جامعة الأمير محمد بن فهد الأهلية
PRINCE MOHAMMAD BIN FAHD UNIVERSITY

COLLEGE OF ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

DESIGN AND FABRICATION OF HEAT PIPE HEAT EXCHANGER

SENIOR DESIGN PROJECT REPORT

TEAM MEMBERS

	Student Name	Student ID
1.	**Matlaq Al Qahtani**	**201502055**
2.	**Abdul Rahman Al Qwirey**	**201501323**
3.	**Ali Alting**	**201402531**
4.	**Hussain Al Zara**	**201600030**

Project Advisor: Dr. Mohammad El Hassan

Abstract

Heat pipe heat exchangers are proved to be a very efficient way to recover waste heat. For this purpose this project aims to design heat pipe in modern heat exchanger in form of thermosyphon heat exchanger. Project tends to show the applications and advantages of the uses of thermosyphon heat exchangers as heat recovery and cooling device either on small or large scale especially in industrial zones. Heat pipe heat exchangers in thermal conductivity are highly effective. Heat pipes requires no other source of energy like electricity, it simply function with a working fluid in the heat pipe and heat is absorbed in the evaporator region and is then transferred to the condenser where the vaporized liquid is then condensed discharging the heat to the cooling area. There are immense applications of the heat pipe heat exchanger and worldwide it has been receiving acceptance as it is cheap and effective and efficient way of recovery of waste heat.

Acknowledgment

First of all, we would like to bow our heads in front of Allah All Mighty, who bestowed us with the knowledge ability of performing our task so that today we are able to complete our final year project.

Secondly, we would like to pay my utmost gratitude to the Dr. Mohammad El Hassan for giving us a lot of guidance and support in order to properly excel in our engineering field by following certain rubrics by which we can raise our university's name. We are obliged with this opportunity to work on senior design project report.

We would also like to thank and appreciate our university lab technicians and technical personnel in the workshops and industry who provided us their time along with their skills to help us achieve the final prototype of our project and Prince Muhammad Bin Fahd University for making us able to achieve something conspicuous by the help of all the technical and engineering knowledge which we gained in our degree program.

List of Acronyms

Cross-sectional area of thermosyphon	$\mathbf{A_{pipe}}$
Efficiency of thermosyphon	$\boldsymbol{\eta}$
Velocity of water flow	$\mathbf{V_{water}}$
Density of water	$\boldsymbol{\rho_{water}}$
Heat supplied to evaporator	$\mathbf{Q_{in}}$
Amount of heat absorbed	$\mathbf{Q_{out}}$
Mass flow rate in kg/s	**m**
Specific heat capacity of water in kJ/kg-K	$\mathbf{C_P}$
Inlet temperature of cooling water	$\mathbf{T_{in}}$
Outlet temperatures of cooling water	$\mathbf{T_{out}}$

List of Tables

List of Figures

Table of Content

Chapter 1: Introduction

1.1 Project Definition

Heat waste is the most underrated wastage of energy although there has been a lot of study and research done on the recovery or storage of wasted energy but still there is a need of proper application and execution of the done research. For this purpose heat exchangers are used for waste energy and make it possible to recover and reuse this energy where ever desired. Saudi Arabia has made significant progress in industrial development. Industrialization is spread on a vast scale as according to Ministry of Energy, Industry and Mineral Resources there were 7,630 number of factories set up in Saudi Arabia until the end of the first quarter of 2018. It can easily be deducted from the above stated fact that unimaginable heat energy has been nothing more than wasted and released through these factories and other sources.

To overcome this heat depletion heat pipe heat exchanger HPHE is an excellent device to recover waste energy. HPHE not only is the effective way of storing the waste thermal energy but also it also prevents global warming. Heat pipes are inert, extremely consistent and provides with high heat transfer rates with minimal heat loss. There are different types of heat pipe heat exchangers that are being introduced since the beginning of the research and application of the heat pipe heat exchangers and it has been changing over the passage of time with modifications to make it more efficient and effective to store latent heat energy.

For this purpose this project focuses on the Water Cooling Thermosyphon. These are the latest developments. Thermosyphon are the commonly used thermosyphons as they require no mechanical pump like general heat pipes rather it is a self-driven heat exchanger perform on the principle of gravity. In thermosyphon to move the working fluid wick is not used rather fluid moves inside pipe as a result of the difference in its gravity at different temperatures. Thermosyphon is divided into three sections evaporator, adiabatic and condenser. Thermosyphons are cost effective and simple in design as they can work on only water as working liquid and needs no mechanical pump.

1.2 Project Objectives:

The main objective of the said project heat pipe heat exchangers are listed below:

- To enhance its ability to recover heat without wasting any thermal energy
- To achieve a compact heat pipe heat exchanger to have the ability to cool a fluid over a large surface area of heat transfer along with using comparatively less amount of space.
- To make sure that heat transfers over a long distance with a consistent small temperature difference.
- Heat pipes should be flexible enough to achieve effective thermal control as heat exchanger.
- Heat pipe exchanger should be designed so that it is effective and efficient in performance and economical cost wise.
- To ensure both energy savings and environmental protection
- To saves electricity and other fossil fuel as it does not recover external power to function.
- To recover and reuse heat energy and prevents global warming
- Effective way of waste heat recovery
- To cool the water by absorbing the heat from it.

1.3 Project Specifications:

The heat pipe heat exchanger that is going to build on the principle of thermosyphon heat pipes. The following are the specifications based on estimations and approximations:

Table # 1.3: System Dimensions

Dimension	***Value***
Copper pipe inner diameter	1.65 mm
Copper pipe outer diameter	3.18 mm
Duct width	45.72 cm
Duct height	60.96 cm
Transverse pitch	2.18 cm
Axial pitch	1.00 cm
Evaporator-side inlet temperature	37.78 °C

Condenser-side inlet temperature	21.11 °C
Volumetric flow rate of air	1.18 m^3/s

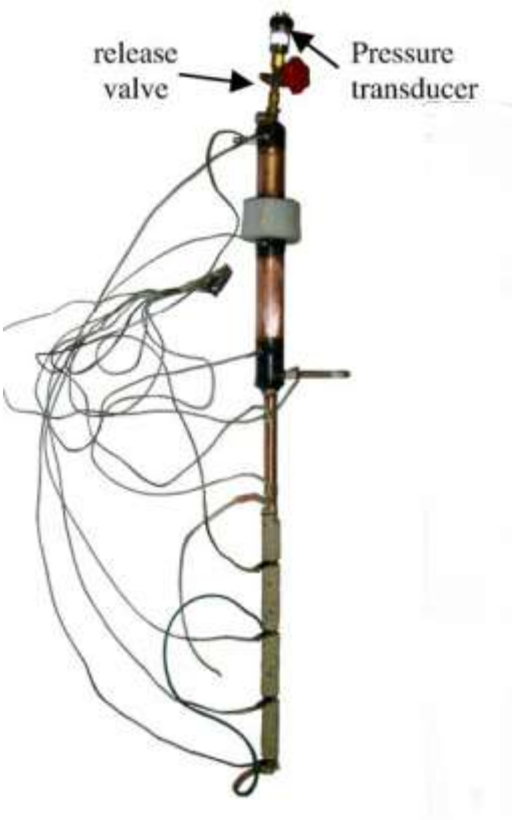


Figure # 1.3: Thermosyphon

1.4 Project Application:

Heat pipes can easily be implemented in heat exchangers as they have effective thermal control. The applications of the said project are vast and spread in many fields and arenas in both commercial and industrial projects. Some of its important applications are mentioned below:

- Heat pipe heat exchangers have important applications in heating, ventilating and air conditioning systems. In this system heat pipe heat exchangers are normally used to recuperate heat from the outlet air to either cool or heat the inlet air.
- Heat pipe heat exchangers can be used to increase the dehumidification of air conditioner. This is the most attractive application specifically in Saudi Arabia as there is considerably a higher level of humidity during summers. This

application improves the indoor air quality by reducing the humidity in the conditioned area by 10 percent.

- ❖ Heat pipe heat exchanger can be applied to chimneys and furnaces to recover heat before combustion for preheated air of the furnace.
- ❖ Heat pipe heat exchangers can be used in hospitals or surgery rooms as cooling agent as the takes in all the heat from the air or area in contact and stores heat leaving the cooled air behind. This experiment is also performed by Noie-Baghban and Majideian.
- ❖ Heat pipe heat exchanger can be used in the car as it can recover heat from the radiator emitting thermal energy.
- ❖ Heat pipe heat exchangers have immense uses in renewable energy systems, cooling electronic devices, heat recovery systems and many other applications.

