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Senior Design Project Report

Design of Solar Thermal Collector for The Purpose of Optimizing Coil View Factor

In partial fulfillment of the requirements for the Degree of Bachelor of Science in Mechanical Engineering

Group Number #4

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Abstract

A recent interest in renewable energy in Saudi Arabia has created a need to find alternative suitable solutions for energy. Solar energy is one of the most interesting solutions to produce renewable energy. Therefore, many research centers and universities have shown interest in conducting experimental studies to improve and develop the efficiency of heat transfer upon the existing system of solar thermal collector. The aim of this project is to design and test a solar thermal collector. The collector will be used to test a number of configurations for coils to maximize the heat transfer. The project results will provide guidelines to utilize the most efficient coil geometry in solar thermal collectors.

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Chapter 1: Introduction

1.1 Project Definition

This project is intended to design and manufacture the solar thermal collector that used to demonstrate how solar energy or radiation energy could be converted into heat energy. We will upgrade this system by puting different geometric of coil shapes painted by black color inside the thermal collector one by one. The set-up for this system includes a wooden box of the solar thermal collector, concave of aluminum sheets fixed inside the wooden wall, different geometries of copper coils pipes, plastic hoses connected between copper coil pipe and plastic pipes. In addition, we put measurements tools (flowumetric and thermometer) for calculations. This system can illustrate how the water heater in a house works or if used without water to illustrate how a radiator heats up a room.

1.2 Project Objectives

We have more than one objective in this project. First, designing a test rig coil in different geometries and then designing a number of coil geometries. Furthermore, designing experiments to study the best coil geometry efficiency in heat transfer.

1.3 Project Specifications

There are three main parts in our projects which are pipe coils, absorber box, and heater. As shown in Figure 1.1 there are four types pipe coils: (A) Conical coil, (B) Barrel coil, (C) Hourglass coil, and (D) Constant pitch coil. Moreover, we have (E) Searchlight which is a device that produces heat and radiation energy to (F) thermal collector box that covers by aluminum sheets from inside to reflect the radiation to the pipe coil.

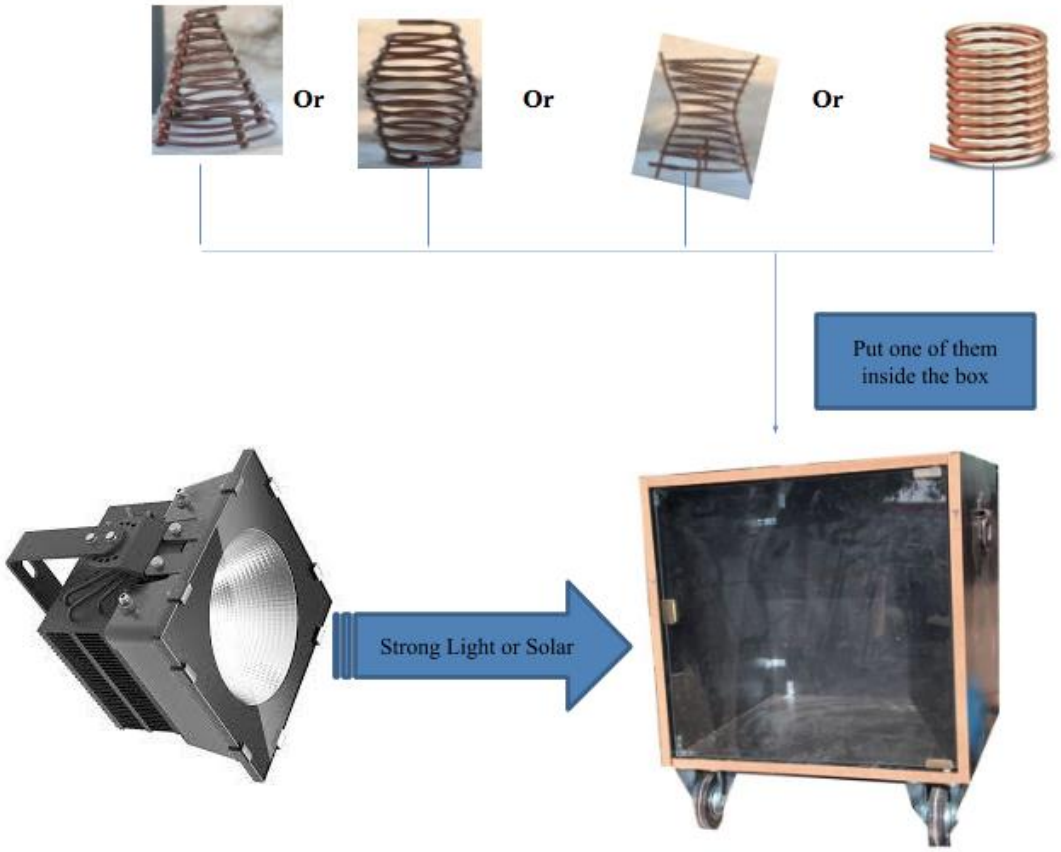


Figure1.1 Solar Thermal System

1.3.2 Specifications of the box

The box is the solar thermal collector. Inside this box we will place the coil pipes. Table 1.1, we listed the specification of box.

Table1.1 Specifications of the box

Specification	Description
Material Of Front Side	Glass
Material Of The Box	Wood
Material Covered The Inside Area Of The Box	Aluminum sheet
Wight	2 kg
Length	50mm
Width	50mm
Depth	50mm
Paint	Black
Heat Absorber Area	1.5 m^2
Volume	125mm
Thickness Of Glass	1mm
Thickness Of Wood	20mm

1.3.3 Specification of the coil pipes

The coil pipes are aimed to increase temperature of the inlet water. The coil pipes will heat up the water and feed it to the tank. We manufactured 4 types of coil pipes. These coil pipes have the same mass and volume, but they have various geometry. Table 1.2 indicates the specification of coil pipes.

Table 1.2 Specification of the coil pipes

Specification	Description
Material	Copper
Height	280 MM
Diameter	96 – 225 mm
Wight	5 kg
Paint	Black
Thickness	1.2mm

1.3.4 Specification of heat supply

Our heat supply is a light. It generates heat to heat up the coil pipes. Table 1.3 displays the specification of heater.

Table 1.3 Specification of the heater

Specification	Description
Power	1200 W
Length	482.6mm
Width From Head	292.1mm
Width From Bottom	304.8mm
Thickness From Head	88.9mm
Thickness From Bottom	114.3mm

1.4 Applications

The main purpose is to use this system in residential buildings or industries where the demand for hot water has a large impact on energy bills. Hence, this is a situation with a large family which the hot water demand is excessive due to the frequent use of hot water along with manufacturing companies.

Chapter 2: Literature Review

The goal of this study is to understand the performance of integrated photovoltaic in addition to the thermal solar system as a compared to a traditional solar water heater, which is the old method to prove the idea of a photovoltaic and thermal solar system design. The consumption of the commercial polycrystalline PV model is to make a PV/T. Additionally, the usage of PV/T collector is to build an IPVTS. Recently all outcomes show that the solar PV/T collector can get an excellent thermal efficiency. However, the study from the economical side shows the idea of IPVTS is feasible too. It is concluded that the solar PV/T collector created from a corrugated polycarbonate panel which can assure an excellent thermal efficiency with very comparable temperature (within 4 C difference) between the PV module and the water in the tank [1]. Figure 2.1 is the schematic diagram of the system.

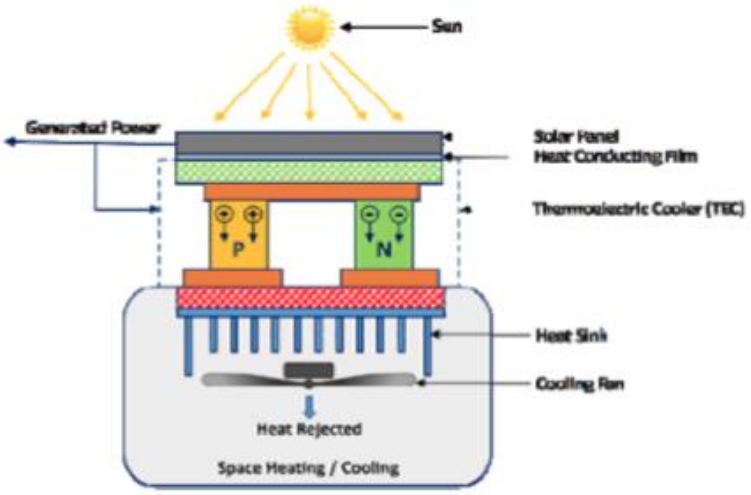


Figure 2.1 Schematic diagram of the system

The spiral coil is allowed to transfer of a considerable amount of heat at a low cost and has a better rate of heat transfer capability. This study aims to examine the different configurations applied in spiral heat exchangers configurations. The research correspondingly explores the concept of transient behavior of spiral shaped tubes, witnessed upon embedment of the coils in the rectangular conducting slab. Various configuration options are considered to identify the most optimal configuration. The research seeks to demonstrate the effectiveness of using large conductors as supplementary storage of heat. Both flowing water and stagnant water are used in the system for different purposes. The container fluid is used as storage whereas the copper made coils are used to carry the cold liquid. Measuring of the water at different depths was used to ensure that the temperature distribution was uniform. It was founded that the geometry of a coil number of loops and its orientation influences heat transfer rate. It was concluded that the performance of vertically embedded coil was better than the spiral coil embedded horizontally which is doubling of the loops enhanced the performance of the coil. An experiment on the standard transfer of heat from a spiral coil was carried out. The research documents how orientation, geometry, and the number of loops affect a coil's performance. The following summarizes the outcomes of the study. A horizontally positioned coil was found out to be less efficient as compared to a vertically positioned one. It was established that the rate of heat transfer increases along with the number of loops. The research similarly indicates the accuracy of the results to be within the margin of +-5%. Finally, It showed that the analysis based on the inclusion of coil curvature does not reliably predict the impact of the orientation of a coil [2]. Figure 2.2 is the spiral coil.

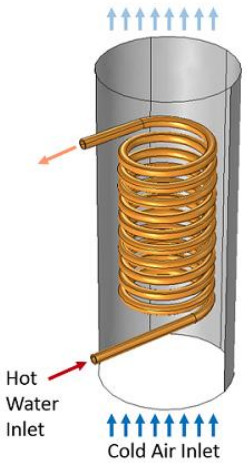


Figure 2.2 Spiral Coil

In this paper, the linear concentrating solar thermal systems will get a promising technique. The objective of this subject is to define the performance curve of this method by means of two experiments and theoretical analysis. The consequence displays that the universal efficiency of the collector is limited to less than 20%. Due to the increasing performance of the system, it is suggested to connect an evacuated receiver to isolate the recirculation system. Based on a dual-axis tracking system that has been analyzed in this study, there are many sources of energy loses. One of them is due to the optical losses in the lens system additionally to the low solar absorbance of the absorber pipe. Radiation and convection determine low percentage of losses energy as relatively low temperatures (up to 90 C). The outcome of this paper is by decreasing the absorption losses in the receiver pipe [3]. Figure 2.3 is results of the simulation.

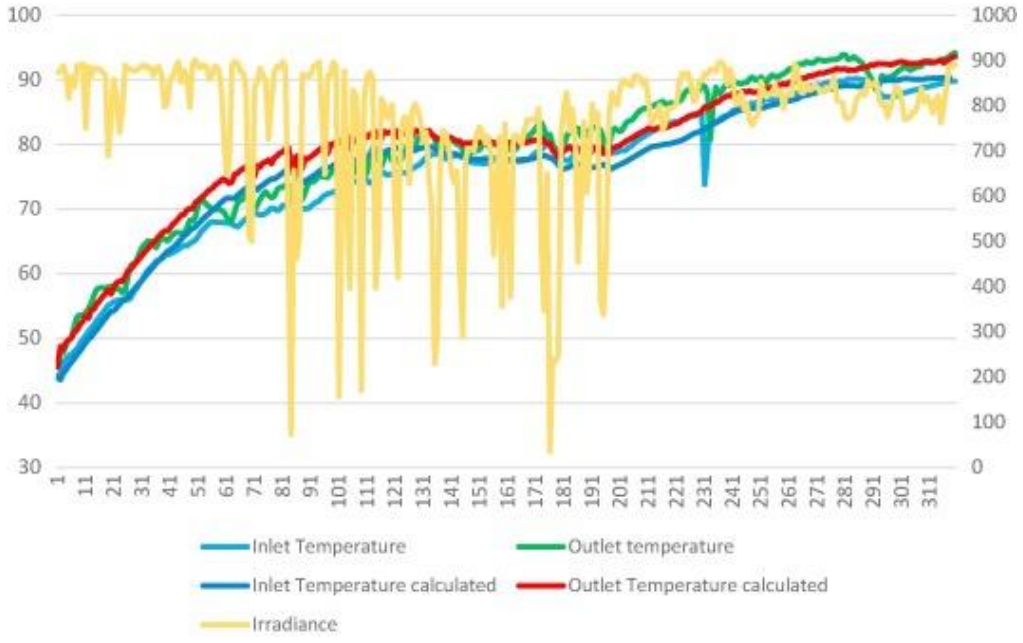


Figure 2.3 Results

The paper focusses on analyzing the various parameters that affect the effectiveness of heat exchanger with the aim of coming up with an efficient design of shell and helical coil heat exchanger. The study uses the experimental method whereby they set up an experimental helical coil copper tube to investigate the various parameters which affect its effectiveness. Their parametrical analysis studies factors are temperature, flow rate of hot water, flow rate of cold water, and the heat transfer coefficient. The study concludes that by maintaining the flow rate of cold water and increasing the flow rate of hot water, the effectiveness of the heat exchanger is improved. It has been indicated that an increase in mass flow rate of hot water leads to an increase in overall heat transfer coefficient and heat transfer rate [4]. Figure 2.4 is showing the experimental setup.

