جامعة الأمير محمد بن فهد
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Senior Design Project Report

Design of Experiments to Study the Performance of Concentric Tube Heat Exchanger

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

Team (12)

Team Members

	Student Name	Student ID
1	Khalid Alnajrani	201602350
2	Turki Almatrook	201602430
3	Omar Rebhan	201602958
4	Khalid Alshamrani	201502449
5	Hussain Al-Malack	201600661

Project Advisor:

Advisor Name: Dr. Essam Jassim

Abstract

The concentric tube heat exchanger is designed to illustrate the working principles of the industrial heat exchanger. The concentric tube heat exchanger is cheap compared with other types of heat exchangers. It also shows the excellent quality and reliability of the heat exchanger by separating the fluids exchanging heat. Its applications are useful in the daily life, such as the chemical and pharmaceutical industry. This concentric tube heat exchanger is an exchanger where hot fluids are exchanging heat with cold fluids. This experiment aims to show the working principles of a concentric tube heat exchanger operating under parallel flow conditions and counter flow conditions. This study will also focus on the performance of a concentric tube heat exchanger using Nano-fluid with different quantities of Nano-fluid particles, which may promote fluid's heat transfer characteristics. In general, heat exchangers are used to cool down a specific fluid using another fluid with different paths. This project consists of two main parts: the heat exchanger and the base unit connected to the electrical supply. This project aims to test the Concentric Tube Heat Exchanger's efficiency and determine the inlet and outlet temperatures.

Acknowledgements

Our senior project team would like to thank and express their feelings toward the advisor Dr. Essam Jassim for his continuous encouragement and support during the course of this project. Our appreciation to the co-advisors, Dr. Nassim Khalid and Mr. Fizan Ahmad, for their effort in the project's following sides. We would also like to thank our first supporter, chairman of the mechanical engineering department at PMU, Dr. Faramarz Djavanroodi, for his support.

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List of Acronyms (Symbols) used in the report

Symbol	Definition
L	Length
$D_{int, ext}$	Diameter (internal or external)
A	Area
M	Mass
$\dot{m}$	Mass flow rate
$T_{c, h}$	Temperature (cold or hot)
ε	Effectiveness
C_p	specific heat capacity
U	The overall heat transfer coefficient
UA	The overall heat transfer coefficient multiplied by the surface
NTU	Number of Transfer unit
As	Heat transfer surface
C_{min}	Smaller heat capacity rate
C_{max}	Bigger heat capacity rate
$A_{c, h}$	Area (external or internal)
P	Power
SC-1	Hot Flow Rate
SC-2	Cold Flow Rate

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Chapter 1

Introduction

1.1 Project Definition

The project is a design of an experiment to study the Concentric Tube Heat Exchanger. Where the heat exchanger should be linked to the unit that consists of the boiler and cold fluid source. Also, the Concentric Tube Heat Exchanger demonstrates the basic principles of heat transfer. In general, the exchanger is a device used to cool down a specific fluid by changing its thermal properties by separating them by solid walls. The concentric tube heat exchanger is used to examine heat transfer between two fluids while the hot fluid in the internal tube and the cold fluid are located in the annular area between the inner and outer tube walls.

1.2 Project Objectives

The primary aims of this project are:

1- Demonstrate the efficient state of the Concentric Tube Heat Exchanger, whether parallel or Counterflow.
2- This exchanger allows measuring hot and cold-water temperatures in different points of the exchanger of the hot and cold fluids at various points.
3- Explain the basic principles of Heat Transfer.
4- Illustrate the effect of temperature variation on the performance of the Concentric Tube Heat Exchanger.
5- To study the effect of flow and counter-current flow and co-current flow of heat exchangers.
6- To study the effect of fluid temperature on counterflow heat exchanger performance.
7- To study the effect of fluid flow rates on heat exchanger performance.

1.3 Project Specifications

This project is used in oil refineries and different chemical processes. The Concentric Tube Heat Exchanger is chosen according to the following specifications:

Table (1): Project measurements.

Item	Size
Base Unit:	
Net Weight	30 kg
Height	400 mm
Width	1000 mm
Depth	500 mm
Heat Exchanger:	
Net Weight	20 kg
Height	200 mm
Width	1000 mm
Depth	500 mm
Electric Supply	220 V 50 Hz (110 V 60 Hz)
Water tap	
Water drain	

1.4 Applications

The essential applications of the project:

- Studying losses and energy balance.
- Knowing the range of the exchanger effectiveness output.
- Heat transfer effect in different flow whether counter or parallel flow.