Chapter 2: Literature Review

2.1 Project Background

Heat Energy preserving in current situation of the world is the need of the hour as many sources of energy are running out and soon will us with the complete extinction of energy along with this to increase the energy efficiency is a relentless test for industry. So to keep the balance it depends on our choice of selection of source of heat energy. It has been years that fossil fuel has used to generate heat energy and now fossil fuel reserves are dangerously limited so to conserve the fossil fuel reserves the researchers in past years suggested to use other natural sources of energy like using solar energy and convert it to desired or required energy like solar energy is being used to produce electricity rather than water or fossil fuel which is even cheaper than the latter. So along with the changing of the choice of source selection it is also required to recover the waste energy which is being released in the atmosphere on daily basis by the industries and factories.

Heat energy is produced by the movement of small particles called atoms, molecules or ions present in gasses, liquids and solids. As heat energy is resulted from movements so it can be transferred from one object to another. Many chemical reactions or industrial apparatus or machineries release heat which is wasted and this is not only waste energy this also pollutes our environment. Recovering waste heat energy is the way out from the current crises of energy although this will take time but eventually we will end up by saving and protecting the environment and remaining fossil fuels. So to recover waste heat energy efficiently and effectively heat exchanger will be used which will work with the heat pipe which will work on the principle of working liquid.

2.2 Previous Work

Recovering waste heat with the use of heat pipe heat exchanger is not a new concept neither unknown. A lot of work has already been done to recover waste heat energy especially from the industries and factories. As waste heat is resulted from the use of machine or the process that involves energy as a by-product of any action. Heat pipe heat exchangers are attached or connected to such appliances and waste heat is recovered.

Among heat exchangers heat pipe heat exchangers is the most effective one as it consumes less energy so the loss of energy is minimal and all the energy is recovered and transferred. In 1942 the original heat pipe operating mechanism was purposed by Richard S. Gaugler of the General Motors Corporations but unfortunately this proposal was neither acknowledged nor known until it was again under research of George M. Grover of Los Alamos Scientific Laboratory in 1963, he autonomously got success on similar device and he coined the name heat pipe to describe the heat exchanger.

Even in recent times researches are still in progress to come up with a better heat pipe heat exchanger another researcher Bhavin shah studied heat pipe heat exchanger and he endorsed the heat pipe much that he deduced that heat pipe itself is very much a heat transfer device in the recent times of heat diffusion efficiently. According to him heat pipe uses the model of evaporation and condensation of working fluid for the transfer of heat. He also shed light on the applications of the heat pipe heat exchanger in various fields like aerospace, electronics packaging, building thermal management, material processing, nuclear, thermo-electro-mechanical device and many more applications.

2.3 Comparative Study:

There is immense research work done on the heat pipe heat exchanger in past and even there is still research going on to make it more efficient and effective and also to explore its applications. Heat pipe heat exchangers have been introduced way back in 1963 but they have not been used like the way they should have been. There is intense research done but lack of practical execution is also observed.

To keep the current project heat pipe heat exchanger useful and related to the country this research is being done, this project will focus on the applications of effective and efficient mechanism of thermo-syphon heat pipe heat exchanger in Saudi Arabia as humanly possible. Heat pipe heat exchanger will be designed in such compact way that capacity to recover the heat energy is increased and it transfers the energy without losing any heat and also without dropping the temperature.

Chapter 3: System Design

3.1 Design Constraints and Design Methodology

3.1.1: Geometrical Constraints

There are many advantages and sound logics to use thermosyphon cooling system in various applications yet there are some geometrical constraints to keep in mind while designing the said project. As thermosyphons principle includes major factor of gravity it makes it essential to model a vertical or almost vertical setup. This may present us with the hurdle while using it in any particular application with horizontal geometrics. Another geometric constraint is that it requires an adequately large distance between top and bottom of the thermosyphon to device convection flow necessary. One more important factor we kept in mind while designing is to avoid any pockets that may trap the returning warm vapour which in result will stop the convective flow. We may face adjustability issue while using in any application which can be limited due to its passive nature.

3.1.2: Sustainability

Thermosyphons have numerous advantages. Thermosyphons being passive in nature need no external pumping for fluid flow and to transfer heat. Leading to a simple and more reliable system. It is quite sustainable and efficient even at cryogenic temperatures. At cryogenic temperatures the thermal conductivity of many materials is very low still water cooling thermosyphons can transfer heat efficiently as compared to solids. Water cooling thermosyphons are considered reliable and sustainable as there are no moving parts. Use of water as cooling agent makes it more efficient as water has very high specific heat which makes it possible for even small amount of water to be able to absorb large amount of heat. Use of thermostat or temperature gauge makes it more sustainable as the temperature is controlled and any unwanted incident can be avoided easily.

3.1.3: Environmental Concern

All types of thermosyphon can be safely called environment friendly as they help to store the wasted and also allow us to utilize that stored heat where required. Thermosyphons due to their quality of storing the released heat are also used as both heating and cooling devices. A lot of heat is just being thrown and released in the air which is effecting ozone layer and cause greenhouse effect. With the use of thermosyphon religiously we can stop doing any more harm to the troposphere. Thermosyphons are usually noise free and energy efficient.

3.1.4: Social Impact

Social impact of thermosyphon is commendable. We can have glimpse of its impact just by considering the applications thermosyphons are being used in. there is no single household where we cannot spot thermosyphons in action. The long list of the applications and uses of water cooling thermosyphon includes modern chip processor, electronics, refrigerator, automobiles (engine cooling), cooling high power LEDs, heat pumps, water heaters, boilers, furnaces, cooling rocket engine and many more.

3.1.5: Economic

Economically thermosyphons are comparatively cheap to use or design as now water pump is required rather it uses convection flow. Even small sized thermosyphon may result in storing larger amount of heat. Water cooling syphon are cheap as it requires water and water is easily accessible and cheaper than other materials or liquids. If attached with the car engine it provides with the two benefits with one devise that the noise of car engine is reduced as the noise passes through the water jacket along with cooling the engine. Another economic factor of thermosyphon using as cooler in the car engine is that the water heated by the car engine can be used simultaneously to heat the car interior as a car heater.

3.1.6: Safety

Thermosyphon being passive in nature and self-driven makes it safe to use. Safety of thermosyphon cooling system can be proved by its use for liquid metal cooled nuclear reactors. The safety if thermosyphon is made sure by using temperature sensors (thermocouples), pressure gauge and pressure relief valve. Along with these accessories one should make sure while designing and constructing that there should be now bubble which may stop the convection flow and will build unwanted pressure.

3.1.7: Ethics

Water cooling thermosyphon is not a unique idea presented by our group. The said project is already being used in many industrial and domestic application either alone or by pairing it with other devices. Our aim is to present and design a sustainable and proficient thermosyphon cooling system which can be adopted a general device in many application where heat energy is being wasted.

3.2 Engineering Design Standards

The components being used for the Water Cooling Thermosyphon design will be mostly made from CNC machines since we want to keep our project in a size that is portable and well-balanced between lifting weight and operational stability. So, based on these primary factors, we decided to follow the following standards:

Table # 3.2: Engineering Design Standards

Components	***Engineering Standards***
Copper coil	ASTM B280
Copper fittings	ASTM B837
Copper nipples	ASTM B837
Copper gee	ASTM B837
Pressure gauge	ASTM E2883
Pressure relief valve	ASTM A351 CF8/CF8M
Temperature sensor	ASTM E2846

3.2.1: Parameter of Thermosyphon

Table # 3.2(a): Parameters

Parameter	***Value***	***Unit***
Evaporator length	**40**	**cm**
Adiabatic length	**20**	**cm**
Condenser length	**40**	**cm**
Inner diameter	**1.4**	**cm**
Wall thickness	**0.5**	**mm**
Thermal conductivity of copper	**350**	**W/mK**
Specific heat of copper	**385**	**J/KgK**

Thermal conductivity of acetone	**0.0115**	**W/Mk**
Viscosity of acetone at 20	**3.2×10^{-4}**	**Pa s**
Thermal conductivity of water	**0.67**	**W/mK**
Viscosity of water at 20	**1.0×10^{-3}**	**Pa s**

3.2.2: Pressure Gauge

We will be using pressure gauge in the setup of water cooling thermosyphon. Pressure gauge is an instrument used to measure the intensity of a fluid. Pressure gauge is required for the machines or setup that are fluid powered and are imperative in troubleshooting them. If pressure gauges are not used then fluid power system will be neither be predictable nor reliable. Gauges in fluid power setups also help in indicating any leaks or pressure fluctuations which can affect the performance of thermosyphon.