Figure 2.4 Experimental setup

Concentrated solar thermal power or concentrating solar power is a perfect technology, which interbreeds with different energy technologies for power generation. Concentrated solar thermal can shares other technology with traditional power generation that can be easily integrated with distinctive types of energy into a synergistic system. Hybridized of concentrating solar power exists in different kinds accompanied by the levels of synergy. This depends on the source of the hybrid energy, the concentrating solar power, and the location of plant. There are numerous opportunities of fossil fuel with concentrated solar thermal that inject solar heat at different temperatures [5].

Thermal solar collector is a device that collects the heat from the sunlight and stores the heat to be used in any system. This type of solar collector does not generate electricity. In fact, the system transfers the collected heat to a fluid such as water. The use of "nanofluids" (fluid nanoparticle suspensions), including expanded viscosity, potential erosion, and settling, in our view. This is more than balanced by the appealing properties that they offer. As this audit has called attention to the transformation of daylight to warm in any case which a single of the potential uses of direct-absorption collectors. Numerous energizing potential outcomes exist to absorb amazingly huge surface territory to-volume proportion of nanoparticles to impact substance responses. These can be either thermochemical in nature where the assimilation of concentrated daylight causes high temperatures. That drives the responses or photocatalytic, where the nanoparticles fill in as photo catalysts for part water, squander remediation, or different purposes. This audit closes with a recommendation for an immediate retention generator as a component of a sun-oriented driven assimilation icebox, a conceivably interesting methodology for the proficient transformation of daylight into chilly [6]. Figure 2.6 is the schematic diagram of the system.

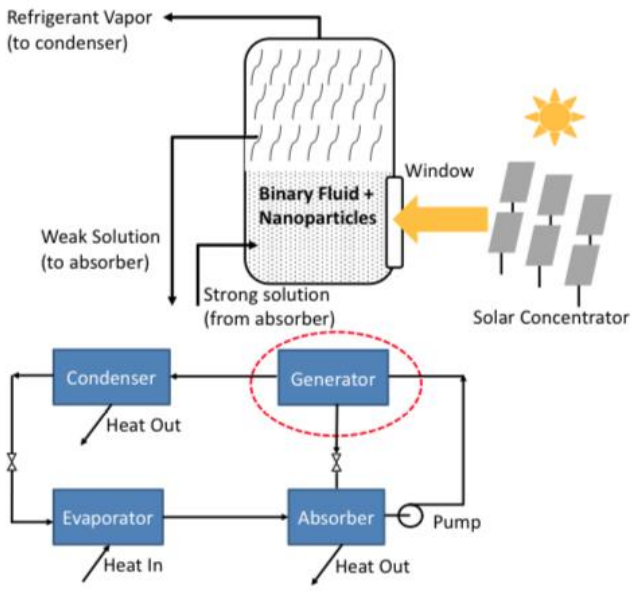


Figure 2.6 Schematic Diagram

The solar thermal collector geometry and its design is a significant factor in solar –to-thermal power conversion. In this research, stationary modern solar collector (helical solar collector) was designed and examined. ASHRAE standards that have been utilized to this collector to find out its performance. In fact, these experiments were conducted with water as a working liquid in the open air of Ahwaz; this is city located at the south of Iran. The results prove that the normal thermal efficiency for this collector is around 53%. However, that can be utilized as an efficient new water heater. The tests demonstrate that the efficiency of the helical solar water heater rises through the mass flow rate. Figure 2.7 is showing the solar thermal collector [7].

Figure 2.7 Solar Thermal Collector

As an effective, renewable, safe and eco-friendly energy resource, efficient utilization of solar energy has been regarded undoubtedly as an encouraging solution to global energy shortage and a mean to achieve sustainable development for human beings. Due to rapid development of solar energy technologies, it decreased cost of solar energy equipment; percentage of renewable energy by solar thermal and photovoltaic which are increasing as the energy supply for buildings. The performance of solar collector highly relies on its tilt angel with respect to horizontal plan and orientation (surface azimuth angle) of the collector. The effective heat collection concept was proposed and optimized a model mathematically further development to determine the optimum tilt angle and orientation for the solar collector. The developed model has been applied in a case study of Lhasa district, in comparison with the result obtained in accordance with conventional optimization results. The research result showed that there is about 5° degree deviation between the optimum results obtained accordingly to effective heat collecting capacity and the optimum results acquired to maximum total solar radiation falling on the solar collector [8].

The paper aimed to analyze and simulate an integrated energy supply solution with extended solar collectors and a combination unit and ground-source heat pump as illustrated in figure 1. A parametric study was carried out that entailed optimizing certain variable such as mass flow rate of collectors, orientation and tilt angle, collector heat loss, zone set point temperature, effectiveness of heat exchanger and supply air flow rate. The study tested different scenarios with different configuration to find the composition that would result in the minimal electricity usage. The results of the study indicated that optimization of these design and/or operating parameters led to a significant reduction in electricity use. This optimization was done with the help of the dynamic simulation software tool IDA Indoor Climate and Energy 4.6 as shown in figure 2.8. The study concluded that a larger solar collector that is optimized in terms of orientation and tilt angle with a combination of a ground-source heat pump would result in a higher reduction in energy utilized and higher share of utilized renewable energy [9].

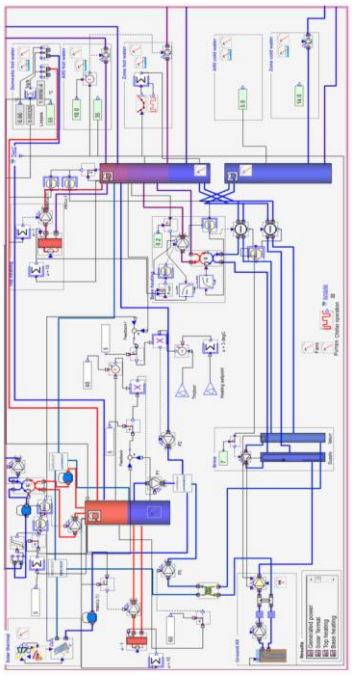


Figure 2.8 The dynamic simulation software tool IDA Indoor Climate and Energy

2.1 Project background

Solar energy is a solution to produce renewable energy. Therefore, many research centers and universities have shown interest in conducting experimental studies to improve and develop the efficiency of heat transfer upon the existing system of the solar thermal collector. The aim of this project is to design and test a solar thermal collector. The collector will be used to test a number of configurations for coils to maximize the heat transfer. The project results will provide guidelines to utilize the most efficient coil geometry in solar thermal collectors. This project is about heat transfer and geometry is a big factor in the heat transfer. In this study, we want to see the effect of heat transfer when changes happen to the coil geometry. Our system components are a heater, solar thermal collector, 4 different shapes of the copper coil, and water tank. The heater generates heat radiation that the solar thermal collector absorbs the radiation heat. The copper coils will be placed inside the solar thermal collector. The current study is to optimize the best copper coil geometry.

2.2 Previous Work

A heat exchanger can be defined as an engineering device that transfers heat from one fluid (liquid or gaseous) stream to another. For this purpose, it usually employs parallel flow or counter flow of the two fluids, constrained to their own series of pipes against each other. The device is generally constructed in the form of one or more connected shells which contain one of the fluids, and a bank of pipes within the shells that cover the other fluid. The shell side is usually outfitted with baffles in order to increase heat transfer and suitably modify pressure drop of the fluid [10]. Heat exchangers may be designed in a horizontal configuration or a vertical one. The latter is especially useful for condensers, which use isothermal flows in order to condense one of the fluids from a vapor to a liquid phase. The experiments revealed that thermal transfer performance using spiral coils is influenced by Reynolds number, fluid properties, coil orientation, and the curvature ratio of the spiral coils (geometric angle). Increasing the number of loops is also shown to enhance the performance of the spiral coil heat exchanger [10]. The experiment concluded that the geometrical structure of the spiral coil heat exchanger and the increase in the number of loops per unit length does affect the heat transfer performance. Moreover, the geometrical effect on the heat transfer performance that was revealed by the experimental study shows that a heat transfer geometrical factor exists.

2.3 Comparative Study

Spiral coil heat exchangers play an essential function in cooling high concentration and high viscous fluids. The experimental study was conducted to investigate the general heat transfer effectiveness of water using the spiral coil heat exchanger with various geometrical shapes. Heat exchangers are used extensively in process industries to extract or transfer heat from or into one stream of fluid to another. They are designed in several configurations, two of which are spiral and shell tube. The study compares five configurations involved in timed heat transfer between a system of spiral pipes and a heat source in the form of a conducting volume. An analysis also includes optimization of the coil configuration based on effectiveness, efficiency, heat transfer, and the effects of different working fluids. The experiments are performed on five spiral coils different in shape and identical length at the transient and steady condition. The goal is to examine the impact of coil geometric shape on the efficiency of heat transfer.

Chapter 3: System Design

3.1 Design Constraints and Design Methodology

Figure 3.1 shows the components of the solar thermal collector that used to study the heat transfer for the different coil geometries. We manufactured four types of copper coils then we performed an experiment for each coil.

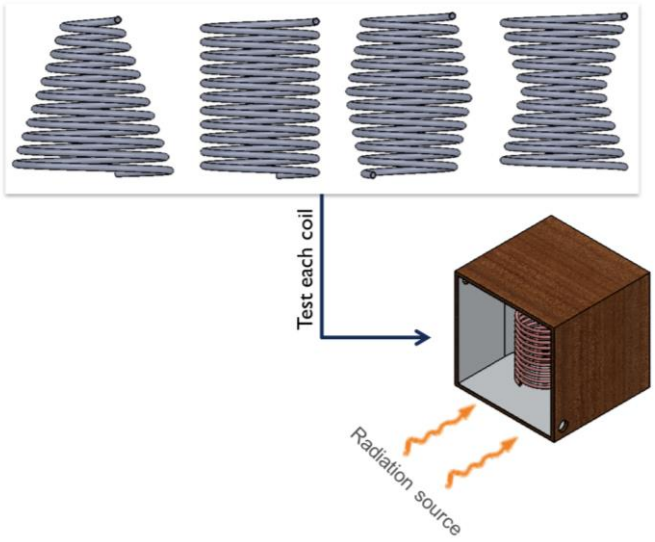


Figure 3.1System Components

3.1.1 Geometrical Constrains

Our system geometrical constrains are explained in table 3.1. The system components include four major components. First, a housing of the solar collector which has a cubical shape. Second, there is the Pressure gauge which has a cylindrical shape. Third, we have the flow meter which has a cubed shape. Forth, we used a flow meter with a spherical shape.

Table 3.1 System Components Shapes

Item	Dimensions	Geometry
Housing of The Solar Collector	50mm x 50mm x50mm	Cubed
Pressure Gauge	6.35mm Diameter	Cylinder
Flow Meter	12.7 mm Diameter	Sphere
Thermometer	110 mmx 30mm	Cubed

3.1.2 Environmental

The solar thermal collector is an alternative solution to produce renewable energy. This design could help reduce the use of unclean power sources. Our study involves heating a tank using solar thermal collector. There is no pollution in this design. Therefore, it will help reduce the carbon emissions into the air.

3.1.3 Economic

Our system could be used for personal use. In home facilities, this system could reduce the power consumption of electricity for heating water. As a result, the load on the power plant would be decreased.

3.2 Engineering Design standards

In this project, the system components are based on standards. The thermal collector box was made of wood (MDF) with medium density fireboard. This material has a high thermal resistance, so it is good insulator. This material was chosen in order to store generated heat.

We designed four copper coils with different geometry (cylindrical, Barrel, conical, Constant Pitch). All the heat coils were made of copper since it has the highest thermal conductivity, Constance. The coils made from copper of Alloy C12200 as per ASTM B88 and ANSI/ NSF 61. In table 3.2 the engineering standards is explained further.

Table 3.2 Engineering Standards

No.	Part name	Type of Material	Reference Standards	Standards Description
1	Coils	Copper of Alloy C12200	ASTM B88 and ANSI/ NSF 61	Seamless Copper Water Tubes
2	Piping connection	CPVC	ASTM D2846	Plastic Hot Water Distribution Systems
3	Thermal box	MDF Wood	ASTM D5664 - 17	Wood of Elevated Temperatures Surface
4	Collector window	Glass	ASTM E765-80	Flat Plate Solar Collectors
5	Solar Diffuser	Aluminum Alloy	ASTM B209M	Aluminum-Alloy Sheet and Plate
6	Hoses connection	Thermoplastic	ASTM F645 - 15a	Thermoplastic Water- Pressure Piping Systems

3.3 Theory and Theoretical Calculations

We will study the heat transfer of different coils geometries by using Equation 3.1:

$Q = \dot{m} \times C_P \times \Delta T$ (3.1)

Where:

Q: total heat transfer [KWh].

$\dot{\boldsymbol{m}}$**:** Mass flow rate. [Kg/s].