Chapter 2

Literature Review

2.1 Project Background

The concentric tube heat exchanger is the simplest form of a heat exchanger and a design that may be successfully analyzed and described by empirical equations. The concentric tube heat exchanger demonstrates the basic principles of heat transfer. The heat exchanger operates when hot flow and cold flow enter the exchanger, where the cold flow will gain some heat and the hot flow losing heat before they both exit the exchanger. A heat exchanger is a device where thermal energy can transfer from one fluid to another [1]. Moreover, the heat exchangers' types to be tested in this experiment are called single-pass, parallel-flow, and counter-flow concentric tube heat exchangers. In a parallel-flow heat exchanger, the working fluids flow in the same direction. In the counter flow exchanger, the fluids flow in parallel but opposite directions [2].

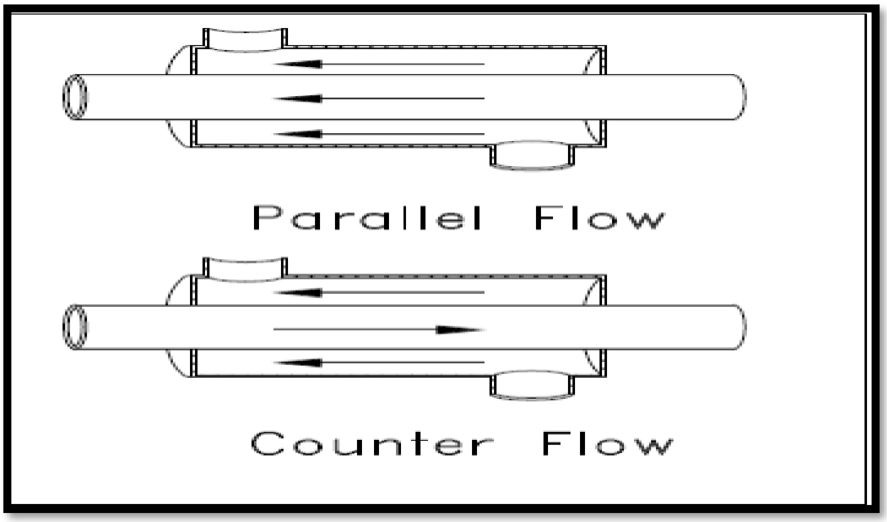

Figure (1): Concentric Tube Heat Exchangers.

For this experiment, the Concentric Tube Heat Exchanger for TICC was designed to demonstrate the heat transfer between hot water flowing through an internal tube and cold water flowing through the annular area between the internal and external tubes [3]. The recent advances in nanotechnology have provided possibilities in advancing technology used in the heat exchange. Argonne Laboratory created a new generation of heat transfer fluids that exhibit higher thermal conductivity known as nanofluids. A "nanofluid" is a fluid with suspended fine nanoparticles, which raises the heat transfer properties in contrast to the initial fluid. Nanofluids are believed to be a new generation of heat transfer fluids and are believed to be two-phase fluids of solid-liquid mixtures. The possible uses of nanofluids in engine cooling, machining process, transformer cooling, and nuclear reactor cooling. It's possible and normal that a heat recovery product's overall performance may be increased by using this sophisticated heat transfer fluid. This particular study tries to take a look at the winter performance concentric tube heat exchanger using nanofluids. Substantial research suggests and considers nanofluids as the replacement of existing heat transfer fluids [four]. Concerning economy nanotechnology, it is possible to attain higher efficiency and cost-saving in heat transfer processes. Nanoparticles are actually regarded as to be brand new generation materials having possible uses in the heat transfer area. Furthermore, the nanofluids are believed to be stable when the concentration stays constant at 5%.

Simply, the Concentric tube heat exchanger demonstrates the basic principles of heat transfer. Like many other projects, it should face many challenges. As a group of senior projects, we should be aware of the challenges. The first challenge of our senior project was how to know the location of the hot pump and cold pump. The second challenge was how to know the location of the parallel-flow and counter-flow concentric tube heat exchangers. The third challenge was the boiler of the experiment. We should wait around two hours to make the boiler cold because we cannot operate the experiment if the boiler is hot.