3.2.3: Pressure Relief Valve

Pressure relief valve is used in the setup of water cooling thermosyphon. This safety device is designed in such a way that it protects the pressurized setup during an overpressure experience. Condition that could cause pressure in the thermosyphon setup to rise beyond the maximum set or allowable working pressure is referred as overpressure event. This pressure relief valve or safety valve controls or manage the pressure in the thermosyphon setup. Pressure valve can be managed both manually and automatically.

3.2.4: Temperature Sensors

Another important device that should be used as safety measure in setups which may operates on extreme temperatures. Temperature sensor is gadget which is used to measure the temperature via electrical signal and for this it needs thermocouple. Thermocouple constitutes of two unlike electrical conductors producing electrical voltage indirectly proportional to change the temperature. A thermocouple as a result of thermoelectric effect generates a temperature-dependent voltage that can be inferred to measure temperature.

3.2.5: Hot/Flat Plate

Hot plate act as heat collector in the water cooling thermosyphon setup. It is metal box with a glass cover which is called “gazing” on the top and there is an absorber plate on the bottom of dark colour. This plat is very effective in changing solar energy into heat energy.

3.2.6: Acetone

We are using acetone as working liquid in the water cooling thermosyphon. Acetone, or propanone, is the organic compound with the formula $(CH_3)_2CO$.

Table # 3.2(b) Properties of Acetone

Properties	***Acetone***
Chemical formula	**$(CH_3)_2CO$**
Appearance	**Clear water white liquid**
Physical state	**Liquid**
Molecular weight	**58.08**
Density at 20 °C	**6.63lb / US gal**
Dielectric constant 25 °C	**21.45**
Specific Gravity (25 °C/25 °F)	**Not over 0.788**
Viscosity at 15 °C	**0.3371 Cp**

3.2.7: Other Gears Required

- Measurement tape
- Digital meter
- Steel bowl

3.3 Theory and Theoretical Calculations

Thermosyphon is self-driven system works on the principle of natural convection in result of variation in the density of water. There is no need of any sort of mechanical pump which makes it more simple and cost effective. Density of working liquid is reduced because the heated water expands, when the temperature is decreased the volume of water decreases and results in the increase in the density.

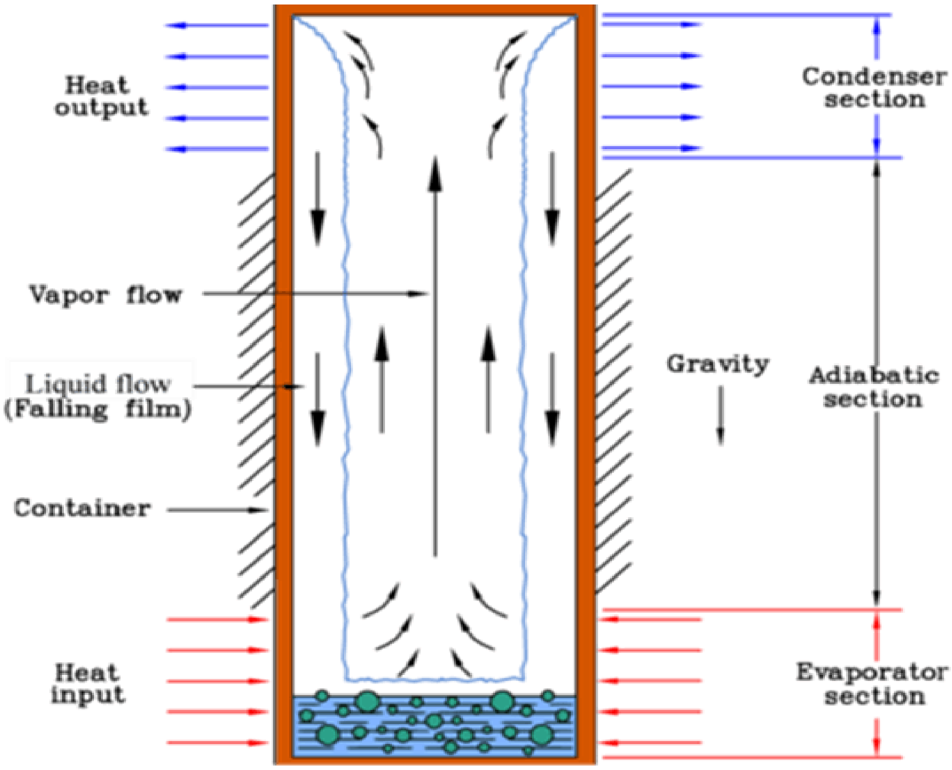


Fig # 3.3: Working Of Thermosyphon

3.3.1: Hypothetical Calculation of Heat Performance of Thermosyphon

The rate of heat transfer to the cooling water Qout, or in other words the amount of heat absorbed by the cooling water in the condenser section will be calculated using the following relation:

$$Q_{out} = mC_p(T_{out} - T_{in})$$

$$Q_{out} = mC_p\Delta T$$

Where,

m = mass flow rate

C_p= specific heat capacity of water

T_{out}= outlet temperature

T_{in}= inlet temperature

ΔT = difference in temperature

To find the amount of total energy or heat supplied to evaporator is $\boldsymbol{Q_{in}}$ to calculate this we will be using the following formula

$$\boldsymbol{Q_{in}} = \frac{\boldsymbol{KA\,(T_{hot} - T_{cold})}}{\boldsymbol{d}}$$

3.3.2: Efficiency of Thermosyphon

The performance of water cooling thermosyphon is evaluated and based on the overall efficiency of the setup. To find the heat performance of the thermosyphon it is calculated as the ration of heat absorbed by the condenser section of thermosyphon to the energy introduces in the evaporation section. Mathematical equation is as follows

$$\eta = Q_{out} / Q_{in} \times 100$$

3.3.3: Mass flow rate of water

The mass flow rate in thermosyphon is defined as the amount of liquid mass flowing through a cross-section per unit time. To calculate the mass flow of water in our case we will be using following equation.

$$\boldsymbol{m_{water} = \rho_{water} * A_{pipe} * V_{water}}$$

Where,

$\boldsymbol{\rho_{water}}$ = density of water

$\boldsymbol{A_{pipe}}$ = cross-sectional area of thermosyphon

$\boldsymbol{V_{water}}$ = velocity of water flow

3.4 Manufacturing and Assembling

Thermosyphon is a passive heat exchange based on natural convection, which circulated the working fluid using the gravity and does not require mechanical pump. To construct a thermosyphon we need to assemble and fix the required items like copper coil, copper fittings, thick pipe insulator, thermocouples, temperature sensors, pressure gauge, pressure release valve, flat plate and steel bowl properly so that there is no leakage when the working liquid is passed through. In thermosyphon to move the working fluid wick is not used rather fluid moves inside pipe as a result of the difference in its gravity at different temperatures. Thermosyphon constitutes of three different parts

1. Evaporator: Heat is introduce d through this section where liquid pool exists, changing the working fluid into vapour.

2. Adiabatic: space between evaporator and condenser where no heat or cooling is applied. Vapour risen from evaporator passes this section to condenser.

3. Condenser: here vapours from the evaporator part are condensed by passing cooling water through water jacket and gives up its latent heat. Then the condensed returns to the evaporator due to gravity. Condenser are always placed above the evaporator.

