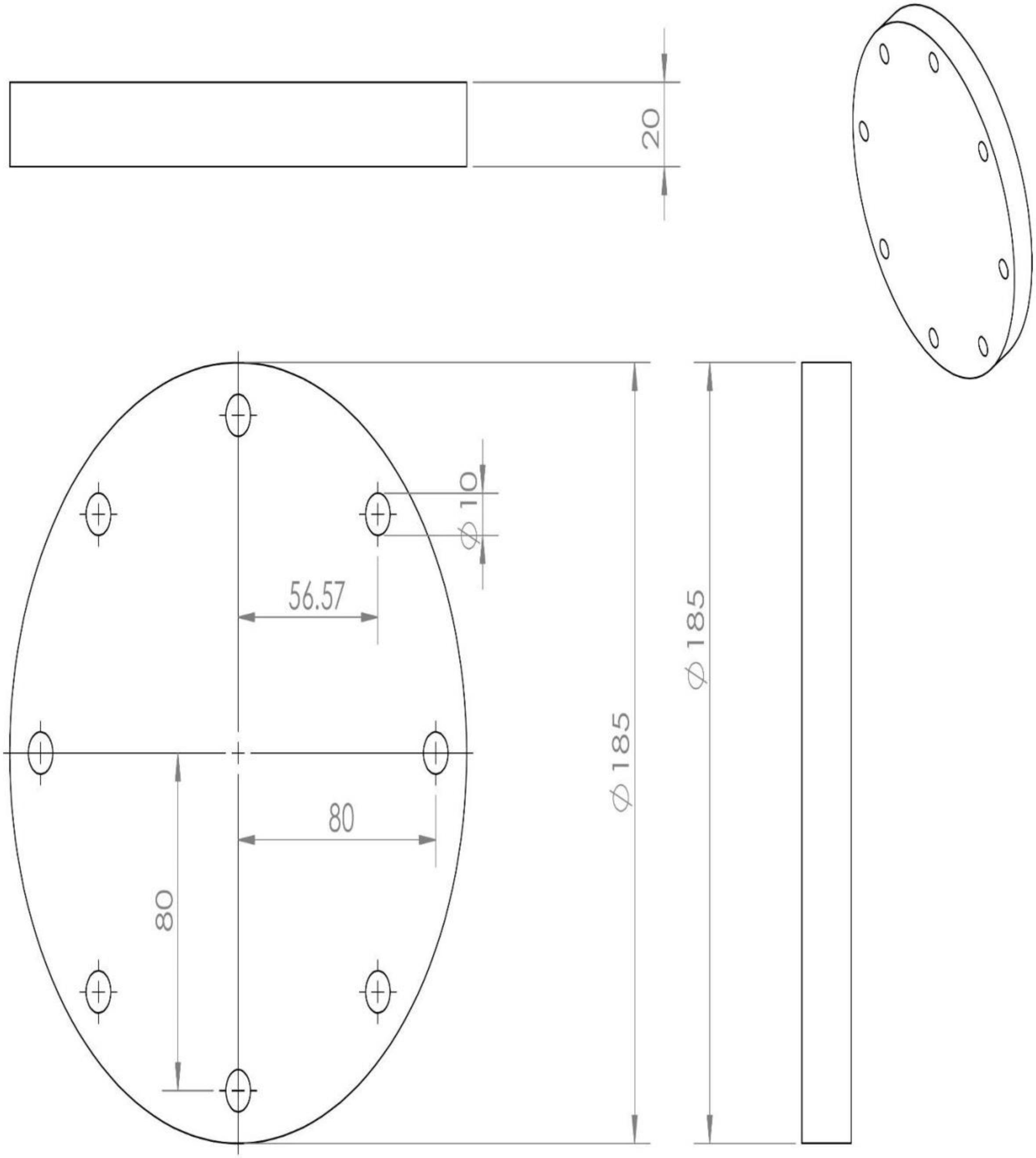
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN MM	DRAWN	ALI	11-03-18	
	CHECKED	DR. MURAT	26-03-18	TITLE:
	COMMENTS:			Shell
MATERIAL STEEL				SIZE A
FINISH ANTI-CORROSION GLOSS PAINT				DWG. NO. 1
DO NOT SCALE DRAWING				SCALE: 1:10 WEIGHT: 40KG SHEET 1 OF 1



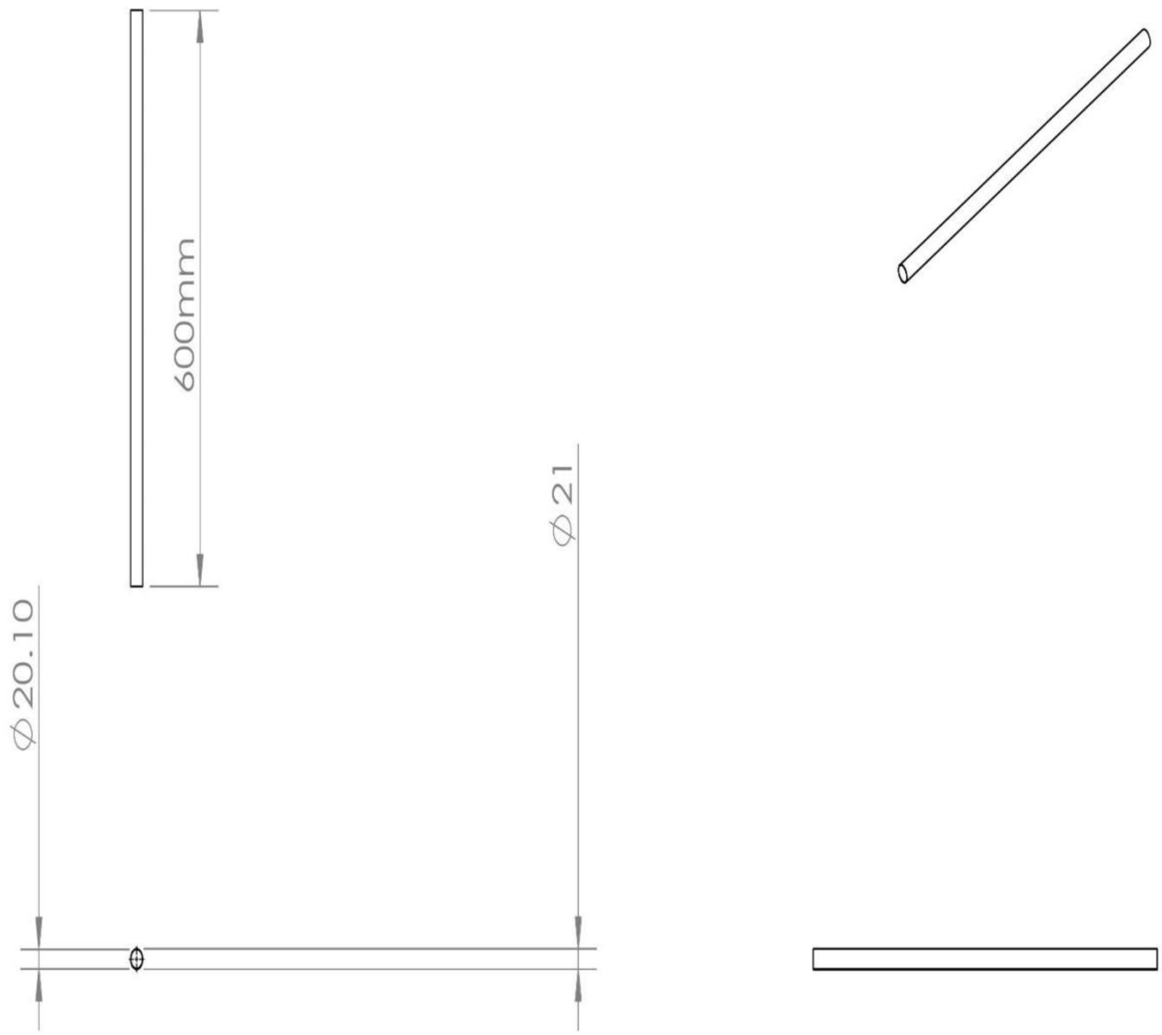
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN MM	DRAWN	ALI	11-03-18	
	CHECKED	DR. MURAT	26-03-18	TITLE: BAFFLES
	COMMENTS:			
MATERIAL STEEL				SIZE A DWG. NO. 1