$\boldsymbol{C_P}$: Heat capacity of water. [4.186 kJ/Kg$K°$].

Δ**T:** temperature difference. [K°]

In the experiment, we took the temprature readings from the inlet and outlet of the system. Table 3.2 is an example of calculating the heat transfer.

Table 3.2 Example of calculating the total heat transfer

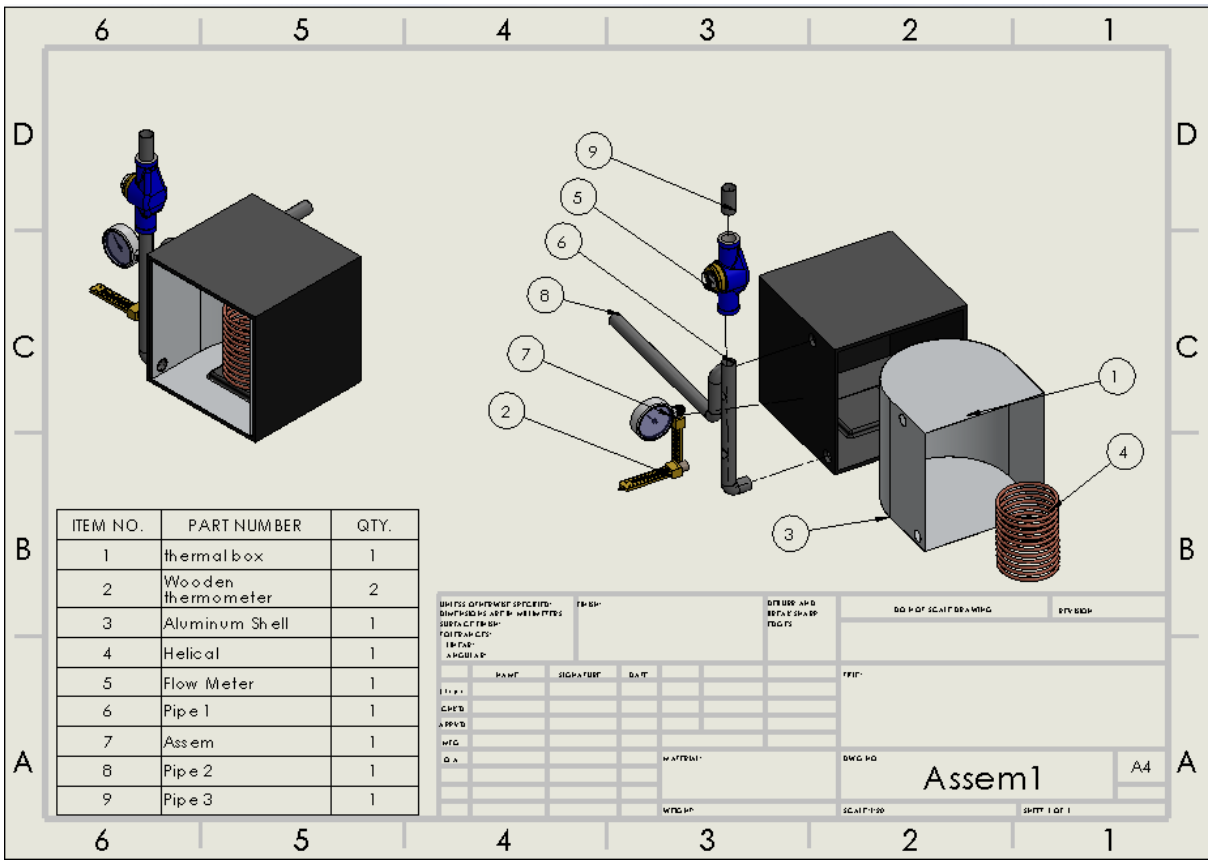
Item	ΔT $(K°)$	C_P (KJ/Kg)	$\dot{m}$ (Kg/s)	Q (KW)
Barrel	10	4.1855	0.78	32.6469
Constant Pitch	7	4.1855	0.78	22.85556
Hour Glass	5	4.1855	0.78	16.3254
Conical	9	4.1855	0.78	29.38572

3.4 Product Subsystems and selection of Components

Our thermal solar collector system contains solar collector box, thermal coils with different geometry.

3.4.1 CAD Design of Product Systems and Component

We used SolidWorks Software to illustrate our system and design components. Figure 3.1 shows the system components.



ITEM NO.	PART NUMBER	QTY.
1	thermal box	1
2	Wooden thermometer	2
3	Aluminum Shell	1
4	Helical	1
5	Flow Meter	1
6	Pipe 1	1
7	Assem	1
8	Pipe 2	1
9	Pipe 3	1

Figure 3.1 CAD System Design Model

We designed 4 geometrical copper tubes. Figure 3.2 shown the coils pipes. There are four different types of the coils pipes. We considered in our design that the four coils have a same pitch, pipe diameter, pipe thickness, pipe outer, inner area and length.

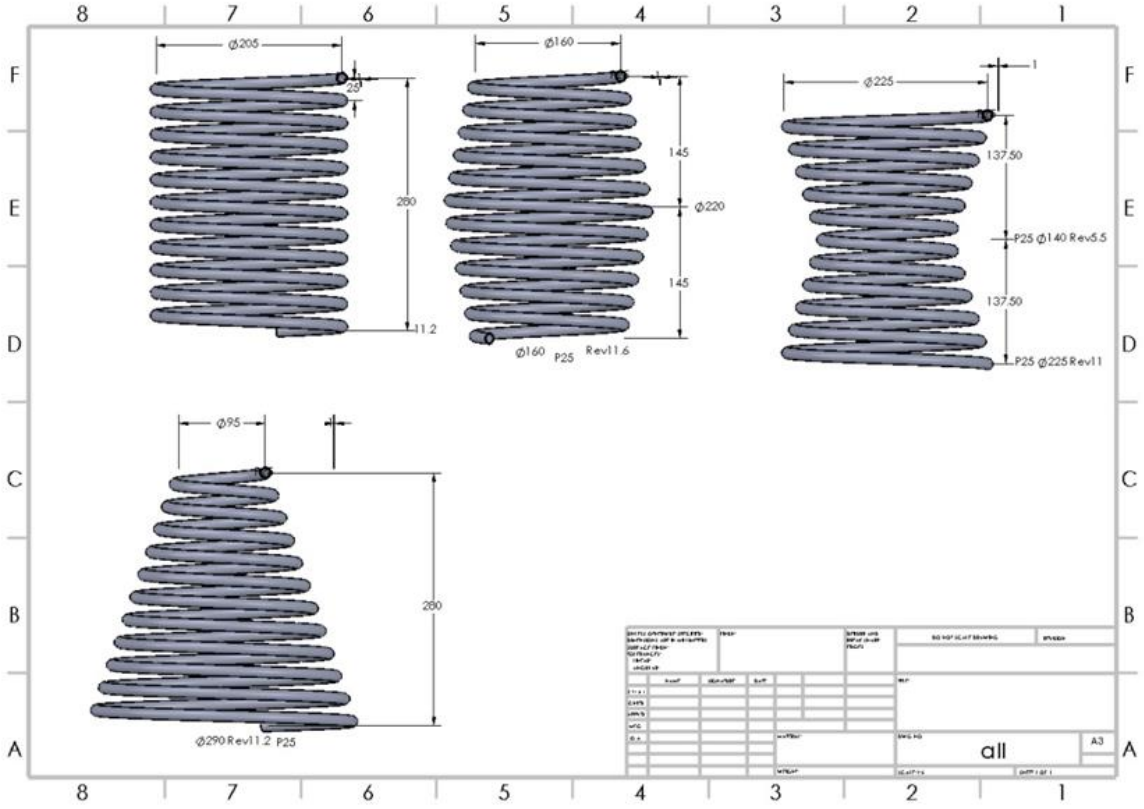


Figure 3.2 displayed four different types of coils geometry

3.5 Manufacturing and assembly (Implementation)

The Manufacturing of the solar thermal collector was established by assembling the solar thermal collect box wood wall. The internal concentrating shape was made out of aluminum sheet to enhance the heat gain from the radiation source and keep the radiation focus to the heat coils. Two temperature gauges were installed to measure in and out flows water. Additionally, pressure gauge along with flow meters was installed into the pipe system to capture and visualize all surrounding parameters variation. Figure 3.3 shown our system after assembly.

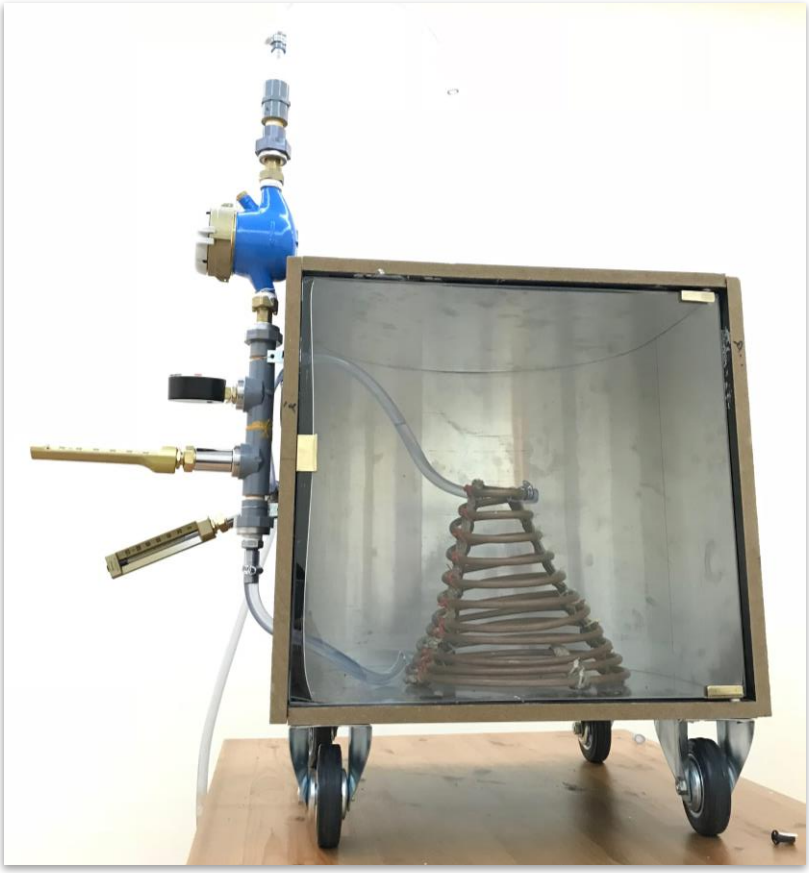


Figure 3.3 The System After Assembly

Chapter 4: System Testing and Analysis

Figure 4.1shown the overview of our experimental setup. There are three main sections: inlet section, radiation collector section, and outlet section. We will discuss the details of the experimental setup which used in this chapter and we focused on the components of the experiment setup for each section that were developed in our experimental.

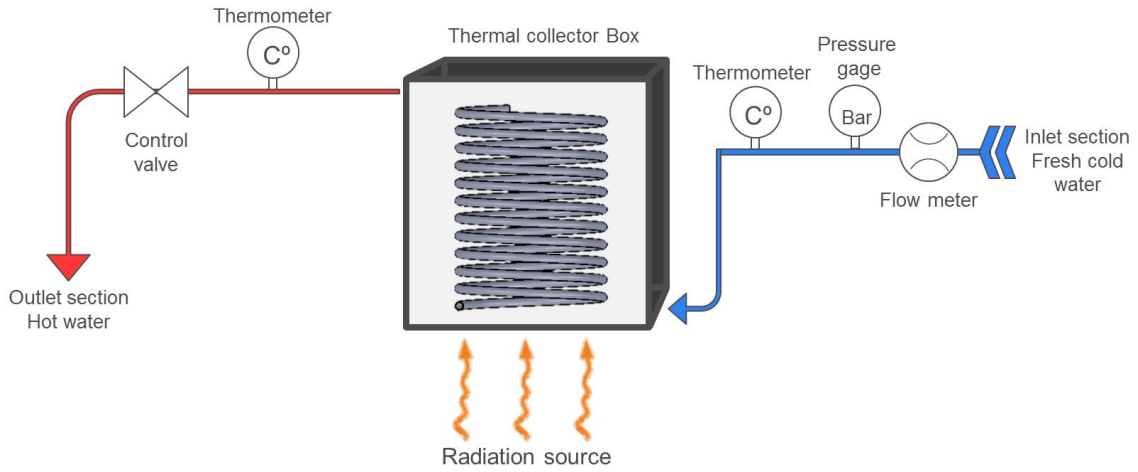


Figure 4.1 Experimental Setup

4.1 Experimental Setup, Sensors and data acquisition system

4.1.1 Inlet section

The inlet section consists of three main sensors as shown in figure 4.1. They are flow meter, pressure gage and thermometer. As showing in figure 4.2, the first device on inlet section is the flow meter and it used to measure the quantity of fluid moving through a pipe to give us the volume of fluid during the experiment. We used this device in order to calculate the mass flow rate. The second device is the pressure gage and it is used to measure the pressure in the system. The third device is the thermometer and it is used to measure the temperature for inlet flow.

Figure 4.2 Sensors places

4.1.1.1 Flow meter device

Flow meter is a device that calculates the volume of a fluid during experiment time as shown in Figure 4.3. We used it to calculate the volumetric flow rate by using the equation No 4.1 in order to find the mass flow by using equation No 4.2.