Figure # 3.4: Pressure Gauge and Copper fittings before Assembling

Figure # 3.4(a): Pressure Gauge and Copper pipe attached

Figure # 3.4(b): Digital meter **Figure# 3.4(c) Measurement tape**

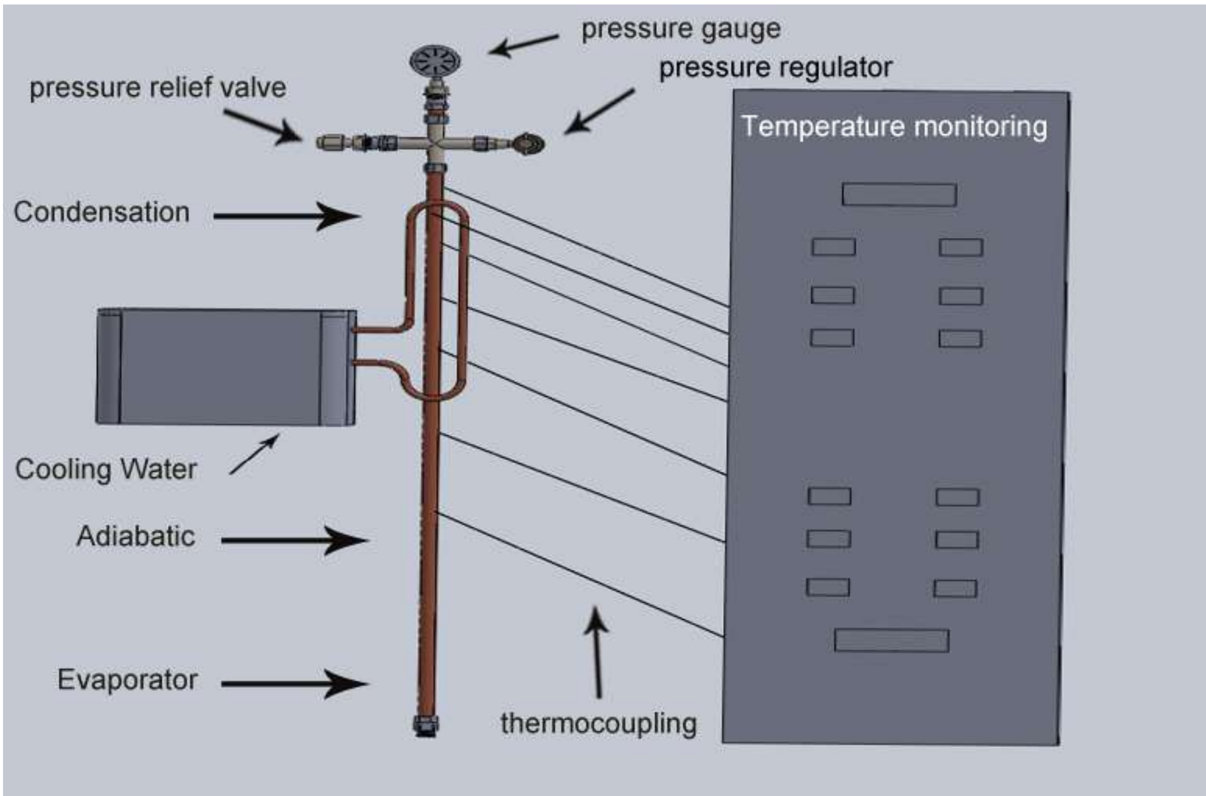


Fig # 3.4(d): CAD Model of Prototype of Thermosyphon

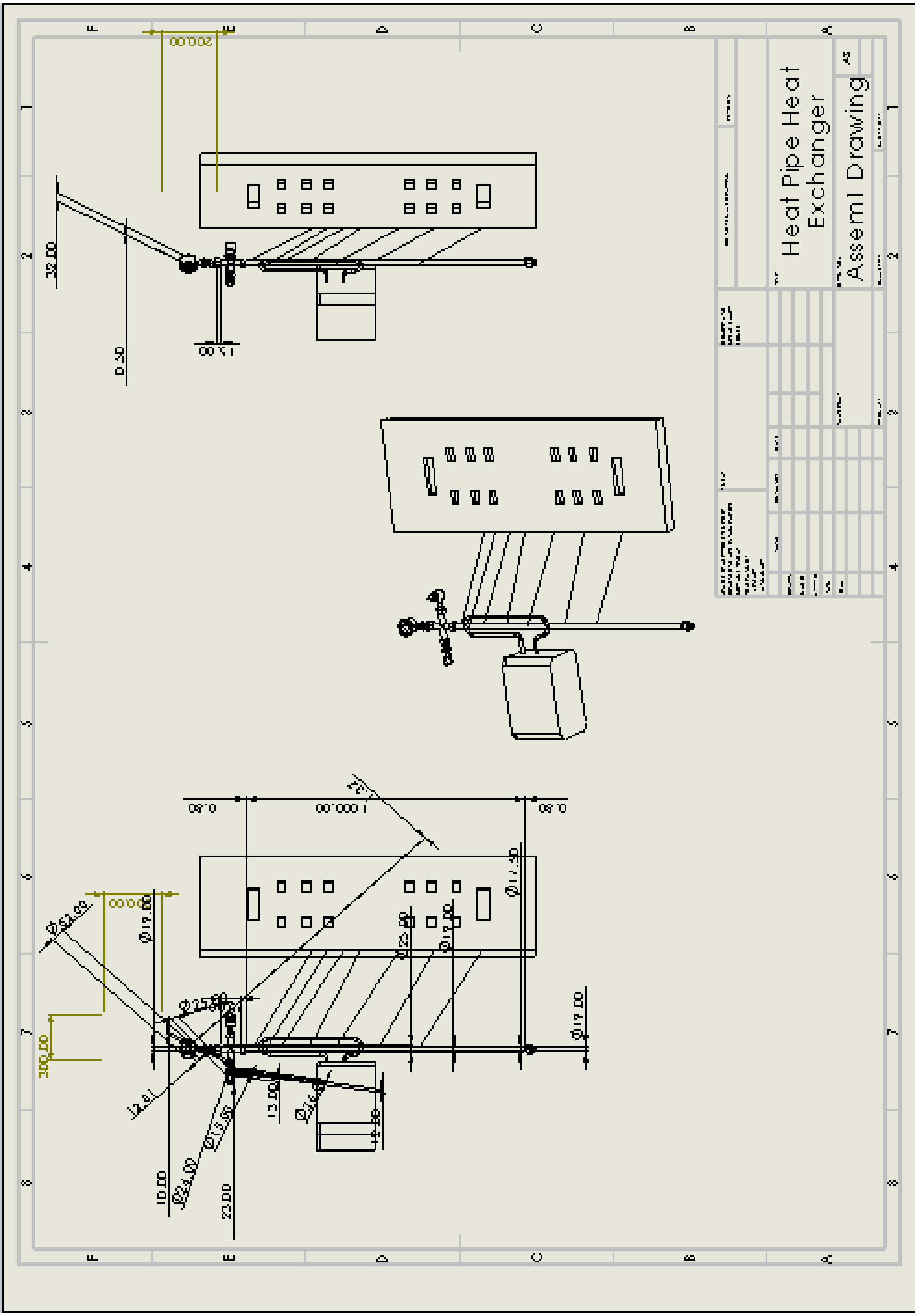


Fig # 3.4(e): Exploded View of Prototype Thermosyphon

Chapter 4: System Testing and Analysis

4.1 Experimental Setup, Sensors and Data Acquisition System

4.1.1: Digital Meter

A digital room thermometer or digital meter are temperature-sensing instruments that are easily portable, have permanent probes, and a convenient digital display. The way a digital thermometer works depends upon its type of sensor. Sensor types include resistance temperature detector (RTD), thermocouple and thermistor. The digital thermometer we used have thermocouples as sensor. Thermocouples are made with two wires of different metals, joined together at one end to form a junction. As the temperature changes, the two dissimilar metals begin to deform, causing a change in resistance. Since our system works on the principles of thermodynamic and temperature difference, there was a need to determine how much heat input was given by the source, which in our case is heated water, and in order to observe and see the temperature difference, we used 5 temperature sensors and digital meter to display water temperature at different distance which was an essential instrument to detect temperature without any physical contact on the system components.