2.2 Previous Work

This project is investigating the effect of using the heat transfer characteristic of nanofluids TiO2/Thermo XT 32 oil on concentric tube heat exchangers. The nanoparticle has a diameter of 21nm mixed in XT 32 oil as a base fluid in three different volume fractions 0.1%, 0.2, and 0.3%. “A straight horizontal stainless-steel tube of 1.2 m length, 0.012 m inner diameter, and 0.022 m outer diameter” were the size of tools used in the experiment. The experiments set it to analyzing the data of the heat transfer using nanofluid in different volume fractions. The result shows that the thermal convection coefficient increasing when the volume fraction increased.

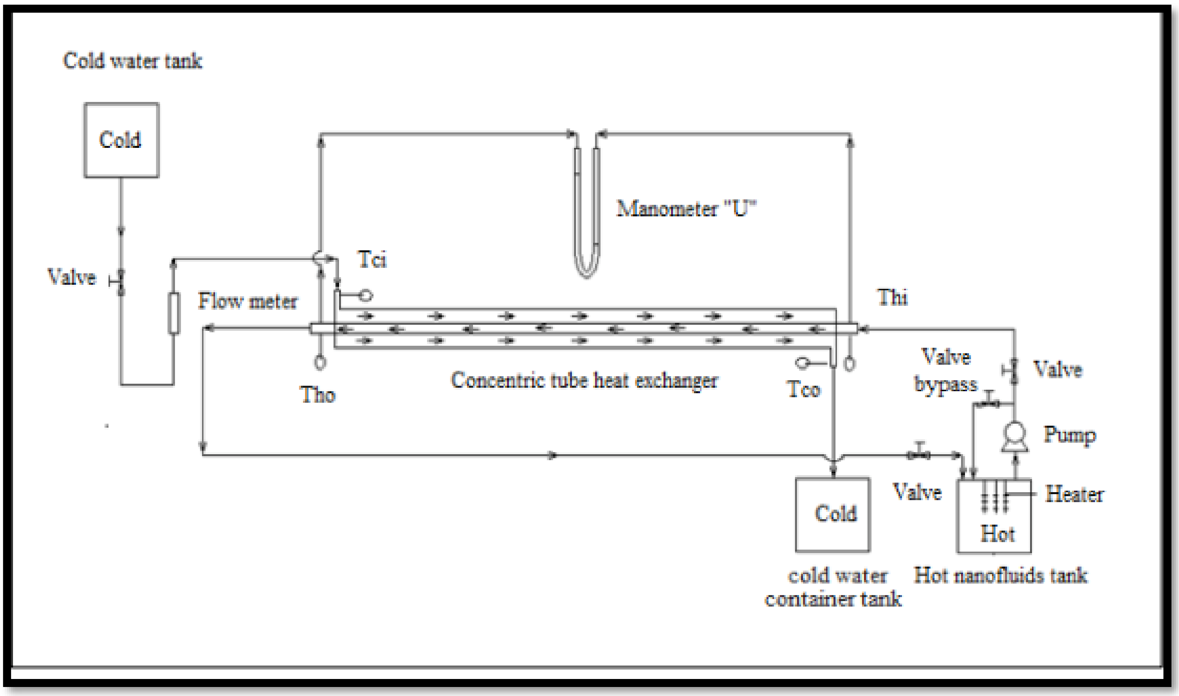

Figure (2): Schematic diagram of concentric tube heat exchanger.

The experiment is working under a cycle consist of a” pump, cold water tank, boiler nanofluid TIO2 tank, Water heater, concentric tube heat exchanger, manometer “U”, flowmeter, thermocouples at the entry and the exit to measure the inlet and the outlet temperature”. The hot flow of nanofluid is setting up to be in these temperatures of 60 °C, 80 °C, 100 °C, and 120 °C. To avoid any incorrect results, it is extremely important to run the cycle for a certain time until the cycle is becoming stable.

The table below is showing the relation between the rate of heat transfer and temperature. As it is showing the rate of heat transfer in (w) of nanofluid when the XT32 oil (base fluid) and the nanofluid in different volume fractions (inner tube) will vary under different temperature and volume fraction [3].