Equation 4.1: volumetric flow rate

$\dot{\boldsymbol{V}} = \frac{V}{t}\ (m^3/s)$.

Where:

V: Volume (m^3).

T: Time. (s)

Equation 4.2: mass flow rate

$\dot{\boldsymbol{m}} = \rho\ \dot{V}\ (Kg/s)$.

Where:

$\boldsymbol{\rho}$: Density(Kg/m^3).

$\dot{\boldsymbol{V}}$: Volumetric flow rate (m^3/s) .

Figure 4.3 Flow Meter Device

4.1.1.2 Pressure Gauge

Pressure gauge is a device that gives a reading for the pressure of the flow inside the PV pipe. We used the pressure gauge to monitor the flow pressure in the system because the pressure might be affected by temperature of fluid. Figure 4.4 is shown the pressure gauge.

Figure 4.4 Pressure Gauge

4.1.1.3 Thermometer Device

Thermometer is device that measures the temperature of fluid as showing in figure 4.5. We used it to measure the inlet and outlet temperature of the flow to calculate ΔT. we use the temperature difference to calculate the heat transfer for each coil.

Figure 4.5 Thermometer

4.1.2 The Radiation Collector Section

The radiation section consists of a light source (figure 4.6). It used to provide a heat radiation source to test the coil geometry absorbance. We placed it on the roof of the thermal collector box to provide similar solar radiation effect.

Figure 4.6 Light

4.1.3 Outlet section

The outlet section consists of two main sensors. They are thermometer and control valve. A thermometer is used to measure the temperature for outlet flow. Control valve is used to control the running fluid inside the pipe.

4.1.3.1 Control valve

Control valve is used to control fluid flow in the line. We used it to control the volumetric flow rate of the fluid through in our system and have same mass flow rate for four different geometry coils. The diameter of control valve is ½ inch and showing in figure 4.7.

Figure 4.7 Control Valve

4.2 Results, Analysis and Discussion

4.2.1 Goals:

The aim of this experiment is to study the effect of heat radiation using different coil geometries. After performing this experiment, we are expecting to identify if the different coil geometries will give us the same temperature difference or not. In addition, we were expected to be able to recommend the geometry that gives the best efficiency. On the other hand, if we get the same temperature difference from all coils geometries we will know that the geometry does not effect on efficiency of heat transfer by radiation.

4.2.2 Experimental methodology

1. Measuring device:

It is the gauge that we utilized for taking the temperature of the fluid on the inlet and outlet sections of the system. We connected the temperature gauges (thermometers) to the fluid pipe through elbows that enables us to take the temperature readings from inside the pipe.

2. Heat radiation source

It used to provide a heat radiation source to test the coil geometry absorbance. We placed it on the roof of the thermal collector box to provide similar solar radiation effect.

3. Flow controller:

It is used to control the running fluid inside the pipe. We placed it at the outlet section to control the volumetric flow rate of the fluid through the pipe in the system.

4.2.3 Errors and Challenges

While building up the solar thermal collector we faced many errors and challenges. We tried to run the system using a small water pump but it was not pumping sufficiently. Consequently, we modified the system and used direct water flow instead of the water pump.

The second error we faced when we tested the system with glass door. The glass door did handle the heat radiation and it broke while we are conducting the experiment. After that we modified the system to perform the system with direct heat radiation without glass door.

Third error is that the copper coil was not painted which resulted in reflecting the heat radiation. As a result we painted the coil in black color to increase the heat radiation absorbance.

4.2.4 Experimental procedure

The below procedure guides us to perform the experiment and test all of the four different coil geometries:

1. Start the experiment by connecting inlet section to water supply line. After that, open the water supply to run the system.
2. Check the water flow in the system and make sure to release all air from system.
3. make sure that all connections are sealed and check system for leakage.
4. Close the control valve.
5. Switch on the heat radiation source (light).
6. Make sure that the radiation is directed to the coil geometry.
7. Wait for 5 minutes.
8. Open the control valve gradually and monitor the exit temperature until becomes stable.
9. Take a reading for the volume from the flow mater.
10. Take the temperature readings from the inlet and exit thermometers.
11. Take the reading again every minute. Total 5 reading.
12. Close the water supply and switch off the light.
13. Replace the coil to start testing the other coil geometries.

The figure 4.8 shows the coils wheel we performed the experimental for each coil.

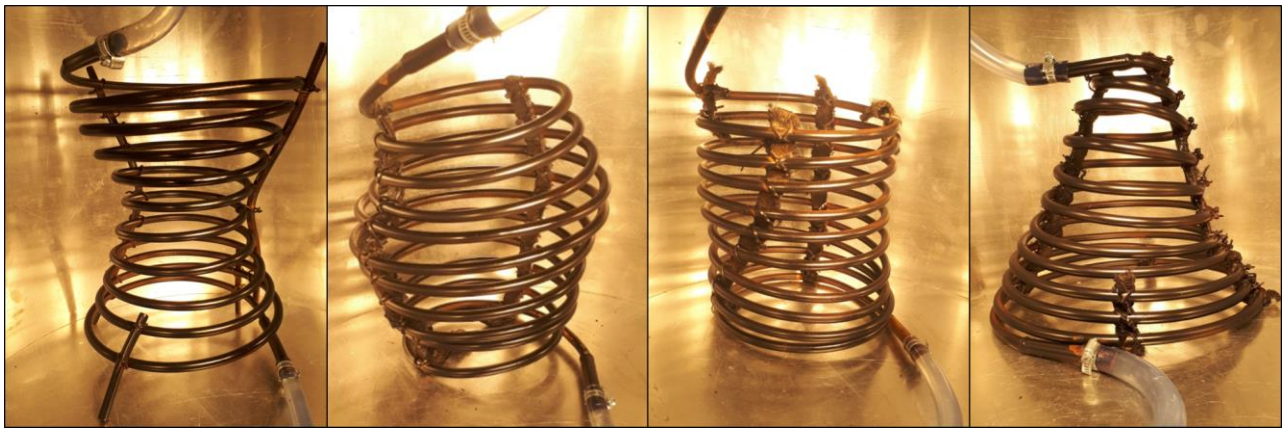


Figure 4.8 coils while the experiment

4.2.5 Results and Discussions

By performing the experiment, we list a table that shows all results. Table 4.1 is showing the water volume reading during time. As we have a flow meter and control valve, we fixed the volume quantity of the fluid that passed through the system for all coils geometries and we got same flow meter for all of them. We will use equitation 4.1 and 4.2 to calculate volumetric flow rate and mass flow rate as below:

Table 4.1 The water volume reading

Time (s)	Volume (m^3)	Density (Kg/m^3).
0	0	1000
55	0.002	1000
110	0.0039	1000
165	0.0060	1000

- Equitation 4.1: Volumetric Flow Rate

$$\dot{V} = \frac{V}{t}\ (m^3/s).$$

$$\dot{V} = \frac{0.006}{165} = 3.6363 \times 10^{-5}(m^3/s).$$

- Equitation 4.2: Mass Flow Rate

$$\dot{m} = \rho\, \dot{V}\ (Kg/s).$$

$$\dot{m} = (1000)(3.6363 \times 10^{-5}) = 3.6363 \times 10^{-2}(Kg/s).$$

Table 4.2 is showing the results of testing the solar thermal collector system. The table shows the temperature difference as a function of time. In this table we took the fluid temperature from the inlet and outlet sections of the system. We tested the four copper coil geometries each at a time under the same room conditions. We are using equation 4.3 to calculate the total heat transfer as below:

Table 4.2 The Test Results

Item	T_{in} (°C)	T_{out} (°C)	$\dot{m}$ (Kg/s)
Barrel	27	30	3.6363×10^{-2}
Constant Pitch	27	30	3.6363×10^{-2}
Hour Glass	27	30	3.6363×10^{-2}
Conical	27	30	3.6363×10^{-2}

Q = [$C_p \dot{m}\, \Delta T$]

So the total heat capacity for four deferent coils as below:

Q = (4.1855) (3.6363×10^{-2}) (30-27) = 0.4565 KW

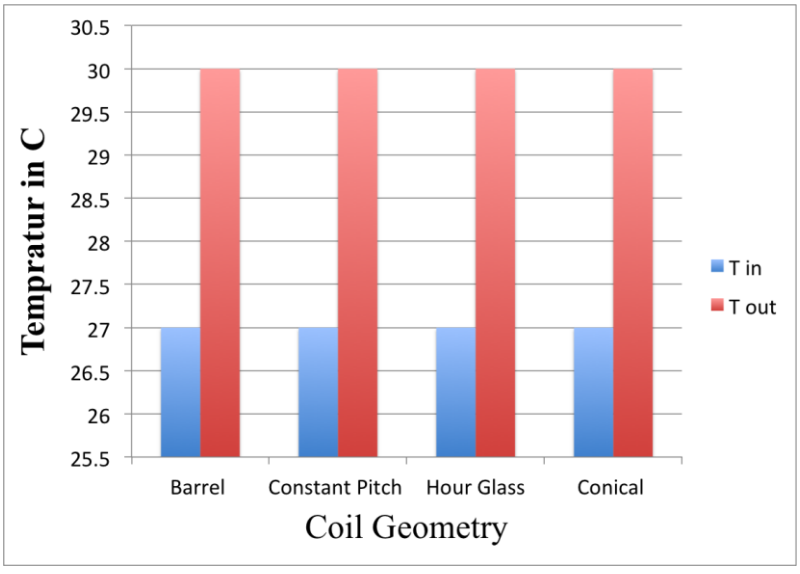


Figure 4.9 The Test Results

In this experiment, we had compared the temperature differences among different copper coil geometries. Figure 4.9 depicts the shape of the copper coil vs. the temperature.

The temperature increased by 3 $°C$ for all copper coil geometries. We also figured out from our experiments that all different coil geometries have same ΔT.

4.3 modeling of temperature difference ΔT of coils:

We studied in this section the theoretical radiation heat transfer for coils on our project. We have three enclosures surface light source, coils, surrounding. The figure 4.10 is showing schematic of three surfaces enclosure.

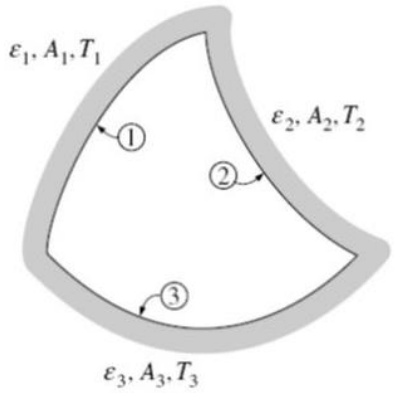


Figure 4.10 schematic of three surfaces enclosure

Where:
1: The light source.
2: Coil surface.
3: Surrounding surface.

The figure 4.11 is showing the draw surface resistances associated with each of three surfaces and connect with space resistances. Where we assume three assumption of emissivity:

Where:

$\boldsymbol{\mathcal{E}_1}$: Light emissivity = 0.02.

$\boldsymbol{\mathcal{E}_2}$: Black copper coil emissivity = 0.98.

$\boldsymbol{\mathcal{E}_3}$: surrounding emissivity = 0.09.

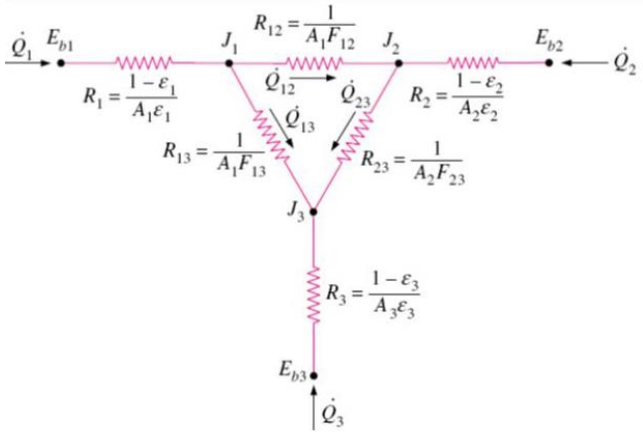


Figure 4.11 the radiation network associated with surfaces.

We used the equations from the previous page to do our calculations. Table 4.3 is showing the results of our calculations. The table contains temperature (T), Area (A), and emissivity ($\mathcal{E}_b$).

Table 4.3 Radiation Test Results

Surface	T(° K)	A (m^2)	$\mathcal{E}_b$	R	J (W/m^2)
1- Light	1350	5.341×10^{-3}	188329.4044	9174.34	7482.47
2- Coil	308	0.2262	510.2534	0.09022	655.64
3- Surrounding	300	0.887	459.27	11.39	5728.92

4.3.1 Calculation of view factor

Radiation heat transfer between surfaces depend on the rate of heat exchange between of them. It considers the surface temperature and emissivity for each surface.

The view factor from a surface i two surface of j is denoted byF_{ij}.

Where:

F_{ij}= The fraction of the radiation leaving surfaces i that strike surface j directly.

We will use equitation 4.3 and 4.4 to find the summation rule for each of the three surfaces gives:

Equitation 4.3

$F_{11} + F_{12} + F_{13} = 1$
$F_{21} + F_{22} + F_{23} = 1$
$F_{31} + F_{32} + F_{33} = 1$

Noting that $F_{11} = F_{22} = F_{33} = 0$

Equitation 4.4

$F_{12}A_1 = F_{21}A_2$
$F_{13}A_1 = F_{31}A_3$
$F_{32}A_2 = F_{32}A_3$

We did the calculation of view factor. The results of the calculations are in table 4.5 below.