Specifications

Model no: TPM-10

Power supply: DC 1.5v

Display: LCD, 3 Digit Display

Precision: ±1%

Measuring Range: -50°C+108°C

Overall size: 48x28.5x16 cm

Installation Dimensions: 46.2x26.7 mm

Fig # 4.1: digital meter

4.2 Results, Analysis and Discussion

Once the setup was completed we tested the performance and functionality of thermosyphon with the help of two different formulas. At first we calculated the total amount of heat absorbed by the water in the condenser section with the help of following equation:

$$\boldsymbol{Q_{out} = mCp\Delta T}$$

Where we know

$\boldsymbol{Cp = 4.186 J/g\,°C}$

But we had to determine the mass of water that absorbed the heat for this we did as follows:

$$\boldsymbol{m_{water} = \rho_{water} * \Delta\, pipe * V_{water}}$$

$$m = 1000kg/m^3 * (3.1699 \ * 10^{-5}m^2) * 75.784m/s$$

$$\boldsymbol{m_{water} = 2.402\ kg/s}$$

After finding next we did was calculate the difference in the temperature of water

$$\Delta T = 34.2 - 27.9$$

$$\boldsymbol{\Delta T = 6.3°C}$$

Now putting all the values in the above equation

$$Q_{out} = 2.402kg/s * 4.186\ J/g°C * 6.3°C$$

$$\boldsymbol{Q_{out} = 63.34W}$$

After finding Q_{out} we calculated Q_{in} by using the following the formula

$$\boldsymbol{Q_{in} = \frac{KA(T_{hot} - T_{cold})}{d}}$$

Where we know,

K = 397.48W/mk

A = 2.74889x10^{-6} m^2

T_{hot} = 59 ºC

T_{cold} = 40 ºC

d = 0.0025 m

Now putting the values in the equation

$$\boldsymbol{Q_{in} = \frac{KA(T_{hot} - T_{cold})}{d}}$$

$$Q_{in} = \frac{397.48\frac{W}{mk} * 2.74889 \times 10^{-6}(59°C - 40°C)}{0.0025m}$$

$$\boldsymbol{Q_{in} = 83.04W}$$

Another way to find the heat performance efficiency of the thermosyphon is to calculate the ratio of heat absorbed by the condenser section of thermosyphon to the energy introduces in the evaporation section. Mathematical equation is as follows:

$$\boldsymbol{\eta = \frac{Q_{out}}{Q_{in}} * 100}$$

Now putting the values in the equation

$$\eta = \frac{63.34}{83.04} * 100$$

$$\boldsymbol{\eta = 76.276}\%$$

In order to analyse the temperatures in different parts like the evaporator, adiabatic and condenser and also when water exists the system. The system was operated for several minutes to reach maximum performance conditions where the output is stable, reasonable and favourable. After that, the temperature sensors sensed all the temperatures and digital meters showed us all the temperature reading at different distances. The following table shows change in temperature at different distance.

Table # 4.2 Temperature Difference

Temperature °C	*Distance cm*
27.3	100
27.0	60
28.1	80
28.5	70
29.7	50
31.6	40
33.6	30
34.5	20
36.6	10
43.5	0

Chapter 5: Project Management

5.1 Project Plan

The project consists of many different tasks which were assigned almost equally to every member of our team. Each member of the team were given a benchmark and a specific time in order to successfully accomplish their part in the project for prosperous results. The following table.

Table # 5.1: Tasks and their Duration

<table>
<tr><th>S. No.</th><th colspan="2">Tasks</th><th>Start</th><th>End</th><th>Duration</th></tr>
<tr><td>1.</td><td colspan="2">Chapter # 1: Introduction</td><td>09/09/19</td><td>15/09/19</td><td>7</td></tr>
<tr><td rowspan="3">2.</td><td rowspan="3">Chapter # 2: Literature Review</td><td>Project Background</td><td rowspan="3">16/09/19</td><td rowspan="3">28/09/19</td><td rowspan="3">14</td></tr>
<tr><td>Previous work</td></tr>
<tr><td>Comparative Study</td></tr>
<tr><td rowspan="5">3.</td><td rowspan="5">Chapter # 3: System Design</td><td>Design Constraints and Design Methodology</td><td rowspan="5">16/09/19</td><td rowspan="5">26/09/19</td><td rowspan="5">10</td></tr>
<tr><td>Engineering Design Standards</td></tr>
<tr><td>Theory & Theoretical Calculations</td></tr>
<tr><td>Product Subsystems & Selection of Components</td></tr>
<tr><td>Manufacturing & Assembly</td></tr>
</table>

4.	Chapter # 4: System Testing & Analysis	Experimental Setup, Sensors and Data Results, Analysis & Discussions	14/10/19	20/10/19	**7**
5.	Chapter # 5: Project Management	Contribution of team Members Project Execution Monitoring Challenges and Decision Making Project Bill of Materials and Budget	20/10/19	25/10/19	5
6.	Chapter # 6: Project Analysis	Impact of Engineering Solution Contemporary Issues Addressed.	26/11/19	28/11/19	2
7.	Chapter # 7: Conclusion & Recommendation	Conclusion Future Recommendation	28/11/1	29/11/19	1
8.	Design of Prototype		27/09/19	02/10/19	5
9.	Parts Purchase		05/10/19	07/10/19	3
10.	Manufacturing		05/10/19	12/10/19	8
11.	Testing		22/11/19	22/11/19	1

Table # 5.1 (a): Assigned Members for Tasks

S. No.	***Task***	***Assigned Members***
1.	Chapter # 1: Introduction	Matlaq Al Qahtani
2.	Chapter # 2: Literature Review	Abdul & Ali
3.	Chapter # 3: System Design	Hussain & Matlaq
4.	Chapter # 4: System Testing & Analysis	Abdul & Hussain
5.	Chapter # 5: Project Management	Ali & Matlaq
6.	Chapter # 6: Project Analysis	Everyone
7.	Chapter # 7: Conclusion & Recommendation	Hussain
8.	Design of Prototype	Everyone
9.	Parts Purchased	Abdul & Ali
10.	Manufacturing	Everyone
11.	Testing	Everyone

5.2 Contribution of Team Members

Since our team has played a role in accomplishing the requirements for the project, each of the members contributed their amount of effort and time depending on the ability of their work and their efficiency. The table below depicts about how much contribution was made by each team member:

Table # 5.2: Contribution of Tasks

<table>
<tr><th>S. No.</th><th colspan="2">Tasks</th><th>Assigned Member</th><th>Contribution</th></tr>
<tr><td>1.</td><td colspan="2">Chapter # 1: Introduction</td><td>Matlaq</td><td>100 %</td></tr>
<tr><td rowspan="2">2.</td><td rowspan="2">Chapter # 2: Literature Review</td><td>Project Background</td><td>Abdul</td><td>50 %</td></tr>
<tr><td>Previous work</td><td>Ali</td><td>50 %</td></tr>
<tr><td>3.</td><td>Chapter # 3: System Design</td><td>Design Constraints and Design Methodology</td><td>Hussain</td><td>20 %</td></tr>
</table>

<table>
<tr><td rowspan="4"></td><td rowspan="4"></td><td>Engineering Design Standards</td><td>Hussain</td><td>20%</td></tr>
<tr><td>Theory & Theoretical Calculations</td><td>Matlaq</td><td>20 %</td></tr>
<tr><td>Product Subsystems & Selection of Components</td><td>Matlaq</td><td>20 %</td></tr>
<tr><td>Manufacturing & Assembly</td><td>Both</td><td>20 %</td></tr>
<tr><td rowspan="2">4.</td><td rowspan="2">Chapter # 4: System Testing & Analysis</td><td>Experimental Setup, Sensors and Data</td><td>Abdul</td><td rowspan="2">100%</td></tr>
<tr><td>Results, Analysis & Discussions</td><td>Hussain</td></tr>
<tr><td rowspan="4">5.</td><td rowspan="4">Chapter # 5: Project Management</td><td>Contribution of team Members</td><td rowspan="2">Ali</td><td rowspan="4">100%</td></tr>
<tr><td>Project Execution Monitoring</td></tr>
<tr><td>Challenges and Decision Making</td><td rowspan="2">Matlaq</td></tr>
<tr><td>Project Bill of Materials and Budget</td></tr>
<tr><td rowspan="2">6.</td><td rowspan="2">Chapter # 6: Project Analysis</td><td>Impact of Engineering Solution</td><td rowspan="2">Everyone</td><td rowspan="2">100%</td></tr>
<tr><td>Contemporary Issues Addressed.</td></tr>
<tr><td rowspan="2">7.</td><td rowspan="2">Chapter # 7: Conclusion & Recommendation</td><td>Conclusion</td><td rowspan="2">Hussain</td><td rowspan="2">100%</td></tr>
<tr><td>Future Recommendation</td></tr>
<tr><td>8.</td><td colspan="2">Design of Prototype</td><td>Everyone</td><td>100%</td></tr>
<tr><td>9.</td><td colspan="2">Parts Purchase</td><td>Abdul & Ali</td><td>100%</td></tr>
</table>

10.	Manufacturing	Everyone	100%
11.	Testing	Everyone	100%

5.3 Project Execution Monitoring

In order to avoid any hurdles or distractions and keep the project developing step by step, we had meetings to attend with team members and with the supervisor and advisor as well. Which proved to be very beneficial as any problem raised was there and then encountered and resolved. Along with these meetings we had to submit initial stage reports and midterm presentations and all of these were managed and executed on time.