DO NOT SCALE DRAWING				SCALE: 1:1 WEIGHT: 1.5KG SHEET 1 OF 1



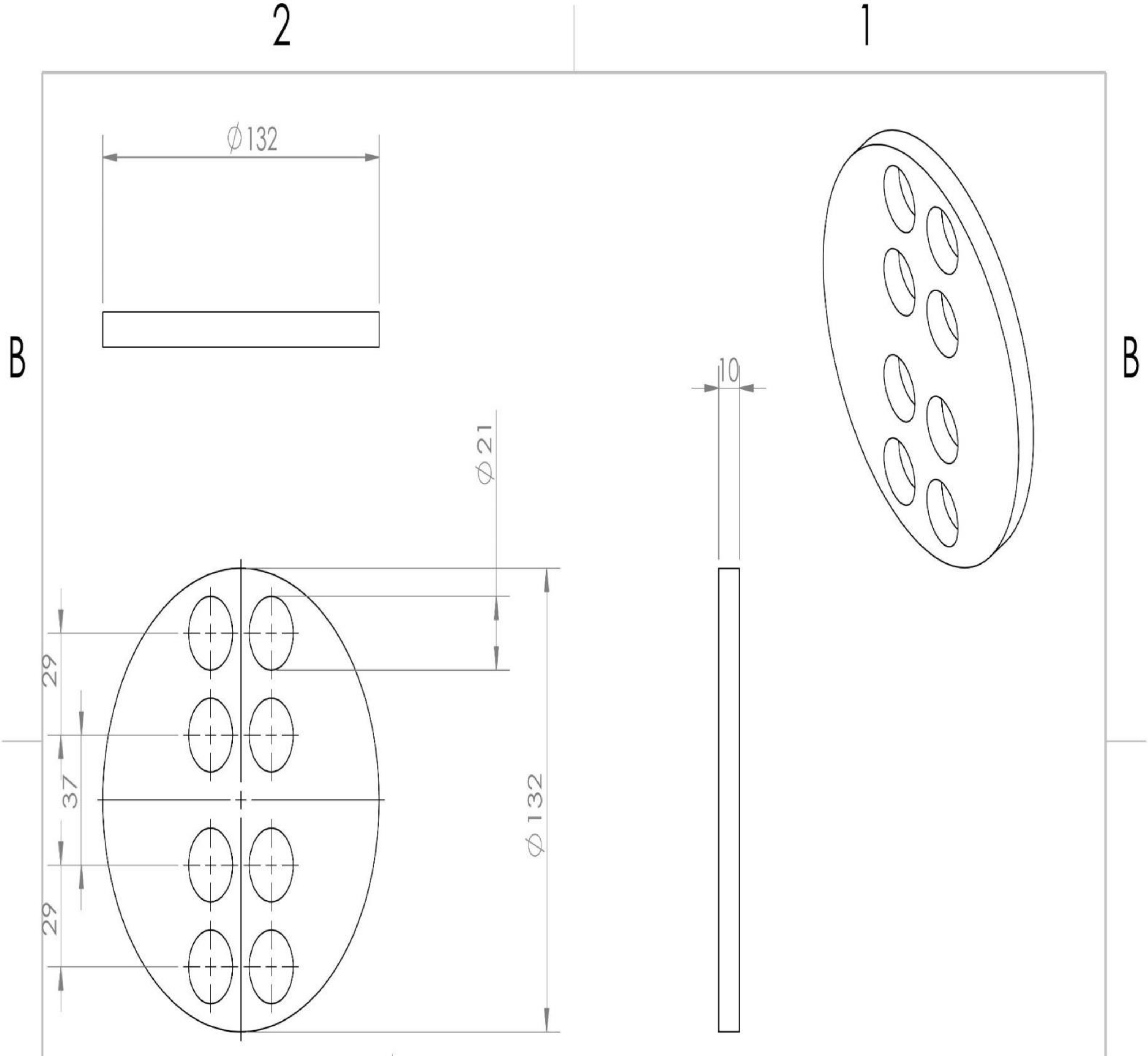
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN MM	DRAWN	ALI	11-03-18	
	CHECKED	DR. MURAT	26-03-18	TITLE: DISC 1
	COMMENTS:			
MATERIAL STEEL				SIZE A DWG. NO. 1
DO NOT SCALE DRAWING				SCALE: 1:5 WEIGHT: 3.0KG SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN MM	DRAWN	ALI	11-03-18	
	CHECKED	DR. MURAT	26-03-18	TITLE: CAP
	COMMENTS:			
MATERIAL STEEL				SIZE A DWG. NO. 1
DO NOT SCALE DRAWING				SCALE: 1:2 WEIGHT:1.5KG SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN MM	DRAWN	ALI	11-03-18	
	CHECKED	DR. MURAT	26-03-18	TITLE: PIPES
	COMMENTS:			
MATERIAL COPPER				SIZE A DWG. NO. 1
DO NOT SCALE DRAWING				SCALE: 1:10 WEIGHT: 0.2KG SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN MM	DRAWN	ALI	11-03-18	
	CHECKED	DR. MURAT	26-03-18	TITLE: TUBE SHEETS
	COMMENTS:			
MATERIAL STEEL				SIZE A DWG. NO. 1
DO NOT SCALE DRAWING				SCALE: 1:10 WEIGHT: 1KG SHEET 1 OF 1