Table (2): The rate of heat transfer relationship with volume fraction

Temperature (°C)	The rate of heat transfer Q (W)			
	0 Vol%	0.1 Vol%	0.3 Vol%	0.5 Vol%
60	443.69	635.15	906.83	1137.31
80	671.60	918.66	1381.81	1850.03
100	812.70	1080.39	1626.67	2184.05
120	999.49	1163.42	1801.48	2294.58

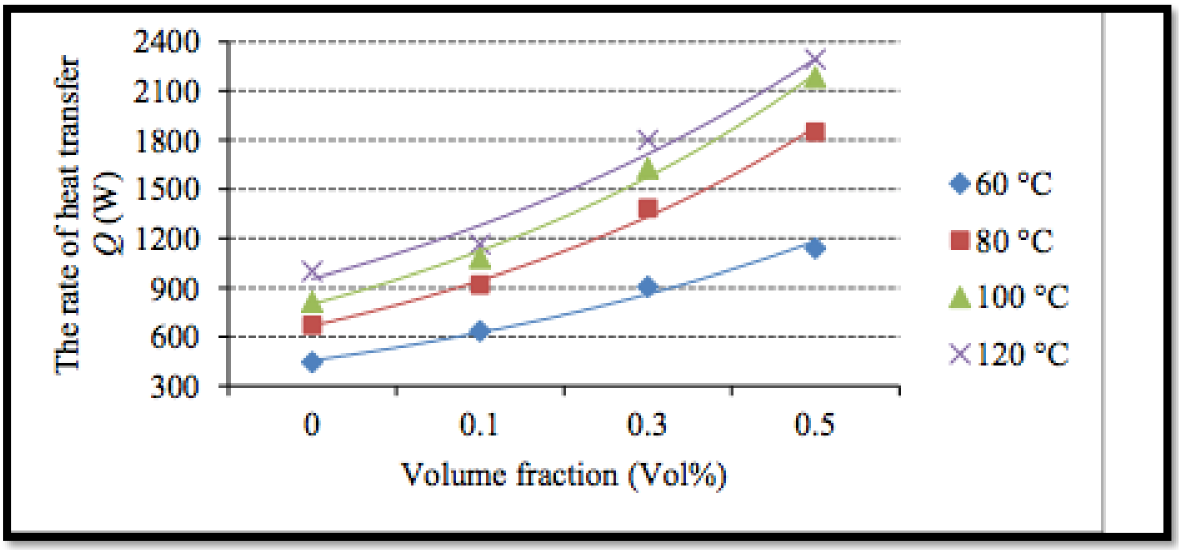

Figure (3): The rate of heat transfer relationship with volume fraction

2.3 Comparative Study

For credibility, we admit that our senior project title is not original from our thoughts. As a result, we looked up through some previous projects similar to our project to improve them. However, members of Visvesvaraya National Institute of Technology, Nagpur, India did a study very similar to our project. They worked on a Heat transfer study on a concentric tube heat exchanger using TiO_2–water based nanofluid. Their research described the heat-transfer features of TiO_2–water nanofluids as a coolant in the concentric tube heat exchanger. The heat exchanger is created from a copper concentric inner tube with a length of 1000 m. The observation of average heat transfer rates for Nano-fluid in their study is higher than the water where both of them are used as a coolant. The results of their study have importance for the efficient design of concentric tube heat exchanger to enhance cooling performance [1].

Another similar project with the title; heat transfer through heat exchanger using Al2O3 Nano-fluid at different concentrations. This project reports concentrating on the forced convective heat transfer and flow features of a Nano-fluid comprising water with different volume concentrations of Al2O3 Nano-fluid that vary between (0.3–2) % flowing in a tube heat exchanger counter flow under turbulent flow conditions are examined. The Al2O3 nanoparticles that have 30 nm diameter are utilized in the current study. The outcomes show that Nano-fluid's convective heat transfer coefficient is somewhat higher than that of the base fluid at the same mass flow rate and at the same inlet temperature. The heat transfer coefficient of the Nano-fluid increments with an expansion in the mass flow rate; likewise, the heat transfer coefficient raises with the increment of the volume concentration of the Al2O3 Nano-fluid; however, expanding the volume concentration cause increment in the friction factor and increment in the viscosity of the Nano-fluid [2].

Comparing with our project, we are going to use Nano-fluid (TiO_2) as a coolant with a different volume fractions and various cold flow rate and study when will be the Concentric Tube Heat exchanger more efficient whether at 3%, 2% or 1%.