Table #5.3: Dates of Activities and Events

Time/Date	***Activities/Events***
Once in week	Assessment Class
Bi-Weekly	Meeting with the group members
Weekly	Meeting with the Advisor
25th October, 2019	First Finished Prototype
14th November, 2019	Midterm Presentation
27th October, 2019	First Test of System
20th November, 2019	Finishing Final Prototype
30th November, 2019	Test of the System
05th December, 2019	Final Submission of Report
12th December, 2019	Final Presentation

5.4 Challenges and Decision Making

Working on project is usually a challenging task to get everything right and to deliver on time. Initial challenges were faced at the time of selecting which type heat exchanger we will be working on. But we kept our minds open and listen to each other’s opinion and also sought guide from our advisor. After doing some research on internet and in the market that which type is achievable we decided mutually to do the project on the thermosyphon heat pipe heat exchanger and it actually paid off as we successfully completed its prototype and experiments on it.

5.4.1: Equipment and Device Problems

Digital Meter

Since our whole setup depends on the temperature change of the working fluid and in the tests we had to take readings of the temperature so in the testing phase we ran into trouble as the temperature sensors were not detecting a small change in temperature but soon we realized the issue and resolve it by using a high quality thermocouple along with the digital meter to automatically take the readings of the change in the temperature.

5.4.2: Testing and Safety Issues

Our system is completely heat based system and works with the fluids so we took every step to make testing very safe. Keeping safety issues in mind we installed the thermosyphon in such a way that it was completely fixed and static and motor was also placed at distance that it does not create any vibrations or cause thermosyphon to fall. We also kept the water tank covered properly so that there is no splash of hot water.

5.5 Project Bill of Materials and Budget

Project requires investment of time, effort and money. Similarly we had to spend money in order to purchase materials and parts for the constructions of the prototype. Following table shows the prices of the materials and the total cost incurred in Saudi Riyal.

Table # 5.5: Project Bill

Materials	***Cost (SAR)***
Pressure release valve	125
Gear T	360
Pressure Gauge	310
Reducer 4 pc	100
¼ pipe	188
Union 5pc	200
Temperature sensor 5pc	11
Pressure regulator	690
3/8 pipe	288
Temperature switch	205
Total cost	2397

Chapter 6: Project Analysis

6.1 Life-Long Learning

We worked on a project that teaches us a lot more than what we have learned in classrooms. We have learned most of these theories in our university, however our project acquire real life execution. During working on our project we came across lifelong learning, we learnt how to be wise enough to make changes in design according to the demand of the situation. In progress of our project we work as a team and had only one aim in our minds. The aim was to achieve or acquire the goals that have been set in the start of the project. The software and hardware skills were used in a very efficient manner.

6.1.1: Software Skills

To design our prototype, we first had to refer to the internet and then try out the constraints on Solid-works Simulation. There we were to design and simulate the necessary components for our system to ensure proper operation according to our need of using less material but sufficient enough to be able to put into our system so that it can run smoothly. It all went extremely well by our contribution and assistance since one of us was able to solve a hurdle much quicker depending on the way he thought.

6.1.2: Hardware Skills

To conduct a performance test of our system, we had to interact with some of the facilities provided in our Laboratories which included a thermocouple and digital meter. Having sufficient background knowledge on using Thermometer sensor we were able to successfully run the test without additional help. However, the thermocouple was a bit tricky to use and by the help of Lab Technician, we were able to learn how to determine several different aspects of a system.

6.1.1: Time Management

We had three months of total time to work on our project. The three months of time seems enough to complete our project but when we started working on project, at first it seems hard to complete on given time. In order to be ahead of time for predicted problems and those problems and issues which would likely to be faced in future, we really needed to manage time in efficient manner. After a proper guidance and help of experts, we finally manage to accomplish a task that was set for us.

6.1.1: Project Management

We thought of a plan to execute and follow it step by step in order to carry out the whole schedule of developing our project. Our project was very simple although it was unique but required late nights to complete the project. It took us three weeks to assemble and manufacture the heat pipe heat exchanger once the purchase of material completed. Tasks were equally distributed among the members of the team. We also help each other in time of need. So, the mutual understanding and communication among the team members make the project completed on time. This efficient and effective teamwork and the help of our doctors and experts led us to successful completion of our project.

6.2 Impact of Engineering Solutions

6.2.1: Society

We worked on this project by keeping in mind that how it would serve to the society and what society needs to be careful. Heat waste is the most underrated wastage of energy although there has been a lot of study and research done on the recovery or storage of wasted energy but still there is a need of proper application and execution of the done research. For this purpose heat exchangers are used for waste energy and make it possible to recover and reuse this energy where ever desired.

6.2.2: Economy

The expenses of the project have been mentioned that how this whole project is economically affordable. Expenses and consideration that are taken made this project low cost. Heat pipe exchanger should be designed in a way that it is effective and efficient in performance and economical cost wise. In our project it was ensured that both heat pipe heat exchangers are energy savings and are for protection of environment. Thermosyphons are cost effective and simple in design as they can work on only water as working liquid and needs no mechanical pump.

6.2.3: Environment

Our motto for this project is to find effective way of waste recovery. Renewable energy is completely environmental friendly and has no pollutants to be produced. The aim of the project is to recover and reuse heat energy and prevents global warming and to cool the water by absorbing the heat from it. By doing this we can accomplish pollution prevention, waste reduction, resource conservation and carbon emission free environment.

6.3 Contemporary Issues Addressed

To help in saving the earth atmosphere or environment, there is a global run towards the fact on going green in terms of using resources and decreasing pollutants. The by-products being produced by kingdom of Saudi Arabia are unfavorable for the environment and economy and the people. So, heat pipe heat exchanger will play an important role in helping and saving the planet and its people from global warming. Heat pipe heat exchanger is environment friendly and it helps recover the waste energy. Heat pipes can easily be implemented in heat exchangers as they have effective thermal control. The applications of the said project are vast and spread in many fields and arenas in both commercial and industrial projects.

Chapter 7: Conclusion & Future Recommendations

7.1 Conclusion

To sum up, our project is on heat pipe heat exchangers. Heat pipe heat exchangers are proved to be a very efficient way to recover waste heat. For this purpose this project aims to design heat pipe in modern heat exchanger in form of thermosyphon heat exchanger. Project tends to show the applications and advantages of the uses of thermosyphon heat exchangers as heat recovery and cooling device either on small or large scale especially in industrial zones. Heat pipe heat exchangers in thermal conductivity are highly effective. Heat pipes requires no other source of energy like electricity, it simply function with a working fluid in the heat pipe and heat is absorbed in the evaporator region and is then transferred to the condenser where the vaporized liquid is then condensed discharging the heat to the cooling area. We did learn a lot from these past three months from our project. We learned how to be constructive and strong-minded in order to achieve our goals and also how to properly use our engineering knowledge and how to apply it on our project.

7.2 Future Recommendations

We could not make our project on larger scale due to limits and limitation of knowledge. Although heat pipe heat exchanger is a successful projects but it needs some improvements. Our focus was to make the project light weight and not very expensive. So that it can be benefit for society and easy purchased. It can also be used in cars. Heat pipe heat exchangers in thermal conductivity are highly effective. Heat pipes requires no other source of energy like electricity, it simply function with a working fluid in the heat pipe and heat is absorbed in the evaporator region and is then transferred to the condenser where the vaporized liquid is then condensed discharging the heat to the cooling area. This idea or project can be of great magnetism for the society as it is environment friendly.