Table 4.5 View Point Calculations

F_{12}	0.38	F_{13}	0.62
F_{21}	0.8976	F_{23}	0.1024
F_{31}	0.30364	F_{32}	0.00212

4.3.2 Calculation of net heat transfer radiation

During a radiation interaction, a surface losses energy by emitting radiation and gains energy by absorbing radiation emitted by other surfaces. A surface experience a net gain or a net loss of energy depending on the quantity is larger. The net rate of radiation heat transfer from a surface i of surface area Ai is denoted by Qi as we use it in equitation 4.5 for each

surface. We will apply also equitation 4.5 to each surface to determine the radiosities in system.

Equitation 4.5

$$\sigma T_1^4 = J_1 + \frac{1-\varepsilon_1}{\varepsilon_1}[F_{12}(J_1 - J_2) + F_{13}(J_1 - J_3)]$$

$$\sigma T_2^4 = J_2 + \frac{1-\varepsilon_2}{\varepsilon_2}[F_{21}(J_2 - J_1) + F_{23}(J_2 - J_3)]$$

$$\sigma T_3^4 = J_3 + \frac{1-\varepsilon_3}{\varepsilon_3}[F_{31}(J_3 - J_1) + F_{32}(J_3 - J_2)]$$

Equitation 4.6

$$\dot{Q}1 = A_1[F_{12}(J_1 - \dot{J}_2) + F_{13}(J_1 - J_3)]$$

$$\dot{Q}2 = A_2[F_{21}(J_2 - \dot{J}_1) + F_{23}(J_2 - J_3)]$$

$$\dot{Q}3 = A_3[F_{31}(J_3 - \dot{J}_1) + F_{32}(J_3 - J_2)]$$

We did the calculation of the net heat radiation. We used equation 4.6 to do the net heat radiation calculations. Table 4.5 is showing the results of our calculations.

Table 4.5 Net Heat Radiation Results

$\dot{Q}1$	1966.12338 KW
$\dot{Q}2$	-150.29 KW
$\dot{Q}3$	-568.9 KW

4.3.3 Calculation of theatrical ΔT

$\Delta T_{Theatrical}$ = 190 °K.
$\Delta T_{Expermantal}$= 3 ° K.

The big different between theoretical and experiment returned to scattered of radiation is very high. If we have concentrated (leans), of course ΔT could reach at least close to 100 °K.

Chapter 5: Project Management

5.1 Project Plan

During the semester we identified the tasks needed in order to complete the senior project design. We made a table called Gantt hart to put all the tasks that the team need to should do. In this table there is activity, tasks, responsibility, duration, and percent complete. Table 5.1 is showing the project plan.

Table 5.1 Gantt Chart

	ACTIVITY	Tasks	Responsible	Duration	Percent Complete
Introduction	Project allocation + introduction	Project Definition	Marwan	1 Week	100%
		Project Objectives			
		Project Specifications			
		Applications			
	Literature Review	Project background	All Team	3 Weeks	100%
		Previous Work			
		Comparative Study			
System Design	Design	Design Constraints and Design Methodology	Omar	2 Weeks	100%
	Equipment and material selection (3.4)	selected the appropriate items	Ibrahim + Meshal	2 Weeks	100%

	Theory and Theoretical Calculations	main calculations required detailed calculations to your design.	Ibrahim + Omar	1 Week	100%
	Prototype assemble	System integration, describe , procedures and Implementation	All Team	3 Weeks	100%
System Testing and Analysis	Testing and analyses	Experimental Setup, Sensors and data acquisition system	All Team	2 Weeks	100%
		Results, Analysis and Discussion			
Project Management and Project Analysis	Project Management	Project Plan	All Team	2 Weeks	100%
		Contribution of Team Members			
		Project Execution Monitoring			
		Challenges and Decision Making			
		Project Bill of Materials and Budget			
	Project Analysis	Life-long Learning	All Team	1 Week	100%
		Impact of Engineering Solutions			

		Contemporary Issues Addressed			
Report submission	Final Report	Writing all chapters	All Team	1 Week	100%
	Presentation preparation	Making Slides	All Team	1 Week	100%
	Presentation practice	Do fake presentation in a random class	All Team	1 Week	100%
	Booklet	Print the report	All Team	5 days	100%
	Banner	Follow rubric	Omar	3 days	100%
	Brochure	Follow rubric	Marwan	1 day	100%
	Final Presentation	Making the slides	All Team	1 Week	100%
Monthly progress report		1st progress report	Ibrahim	Monthly, 1 Day	100%
		2nd progress report			
		3rd progress report			

5.2 Contribution of Team Members

After making the Gantt chart used to distribute the tasks for each member, we made monthly progress report. Progress report shows the task progress percentage that we update every week. Table 5.2 shows the progress of our tasks we completed during the semester.

Table 5.2 Team Members Task

Tasks	Responsible	Percent Complete
Project Definition Project Objectives Project Specifications Applications	Marwan	100%
Writing literature review article Project Background Previous Work Comparative Study	Meshal 2 article Marwan 2 article Mahmoud 2 article, Ibrahim 4 article	100%
Design Constraints and Design Methodology, Solid work design	Omar	100%
Selected The Appropriate Items and measuring device	Ibrahim + Meshal +Omar	100%
Main Calculations Required Detailed Calculations To Your Design.	Ibrahim + Omar	100%
System Integration, Describe , Procedures and Implementation	All Team	100%
Experimental Setup, Sensors And Data Acquisition System Results, Analysis and Discussion Modeling of ΔT of coils discussion and calculation	Omar + Mahmoud + Marwan Omar + Mahmoud Ibrahim+ Omar + Meshal + Marwan	100%
Project Plan (Gantt) Contribution Of Team Members Project Execution Monitoring Challenges And Decision Making Project Bill Of Materials And Budget	Omar Ibrahim Ibrahim All team Ibrahim + Meshal	100%

Life-Long Learning Impact Of Engineering Solutions Contemporary Issues Addressed	Ibrahim + Meshal	100%
Slides preparation	All Team	100%
Perform dry run presentation	All Team	100%
Design of project slides PowerPoint and video record and editing	Omar	100%
Design of brochure and Poster	Mahmoud	100%
1st Progress Report 2nd Progress Report 3rd Progress Report	Ibrahim	100%

5.3 Project Execution Monitoring

During the period of 4 months we set up meetings with our advisors, meetings with the team member, and meetings for testing. We set up meetings with our advisors to help us if we were facing a problem in the project, and to teach us to write the report. Also, we set up meetings with the team members to plan for the design project. In our senior design project it is required to do a test based on about our project. Table 5.3 is showing the dates of meetings with our advisors, team member, and meetings to do the test.

Table 5.3 Project Monitoring

Month	January	February	March	April
Meetings with advisors	10-17-24-31	7-14-21-28	7-14-21-28	4-11-18-25
Meeting with the team members	9-16-23-30	6-13-20-27	6-13-20-27	3-19-17-24
Testing	-	-	-	1 to 20

5.4 Challenges and Decision Making

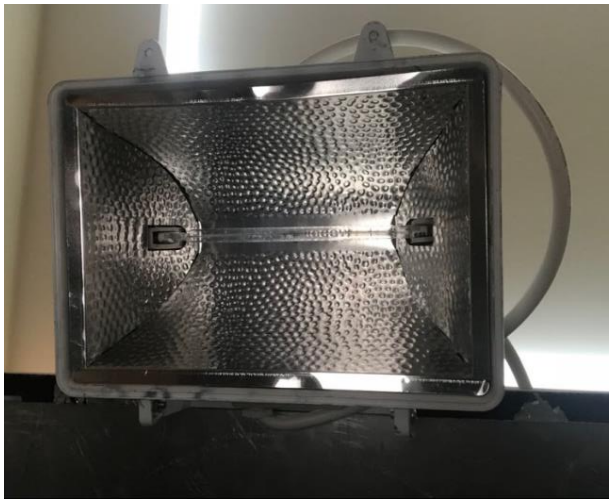
During this semester we had a problems such as getting the parts, assembly, and during the experiment. with the getting the heat form the heater. Also, we had some issues with our team members in the case of establishing our meetings, because we had classes that are different from member into other members. All the team member have jobs, so it was difficult for us to have the work done. However, we had another sort of problem which is the time, because there is no much time to finish all the challenges and objectives that we are seeking for, and that was good experience to overcome the challenges.

5.4.1 Project Set Up Failures

The Heat Source

In this project we faced difficulties in the experimental part. One of the problems was the heat source. We purchased a heater from the local market. After the first test the results was not promising. The problem was the heater has not enough radiation energy to heat up the copper coils. After discussing with our advisors, we decided to change the heat source from heater to one light. This light has higher radiation energy than the heater. After we changed the heat source we did a test, and the results of the test were better than before. Figure 5.1 is showing the heat source before and after.

Before



After

Figure 5.1 The Heat Source

The Glass Door

The box of solar thermal collector comes with a glass door. The glass could not handle the heat of the heater. When we applied the heat on the solar box the glass door was broken. Figure 5.2 is showing the thermal box with glass door. We wanted the glass door to keep the heat inside the box. We did not want heated air inside the box gets out, because hot air is less dense than the cold air.

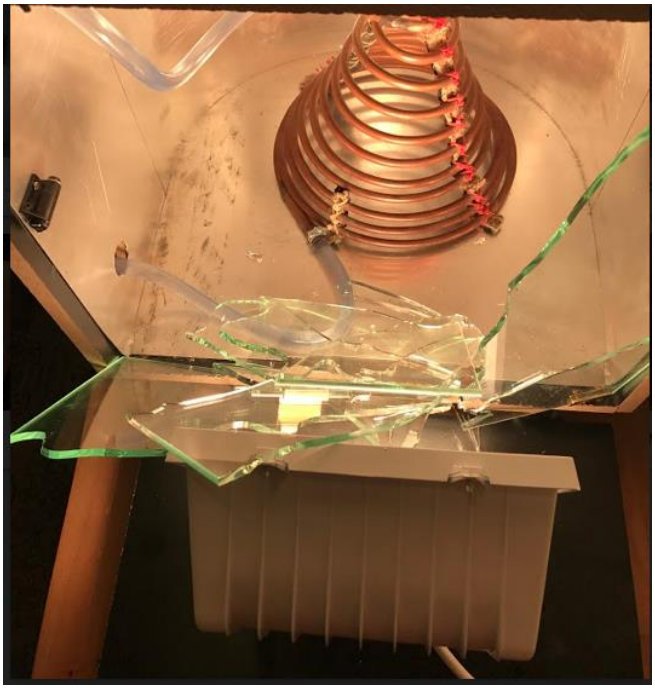


Figure 5.2 Thermal Collector Box

Copper Coils

In order to make the copper coils absorb more heat we painted them with black color. The reason is a black body absorbs all that fall on its surface, so it will increase the heat of the water inside the copper coils. After the paint job of the copper coils we tested it, and the result was good. Figure 5.3 shows the copper coils after the pain job.

Figure 5.4 Copper Coils after Paint Job

Instable Flow

The flow of the water inside the copper coils was not stable. To fix this problem we put a control valve to keep the water in the piping stable. We want the rate volume of the water the same in every test, so the control valve helped us to keep the rate of volume constant. Figure 5.5 is showing the control valve.

Figure 5.5 Control Valve

5.5 Project Bill of Materials and Budget

We listed all the expenses incurred in order to complete our project. We purchased many parts and we went to workshops to complete our design. Table 5.3 is showing all the parts that we purchased, and the labor cost.

Table 5.3 Expenses of Material and Labor Work

Item	Price SR
MDF plate	90
Assembly Labor	50
Labor cut	15
Glass	100
Labor work glass	50
4 Tires	32
Handle	6
Aluminum Foil	50
Aluminum Sheet bended	150
Nails	5
Glue	11
Hose	20
Clips	2
Thermometer	250
Heater	120
Control Valve	15
Fitting PVC	30
10m Hose	30
Light	60
PVC Pipes	50
Copper Coil with Labor	500
Banner	150
Books	300
Brochure Poster	50
Pump	45
Total	2181

Chapter 6: Project Analysis

6.1 Life-long Learning:

There are so many great lessons we all learn from project's life. We are as a group made a list with some of the most important ones so far, lessons that had a great impact in project's life. The challenges and opportunities that we have faced during this project have helped us discover some hidden abilities that we had not been able to explore in the past. One of the assignments of the group is to meet once a week and discuss previous problems, some of activities that related to the project. We review reports and provide comment. By joining a group, you will fuel your interests, challenge and reinforce your learning, Brainstorming, and have the opportunity to ask questions. Our comments are then forwarded to our instructor to give the final approve. Even though all of us improved our knowledge, skills and abilities in different ways, we can summarize our overall learning experience using the following sections.

6.1.1 Improve our Skills in Sensors Tools

In this project we had use many of sensors such as thermometer, flow meter, pressure gauge. There are many different types of thermometer available in today's market, we used show different types one of them to measure the inlet temperature and the other on is to measure the outlet temperature. We believe it is important to choose the right thermometer to suit our intended application. Moreover flow meter one of the most common flow measurement mistakes is the reversal of this sequence: instead of selecting a sensor which will perform properly, an attempt is made to justify the use of a device because it is less expensive therefor we selected the right one to avoid any mistakes. Finally, we used flow meter, they are many types of gauge styles, they are many types of gauge styles, the most common being Bourdon tubes and bellows gauges, we used simple one to be easy for calibrate and maintain.

6.1.2 New Tools Helped With The Research

We used various tools to help complete this project. we used some applications such as solid work and Microsoft of power point. Solid work program which helps to create 2D or 3D solids models without any complexity, faster and in the cost effective way. It assists us to

create models and assemblies. On other hand, the importance of explanation and presentation in learning skills are two processes cannot be separated therefor we used power point to summary our senior project because explanation alone is not enough and presentation alone is not enough and are not influential in the process of learning fully. We used Google Scholar website to look for articles similar to our research. Also we used science direct website to look for articles similar to our research. These tools will help us to do research in the future. We also read the heat transfer book to learn about our project.

6.1.3 Project management skills

Management skill is very important skill. In order to finish the project in time and ensure that our objectives were accomplished, we had to be managers of our own. We've trimmed our project management skills list to just five areas that we think it's important to master to be an effective project, here is our short list of some skills for our project management, leadership, communication, planning skills, time management, and Subject matter expertise. Creating realistic project plans, budgets, estimating time and effort, etc. are all things that a good project manager must do. We keep our work organized and our teams informed and happy to success and achieve the main goal. We also improved our collaboration and coordination skills. We subdivided the project to various tasks and each one had to undertake certain tasks, which we later met and collaborated to come up with the final project.

6.2 Impact of Engineering Solutions

This project is about the solar thermal collector. We want to optimize a geometry that absorbs heat. Using the sun as a source of energy would affect the economy, society, and environment. We will explain the impact of each of them in details.

6.2.1 Economy

The impact of our project has an effect on the economy side, due to simplicity and the high efficiency of the solar thermal collector. It's economical water heater with the usage of the radiation as an energy source. The solar thermal collector offers a cheaper source of energy for households because they will be harnessing solar energy, which is cheaper compared to

other sources of energy in the country. As such several, households will be able to make savings that may be utilized for other purposes and in the process of raising the living standards. Our solar thermal collector has a comparatively free maintenance cost since it can be used for longer period of time without any frequent repairs.

6.2.2 Society

Society it is the most important driver in this project, since Saudi Arabia government motivate the society to utilize the renewable energy source, and solar energy is one of them. The solar thermal collector can be used in communities and industries to reduce the power consumption which would result to a reduce the load on power plants.

6.2.3 Enviorment

The solar thermal collector is an alternative solution to produce renewable energy. This design could help to reduce the use of polluting power generation. Our study is heating water using solar thermal collector. It's an environmentally friendly device, and it's a useful tool that will help to reduce the carbon emissions as well as the from environment as.

6.3 Contemporary Issues Addressed

Electricity consumption is one of our project concerns. Our project objective is to reduce the power consumption. The solar thermal collector provides an alternative source of power that will offer people another solution, instead of relying on the conventional power suppliers. The issue of global warming has been another challenge across the world. In Saudi Arabia, a larger percentage of the electricity supplied utilizes non-renewable sources that increase pollution adding to the problem of global warming. Solar collector is eco-friendly, reduces the air pollution. Also it saves money, because it reduces the electric use for the power plant.

Chapter 7: Conclusions and Future Recommendations

7.1 Conclusions

Affordable and reliable energy has become a main focus and challenge in the recent world following the increase in the demand of energy both for domestic and industrial use. This demand has seen a scramble for energy between the domestic and the industrial sectors in which the domestic sector has at times have to bear with shortages due to the increased demand in the industrial sector. This is in reference to the need for electricity for heating water used for the purposes for bathing in the domestic sector.

The team was driven by the desire to make energy available and more affordable for the domestic sector to use for the purposes, which to some extent are not perceived to be very important to the industrial sector. In this light, the team borrowed an idea from the heat exchanger, how it operates and the underlying principles. The influence of the geometric structure of a coil formed the main point of focus and thus of interest for the team which aimed at availing enough energy to the families through the heat exchanger.

The experiment met the objectives which were designing a test rig coil in different geometries and then designing a number of coil geometries. Furthermore, designing experiments to study the best coil geometry efficiency in heat transfer. Whereas there were a number of challenges in the process of performing the experiment in relation to the technical and legal aspects of the experiment, achievements were made in relation to the aims and objectives. Based on the various test results, each of the objectives of the experiment was achieved. The test results on the volume of water reading during time were used in establishing the efficiency of the control valves and the flow meter in which the volume quantity of water that passed through the system was fixed for all the different coil geometries. A calculation of the volumetric flow rate and mass flow rate was used for the

purposes of making comparison between the different coil geometries in order to establish which geometry was more efficient. Another test was done on the solar thermal collector systems using the four different copper coil geometries each of them at a time under the same conditions of temperature and pressure. The results established illustrated that the entire different coil geometric had the same change in temperature throughout this experimental research.

7.2 Future Recommendations

The project can incorporate a number of adjustments or modifications in order to increase its usage and benefit to the day-to-day lives of the members of a society. The project does not specify the size of the solar panels used in the experiment. To make it clearer and broaden the objective of the project, the use of high wattage solar panels in encouraged. Through the high wattage solar panels, the amount of energy supplied will be higher and hence raising the levels of reliability of the energy source. On the same note, solar panels of high wattage would maximize the solar radiation produced such that the energy supply can be continued even the absence of solar radiation. This happens in such a way that the photovoltaic cells of the solar panel would ensure maximum trapping of the solar radiation and conversion into electricity.

Solar energy is an eco-friendly source of energy whose use should not only be limited to the domestic set up. The project can thus be expanded in such a way that the solar panels used in the project are projected to the national grid where the project can as well supply power for use in the industries. This will in turn increase environmental sustainability as well as help in increasing the supply of energy. There will as well be economic benefits that are accrued by using the project in the industries especially when it is used in running such equipment as boilers that consume a lot of energy at ago.

8. References

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Appendix A: Progress Reports

A.1 Progress Report on March

SDP – Monthly MEETING REPORT

Department of Mechanical Engineering
Prince Mohammad bin Fahd University

SEMESTER:	Spring	**ACADEMIC YEAR:**	2018
PROJECT TITLE	Design coils and study their geometry effect of heat transfer		
SUPERVISORS	Dr. Essam Jassim		

Month: February

ID Number	Member Name
201302587	Ibrahim Balhareth*
201303522	Meshal Al Saiari
201301889	Omar Al Otaibi
201300164	Marwan Al Refaei
201200399	Mahmoud Khujandi

List the tasks conducted this month and the team member assigned to conduct these tasks

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
1	Project allocation+ introduction	Marwan	100%	
2	Literature review	Ibrahim+Mahmoud	20%	
3	Design	Omar	20%	
4	Equipment and material selection	Ibrahim+Meshal	90%	

List the tasks planned for the month of March and the team member/s assigned to conduct these tasks

#	Task description	Team member/s assigned
1	Theory and Theoretical Calculations	Ibrahim+Omar
2	Prototype assemble	All team
3		
4		

- **To be Filled by Project Supervisor and team leader:**
- **Please have your supervisor fill according to the criteria shown below**

Outcome f:
An understanding of professional and ethical responsibility.

Criteria	None (1)	Low (2)	Moderate (3)	High (4)
f1. Demonstrate an understanding of engineering professional and ethical standards in dealing with public safety and interest	Fails to Demonstrate an understanding of engineering professional and ethical standards in dealing with public safety and interest	Shows limited and less than adequate understanding of engineering professional and ethical standards in dealing with public safety and interest	Demonstrates satisfactory an understanding of engineering professional and ethical standards in dealing with public safety and interest	Understands appropriately and accurately the engineering professional and ethical standards in dealing with public safety and interest

Outcome d:
An ability to function on multidisciplinary teams.

Criteria	None (1)	Low (2)	Moderate (3)	High (4)
d1. Ability to develop team work plans and allocate resources and tasks	Fails to develop team work plans and allocate resources and tasks	Shows limited and less than adequate ability to develop team work plans and allocate resources and tasks	Demonstrates satisfactory ability to develop team work plans and allocate resources and tasks	Understands and applies proper and accurate team work plans and allocate resources and tasks
d2. Ability to participate and function effectively in team work projects	Fails to participate and function effectively in team work projects	Shows limited and less than adequate ability to participate and function effectively in team work projects	Demonstrates satisfactory ability to participate and function effectively in team work projects	Understands and participates properly and function effectively in team work projects
d3. Ability to communicate effectively with team members	Fails to communicate effectively with team members	Shows limited and less than adequate ability to communicate effectively with team members	Demonstrates satisfactory ability to communicate effectively with team members	3. Understands and communicates properly and effectively with team members

Indicate the extent to which you agree with the above statement, using a scale of 1-4 (1=None; 2=Low; 3=Moderate; 4=High)

#	Name	Criteria (d1)	Criteria (d2)	Criteria (d3)	Criteria (f1)
1	Ibrahim Balhareth	4	4	4	4
2	Meshal Al Saiari	4	4	4	4
3	Omar Al Otaibi	4	4	4	4
4	Marwan Al Refaei	4	4	4	4
	Mahmoud Khujandi	4	4	4	4

Comments on individual members

Name	Comments
Ibrahim Balhareth	
Meshal Al Saiari	
Omar Al Otaibi	
Marwan Al Refaei	
Mahmoud Khujandi	

A.2 Progress Report on April

SDP – Monthly MEETING REPORT

Department of Mechanical Engineering
Prince Mohammad bin Fahd University

SEMESTER:	Spring	ACADEMIC YEAR:	2018
PROJECT TITLE	Design coils and study their geometry effect of heat transfer		
SUPERVISORS	Dr. Essam Jassim		

Month: March

ID Number	Member Name
201302587	Ibrahim Balhareth*
201303522	Meshal Al Saiari
201301889	Omar Al Otaibi
201300164	Marwan Al Refaei
201200399	Mahmoud Khujandi

List the tasks conducted this month April and the team member assigned to conduct these tasks

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
1	Design Constraints and Design Methodology	Omar	90	
2	selected the appropriate items	Ibrahim+Meshal	100	
3	main calculations required detailed calculations to your design.	Omar	90	
4	System integration, describe , procedures and Implementation	All Team	100	

List the tasks planned for the month of April and the team member/s assigned to conduct these tasks

#	Task description	Team member/s assigned
1	Testing and Analyses	All Team
2	Worked on Draft	All Team
3	Project Management	All Team
4	Project Analysis	All Team
5	Submission Final Report	All Team

- **To be Filled by Project Supervisor and team leader:**
- **Please have your supervisor fill according to the criteria shown below**

Outcome f: An understanding of professional and ethical responsibility.				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
f1. Demonstrate an understanding of engineering professional and ethical standards in dealing with public safety and interest	Fails to Demonstrate an understanding of engineering professional and ethical standards in dealing with public safety and interest	Shows limited and less than adequate understanding of engineering professional and ethical standards in dealing with public safety and interest	Demonstrates satisfactory an understandin g of engineering professional and ethical standards in dealing with public safety and interest	Understands appropriately and accurately the engineering professional and ethical standards in dealing with public safety and interest

Outcome d: An ability to function on multidisciplinary teams.				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
d1. Ability to develop team work plans and allocate resources and tasks	Fails to develop team work plans and allocate resources and tasks	Shows limited and less than adequate ability to develop team work plans and allocate resources and tasks	Demonstrates satisfactory ability to develop team work plans and allocate resources and tasks	Understands and applies proper and accurate team work plans and allocate resources and tasks
d2. Ability to participate and function effectively in team work projects	Fails to participate and function effectively in team work projects	Shows limited and less than adequate ability to participate and function effectively in team work projects	Demonstrates satisfactory ability to participate and function effectively in team work projects	Understands and participates properly and function effectively in team work projects
d3. Ability to communicate effectively with team members	Fails to communicate effectively with team members	Shows limited and less than adequate ability to communicate effectively with team members	Demonstrates satisfactory ability to communicate effectively with team members	3. Understands and communicates properly and effectively with team members

Indicate the extent to which you agree with the above statement, using a scale of 1-4 (1=None; 2=Low; 3=Moderate; 4=High)

#	Name	Criteria (d1)	Criteria (d2)	Criteria (d3)	Criteria (f1)
1	Ibrahim Balhareth	4	4	4	4
2	Meshal Al Saiari	4	4	4	4
3	Omar Al Otaibi	4	4	4	4
4	Marwan Al Refaei	4	4	4	4
5	Mahmoud Khujandi	4	4	4	4

Comments on individual members

Name	Comments
Ibrahim Balhareth	
Meshal Al Saiari	
Omar Al Otaibi	
Marwan Al Refaei	
Mahmoud Khujandi	

Appendix B: Engineering standards

Engineering standards are important. In every component of our design we looked in the engineering standards for the best material for the system. Table B.1 is showing the material we purchased for our project.