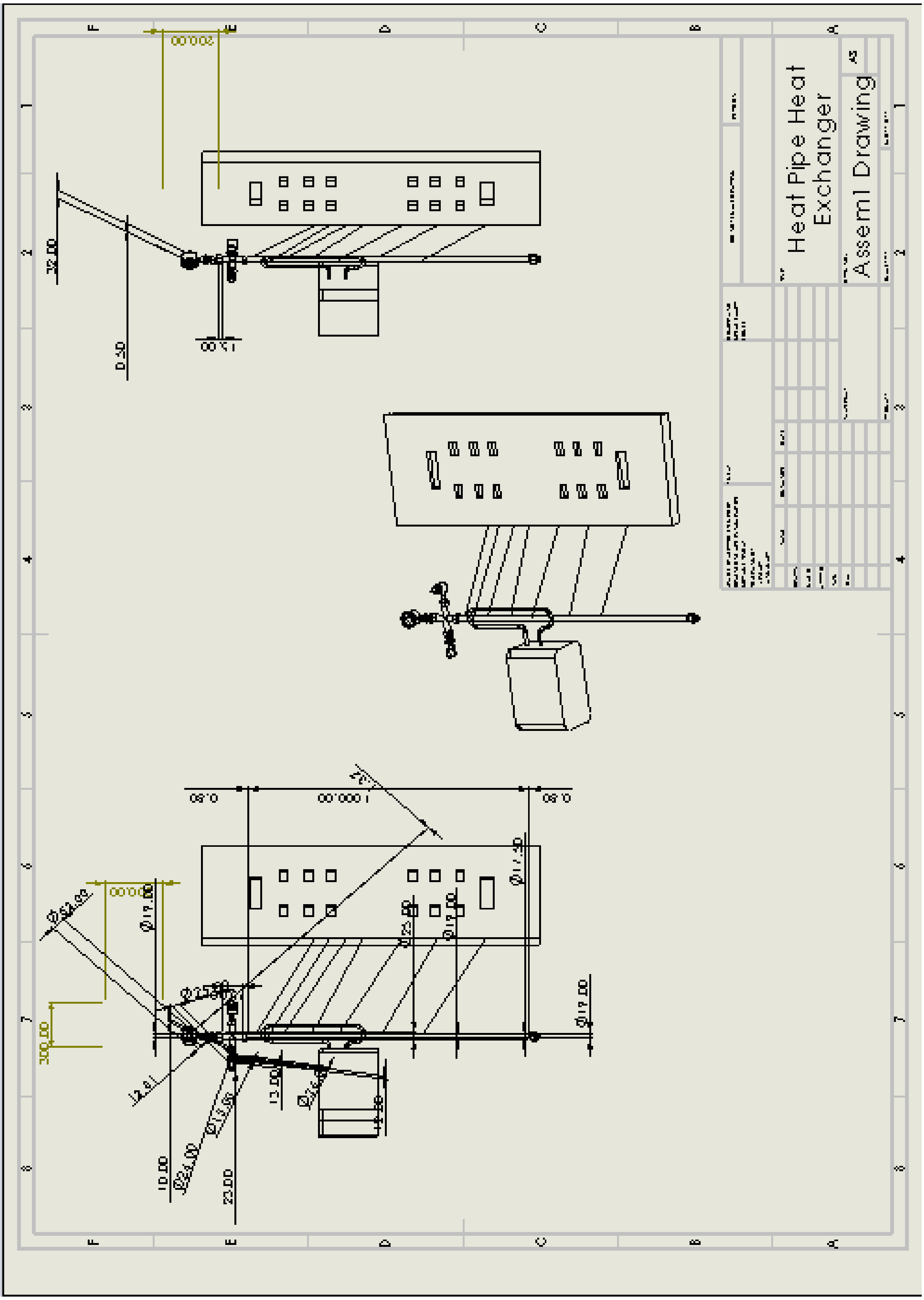
References

1. Pal, A., Joshi, Y., & Wenger, T. (2001). Design and Performance Evaluation of a Compact Thermosyphon. Retrieved on Sept 15, 2019 from https://pdfs.semanticscholar.org/bfaa/438800fd68aa238cc05a2ab3e540630b1b5a.pdf
2. Howell, D., (2019). Thermosyphons. Retrieved on Sept 22, 2019 from https://www.sciencedirect.com/topics/engineering/thermosyphons
3. Streicher, W.,& Soteris, A. (2016). Thermosiphon System. Retrived on Oct 01,2019 from https://www.sciencedirect.com/topics/engineering/thermosiphon-system
4. Abdullahi, B., Raya, K., & Sa'ad, M. (August 7, 2019). Thermosyphon Heat Pipe Technology. Retrieved on Oct 01, 2019 from https://www.intechopen.com/books/recent-advances-in-heat-pipes/thermosyphon-heat-pipe-technology
5. Lamaison, N., Marcinichen, J., Szczukiewicz, S., & John, R. (January, 2016). Passive Thermosyphon Cooling System for High Heat Flux Servers. Retrieved on Oct 03, 2019 from https://www.researchgate.net/publication/301238878_Passive_Thermosyphon_Cooling_System_for_High_Heat_Flux_Servers

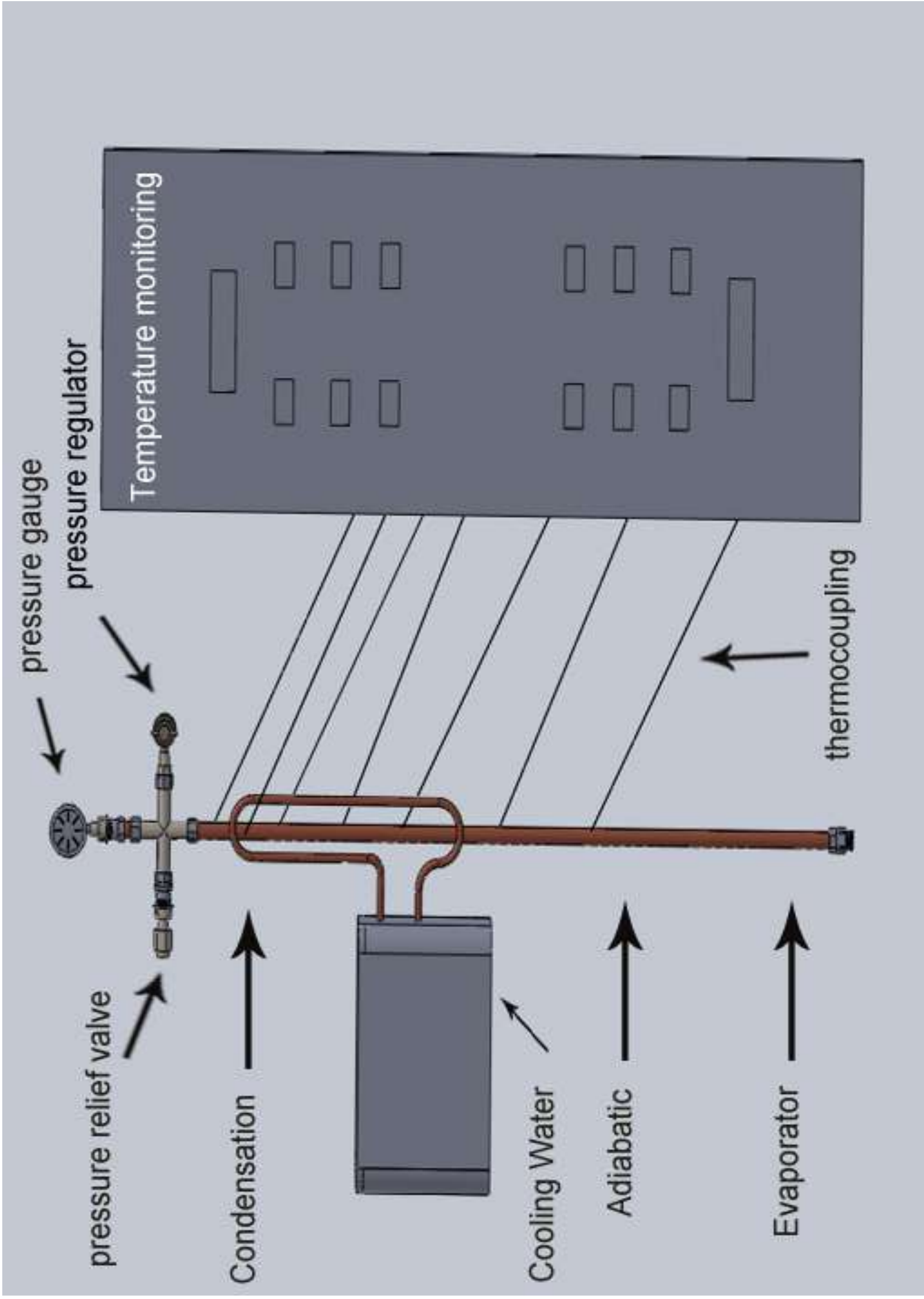
Appendix A: Engineering Standards

Components	***Engineering Standards***
Copper coil	ASTM B280
Copper fittings	ASTM B837
Copper nipples	ASTM B837
Copper gee	ASTM B837
Pressure gauge	ASTM E2883
Pressure relief valve	ASTM A351 CF8/CF8M
Temperature sensor	ASTM E2846