Table B.1 Engineering Standards

No.	Part name	Type of Material	Reference Standards	Standards Description
1	Coils	Copper of Alloy C12200	ASTM B88 and ANSI/ NSF 61	Seamless Copper Water Tubes
2	Piping connection	CPVC	ASTM D2846	Plastic Hot Water Distribution Systems
3	Thermal box	MDF Wood	ASTM D5664 - 17	Wood of Elevated Temperatures Surface
4	Collector window	Glass	ASTM E765-80	Flat Plate Solar Collectors
5	Solar Diffuser	Aluminum Alloy	ASTM B209M	Aluminum-Alloy Sheet and Plate
6	Hoses connection	Thermoplastic	ASTM F645 - 15a	Thermoplastic Water- Pressure Piping Systems

Appendix C: CAD drawings and Bill of Materials

In this part we put the 2D drawings of everything we manufactured and some of the parts we purchased. Figure C.1 is showing the exploded view, and bill of material.

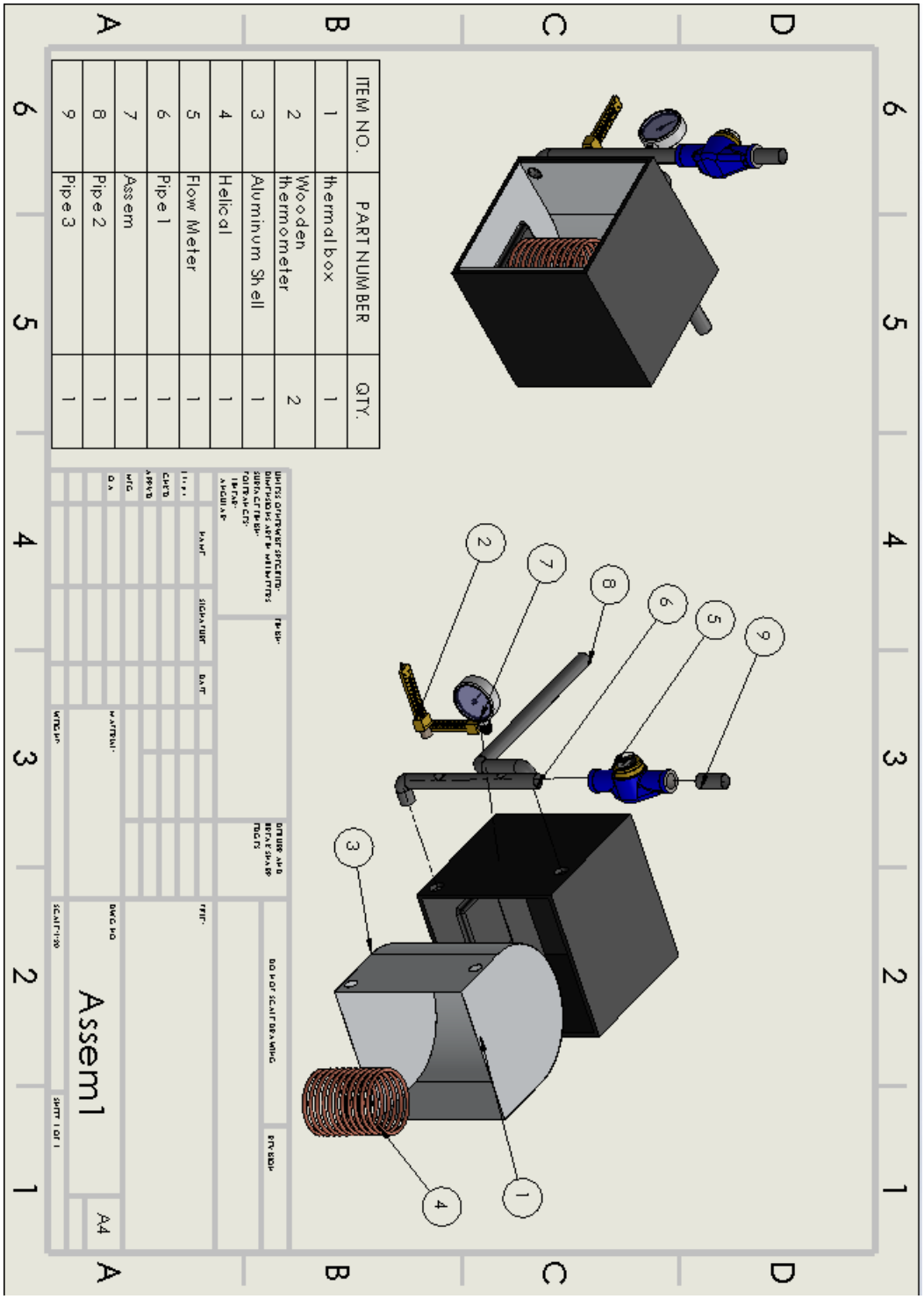

Figure C.1 Exploded View

Figure C.2 is showing the 4 different types of copper coils.

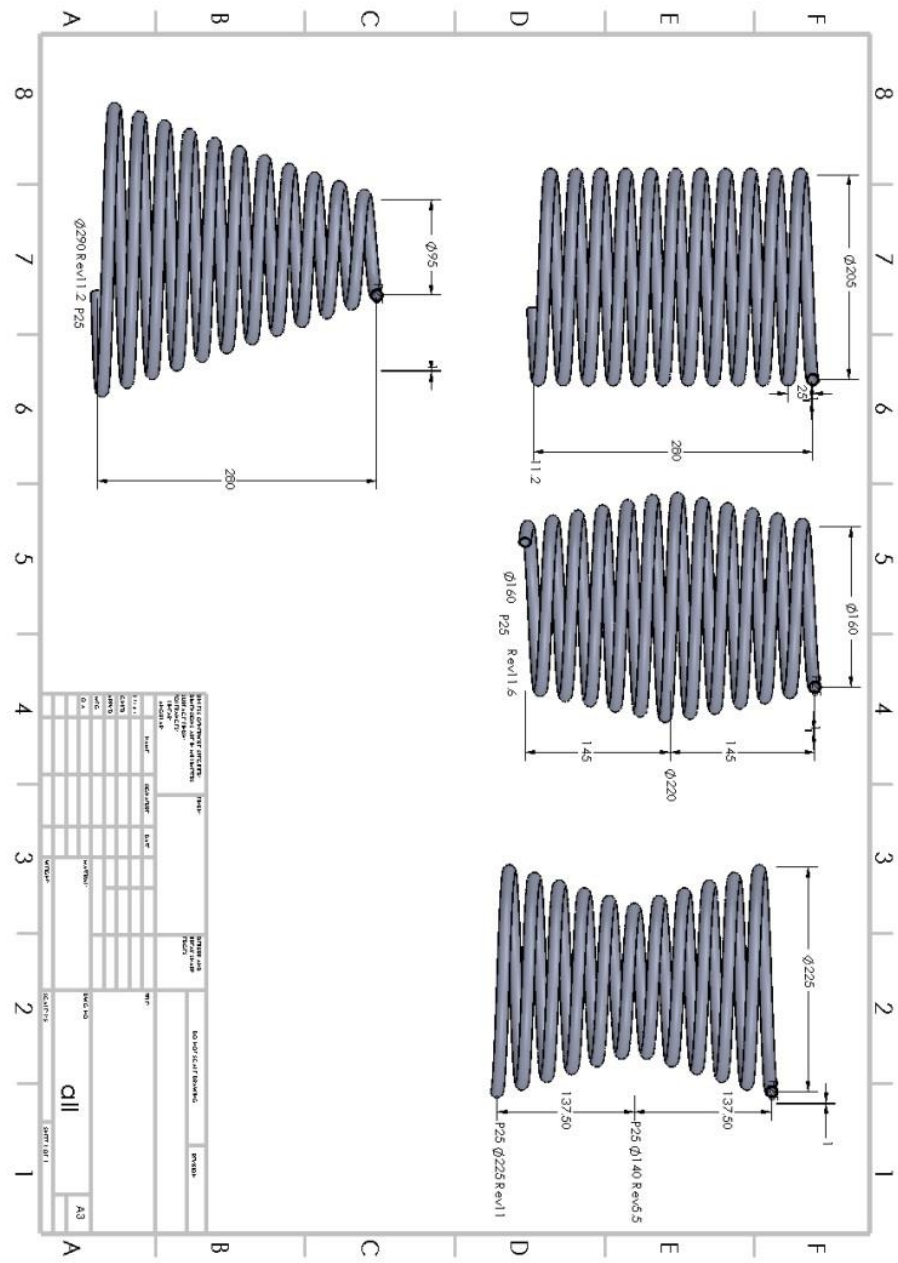

Figure C.2 Copper Coils

Figure C.3 is showing the pressure gauge.

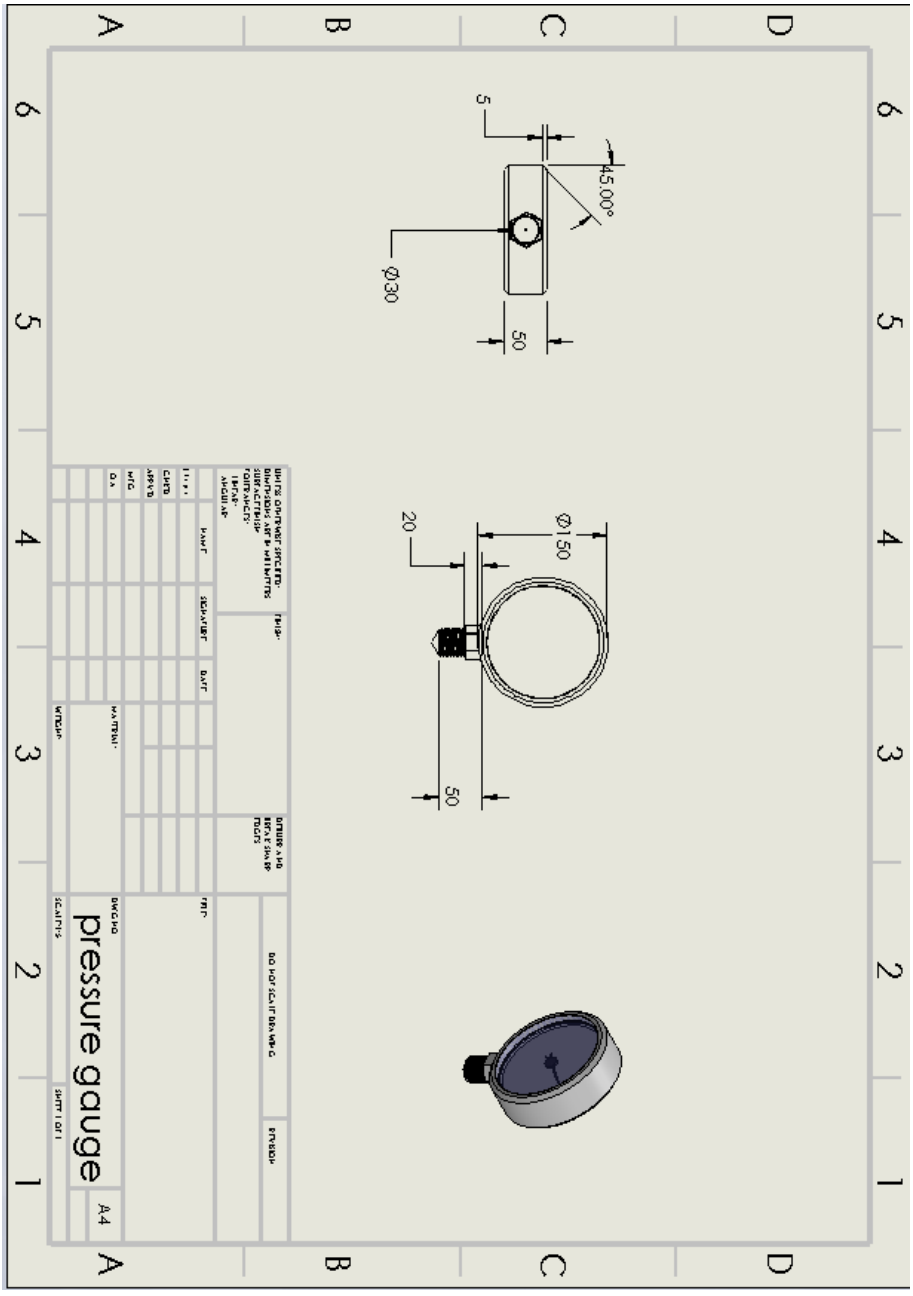

Figure C.3 Pressure Gauge

Figure C.4 is showing the thermomter.

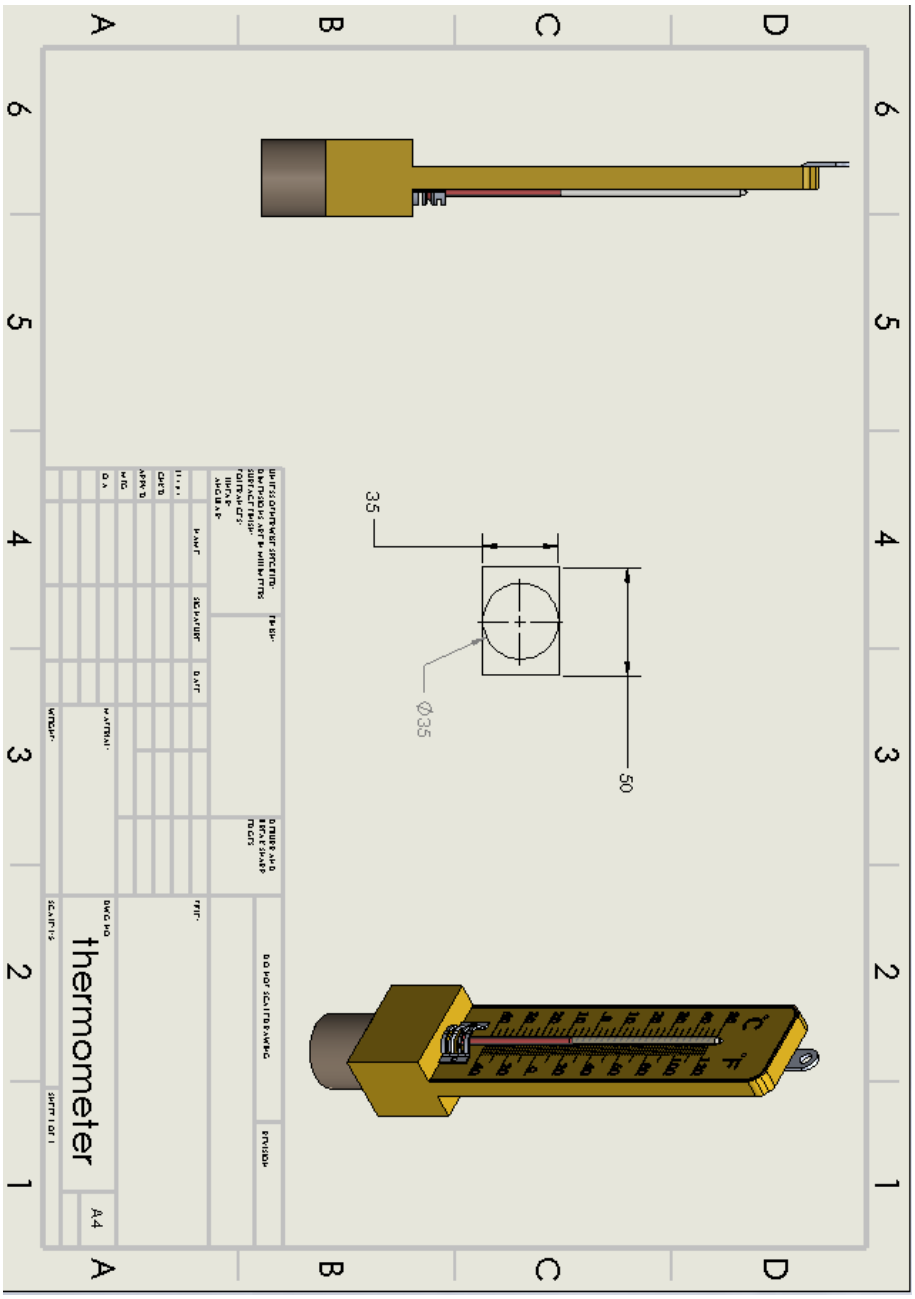

Figure C.4 Thermometer

Figure C.5 is showing the pressure gauge.

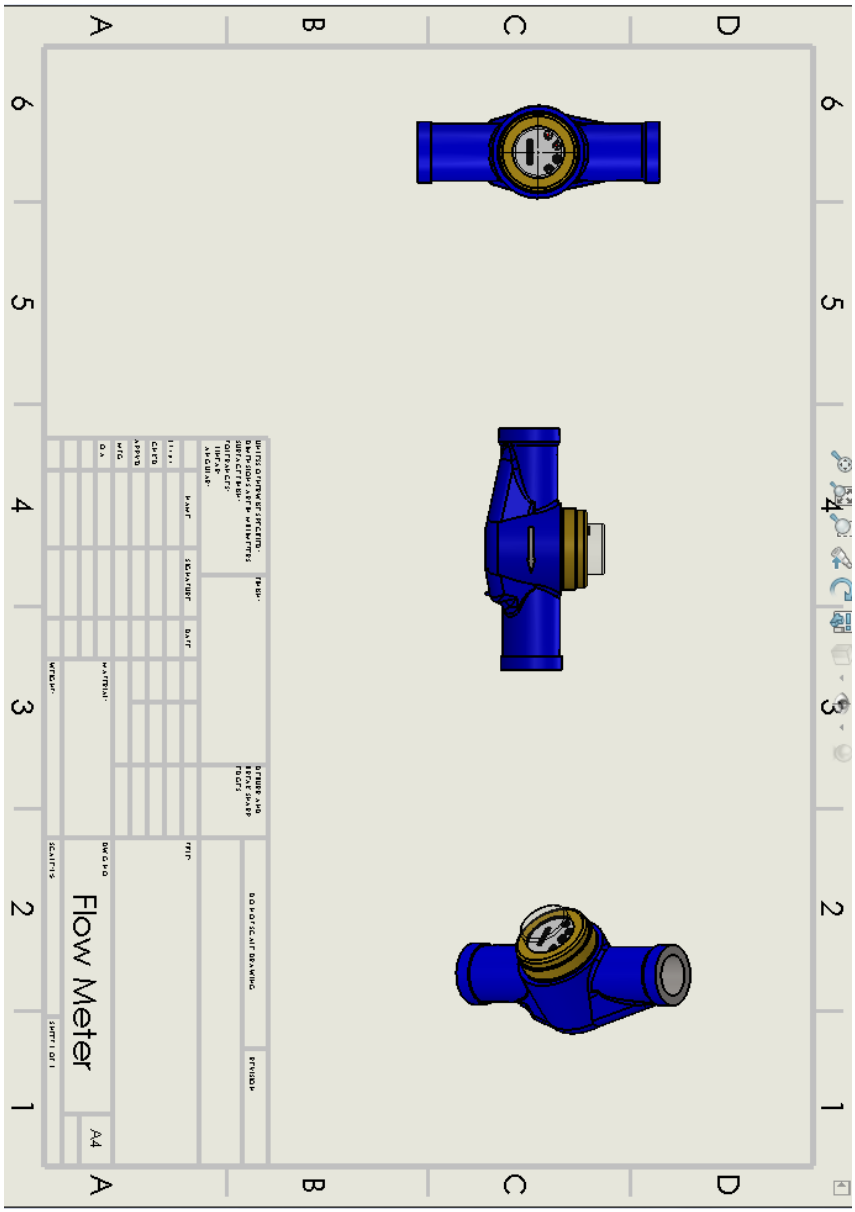

Figure C.5 Flow Meter

Figure C.6 is showing the alumnim sheet.

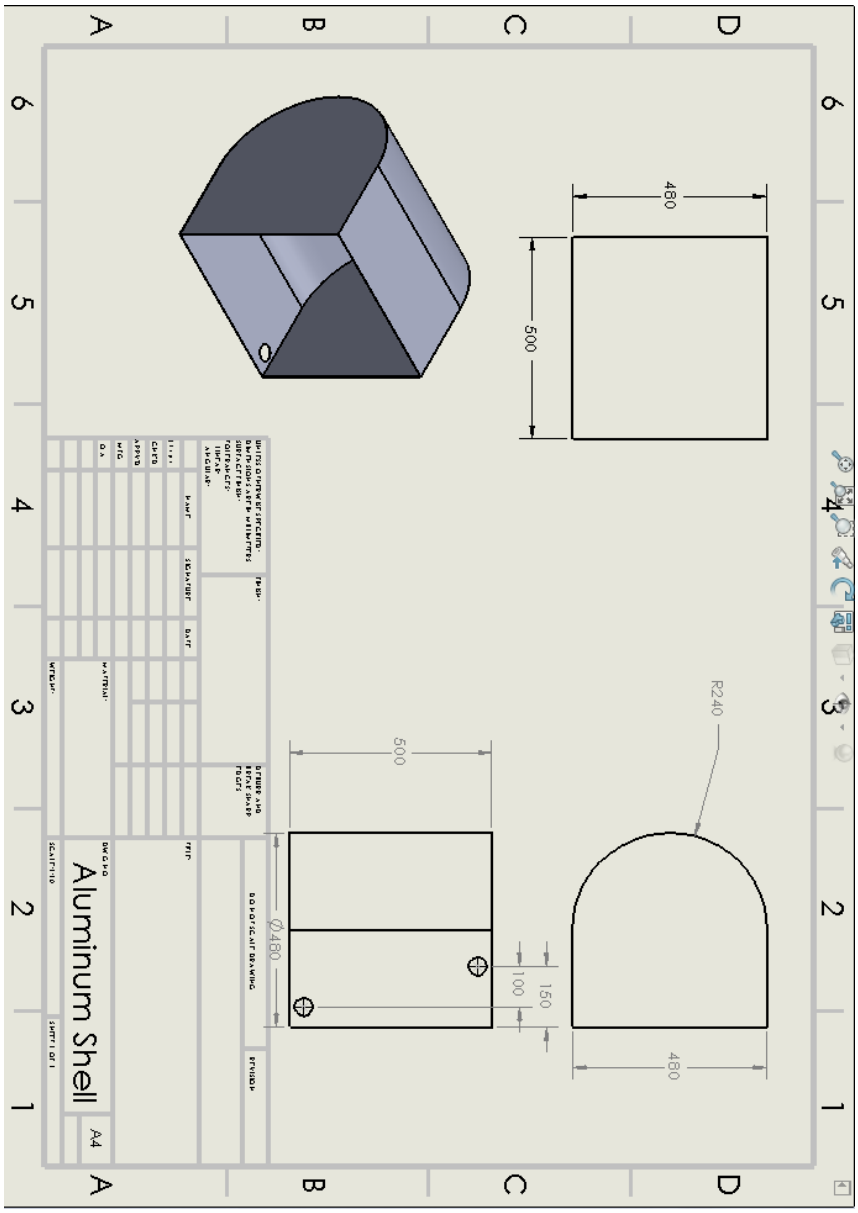

Figure C.6 Aluminum Sheet

Figure C.7 is showing the thermal box that stores the heat.

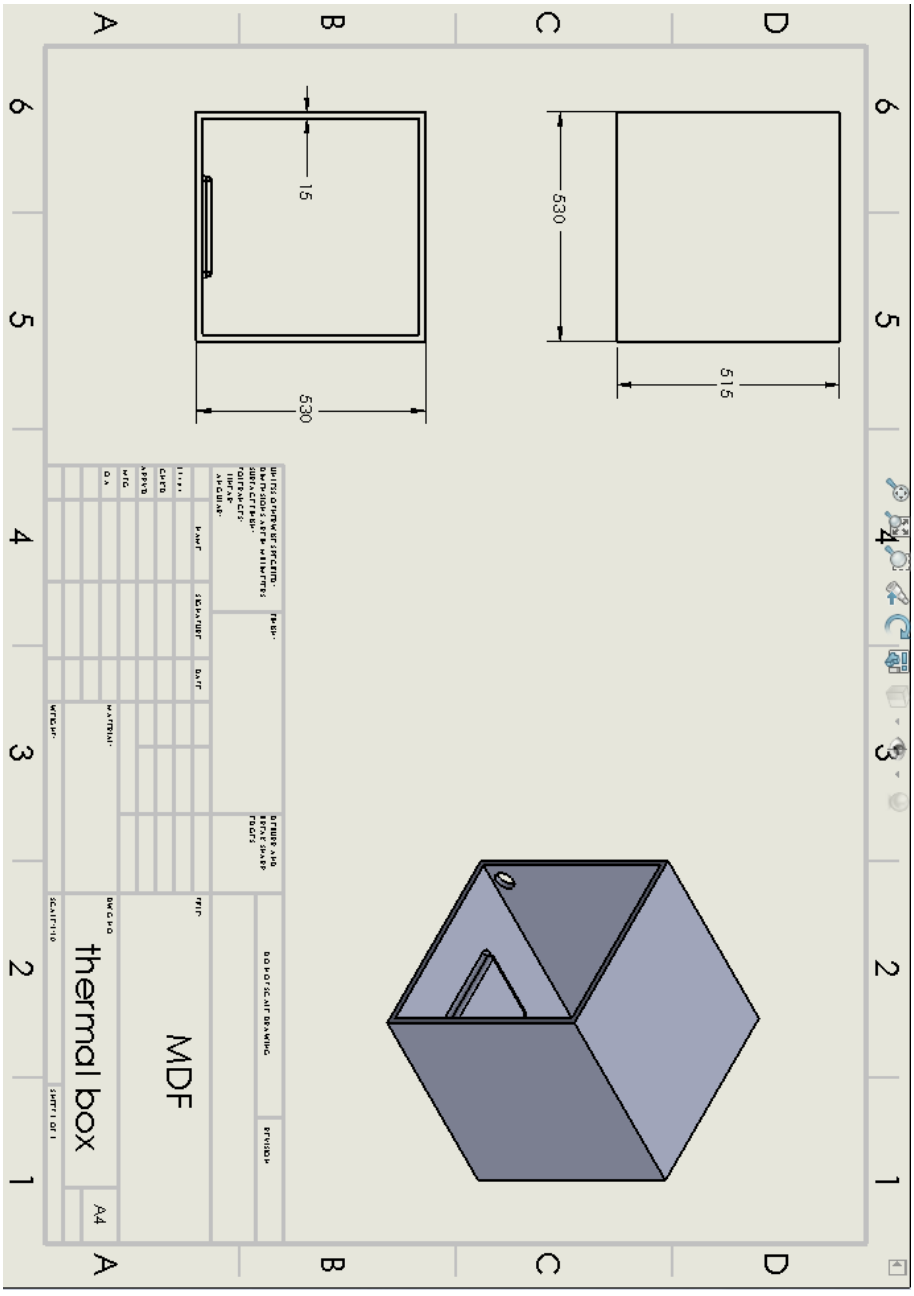

Figure C.8 Thermal Box