Appendix B: CAD Drawing



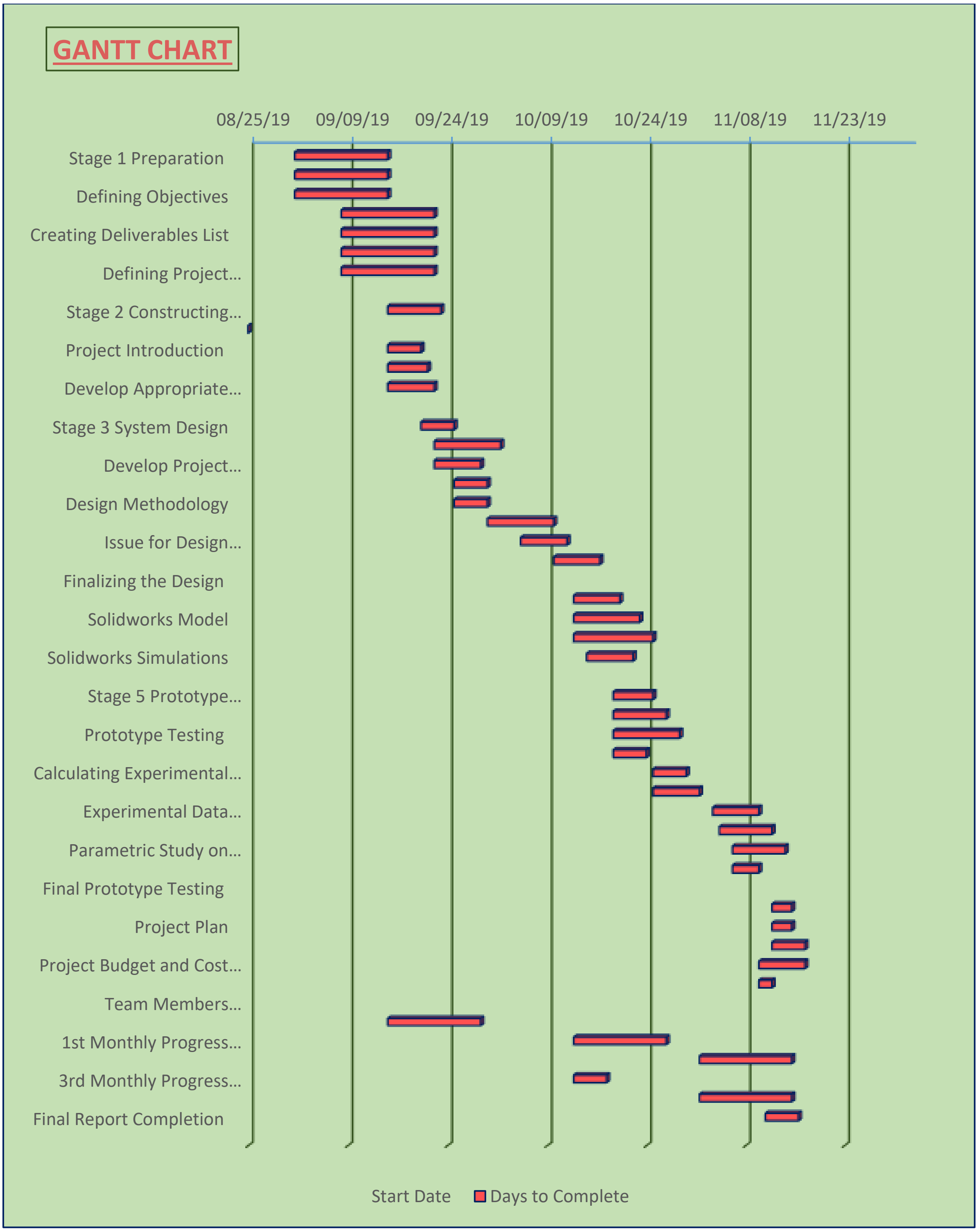
CAD MODEL



Temperature monitoring
pressure gauge
pressure regulator
thermocoupling
pressure relief valve
Condensation
Cooling Water
Adiabatic
Evaporator

Appendix D: Prototype Picture

Appendix E: Gantt chart



Stage 1 Introduction	**Start Date**	**Days to Complete**	**Responsible**
Project Identification	01/09/2019	14	Everyone
Defining Objectives	01/09/2019	14	Everyone
Assessing Project Needs	01/09/2019	14	Matlaq Al Qahtani
Creating Deliverables List	08/09/2019	14	Ali Alting
Developing General Scope	08/09/2019	14	Hussain Al Zara
Defining Project Applications	08/09/2019	14	Everyone
Organizing Gantt Chart	08/09/2019	14	Abdul Rahman
Stage 2 Literature Review	**Start Date**	**Days to Complete**	**Responsible**
Preparing Abstract, Acknowledgment, Table of Content	15/09/2019	8	Matlaq Al Qahtani
Project Introduction	15/09/2009	5	Abdul Rahman
Defining Project Objectives and Specifications	15/09/2019	5	Ali Alting, Matlaq Al Qahtani
Develop Appropriate Strategies	15/09/2019	6	Hussain Al Zara
Literature Review	15/09/2019	7	Abdul Rahman, Hussain Al Zara

Stage 3 System Design	**Start date**	**Days to Complete**	**Responsible**
Developing System Design	20/09/2019	5	Matlaq Al Qahtani
Develop Project Procedures	22/09/2019	10	Abdul Rahman
Identify Design Constraints	22/09/2019	7	Ali Alting
Design Methodology	25/09/2019	5	Hussain
Selecting Equipment and Materials	25/09/2019	5	Everyone
Issue for Design Equipment List	30/09/2019	10	Matlaq Al Qahtani, Hussain
Design Calculations	05/10/2019	7	Hussain
Finalizing the Design	10/10/2019	7	Matlaq Al Qahtani
Stage 4 CAD	**Start Date**	**Days to Complete**	**Responsible**
Solid works Model	13/10/2019	7	Ali Alting
Stress Analysis	13/10/2019	10	Abdul Rahman
Solid works Simulations	13/10/2019	12	Matalq Al Qahtani
Result, Analysis and Discussion	15/10/2019	7	Everyone

Stage 5 Prototype completion	**Start Date**	**Days to Complete**	**Responsible**
Laboratory Prototype complete at PMU	19/10/2019	6	Abdul Rahman
Prototype Testing	19/10/2019	8	Ali Alting
Calculating the Efficiency	19/10/2019	10	Matlaq Al Qahtani
Calculating Experimental Losses	19/10/2019	5	Hussain Al Zara
Numerical Modelling CFD	25/10/2019	5	Ali Alting, Abdul Rehman
Experimental Data Collection and CFD Validation	25/10/2019	7	Hussain, Matlaq
Integration of Flow Control Methods	03/11/2019	7	Abdul Rehman
Parametric Study on Passive Flow chart	04/11/2019	8	Hussain
Finalizing the Prototype	06/11/2019	8	Ali
Final Prototype Testing	06/11/2019	4	Matlaq Al Qahtani
Stage 6 Project Management and Analysis	**Start date**	**Days to Complete**	**Responsible**
Project Plan	12/11/2019	3	Everyone

Project Execution and Monitoring	12/11/2019	3	Matlaq Al Qahtani, Abdul Rehman
Project Budget and Cost Analysis	12/11/2019	5	Hussain Al Zara, Ali Alting
Challenges and Decision Making	10/11/2019	7	Everyone
Team Members Contribution	10/11/2019	2	Everyone
Stage 7 Final Report and other Deliverables	**Start Date**	**Days to Complete**	**Responsible**
1st Monthly Progress Report	15/09/2019	14	Hussain Al Zara
2nd Monthly Progress Report	13/10/2019	14	Matlaq Al Qahtani
3rd Monthly Progress Report	05/12/2019	14	Ali Alting
Preparing Midterm Presentation	13/10/2019	5	Abdul Rahman
Final Report Completion	21/12/2019	14	Matlaq Al Qahtani, Ali Alting
Preparing Final Presentation	01/12/2019	5	Hussain Al Zara