Chapter 3
System Design

3.1 Design Constraints and Design Methodology

3.1.1 Geometrical Constraints

In the beginning, the Concentric Tube Heat Exchanger that we work on, was ready to conduct our experiments, while the other parts related to the Heat exchanger such as Cold Fluid Tank, Pump, and sensor should be provided to start the experiments. The rest parts are easy to find in the local market. Furthermore, the real challenge we faced and is an expected problem which is ordering the Nano-fluid that is considered the base in our project. Searching for a verified website that provides the titanium oxide within a certain amount is not easy to find.

3.1.2 Sustainability

In terms of sustainability, we decided to use pure water (No minerals and Salts) instead of tube water because the pipes are made from metallic materials and corrosion can take place. Also, Nano-fluid is reusable so, we use it as a coolant and our project is studying the performance of using different amounts of Titanium dioxide with the ability to benefit from the previously added quantity.

3.1.3 Environmental

One of the Concentric Tube Heat Exchanger Characteristics is the simplicity of cleaning and maintaining inside the pipes which make the heat exchangers ideal for use with fouling fluids as well as their resistance to the high pressure. For the Nano-fluid, Titanium dioxide is a beneficial and non-toxic fluid, but its waste is acidic and the ways to eliminate these wastes may cause environmental problems.

3.1.4 Social

Our project can be used to raise the efficiency of the Concentric Tube Heat Exchangers. That means the efficiency of multiple applications will increase. For instance, Heat recovery from engine cooling, chemical industries and refineries. This project will improve the usage of the heat exchangers in general and Concentric Tube Heat Exchangers in particular.

3.1.5 Economic

Our project assists the companies, factories, and refineries to save money because of the low cost of the maintenance and cleaning of the pipes of Concentric Tube Heat Exchangers. This increases reliability on them and shows the efficiency of using them with Nano-fluids without big losses.

3.1.6 Safety

For the safety side, we keep checking the open and closed valves to make sure that the correct valves are open for the required flow direction. The boiler temperature also should be cooled down before starting other experiments to collect more accurate data. Closing the pump from the TITC program and closing the cold flow rate valve to use the rest of the fluid for the second and third experiments.

3.1.7 Ethical

There are some old projects that have the same idea. We concluded the main ideas and decided to improve the Heat Exchanger in terms of efficiency, sustainability.

3.2 Engineering Design standards

Engineering design standards is an important matter because it helps to ensure that the products and services are totally safe and effective. In this section, we set all the standards for each component that has been used in our project. The components that have been used are the following, concentric tube heat exchanger, base unit, tank, controller, fittings, boiler, and pump.

Table (3): Components Engineering Standards

Component	Engineering standards
Heat exchanger	ISO9001
Tank	AS/NZS 4766
Pump	PTC 8.2 - 1990
Boiler	ASME B31.1
fittings	ASTM D2846
controller	ASME A112.18.1
Flow sensors	PTC 19.5 – 2004(R2013)

Concentric Tube Heat Exchanger

this type of heat exchanger contains two tubes, one tube is for the hot flow and it's the inner tube, the other is for the cold flow and it's the outer tube that has a ring-shaped area.

Exchanger length L = 1 (m)

Inner tube:

- Internal diameter: $\mathbf{D_{int} = 16 \times 10^{-3}\ m}$
- External diameter: $\mathbf{D_{ext} = 18 \times 10^{-3}\ m}$
- **Depth = 10^{-3} m**
- Heat transfer internal area: $\mathbf{A_h = 0.0503\ m^2}$
- Heat transfer external area: $\mathbf{A_C = 0.0565\ m^2}$

Outer tube:

- Internal diameter: $\mathbf{D_{int} = 26 \times 10^{-3}\ m}$
- External diameter: $\mathbf{D_{ext} = 28 \times 10^{-3}\ m}$
- **Depth = 10^{-3} m**

1. **Boiler or heating tank:** It is made of stainless steel that equipped with the following:

- Thermal resistor to heat the water called (AR-1).
- Thermocouple to measure water temperature (ST-16).
- Level controller in order to control the water level in the tank (AN-1).
- A stainless-steel cover is included to prevent any contact with hot water.
- Contains a draining valve of the water in the tank.

2. **Pump:**

- It’s a centrifugal pump with mutable speed convertor. (AB-1)
- Has a power of a half horse that is equivalent to 373 Watts.

3. **Flow sensor:**

- Transducer for electronic flow with acetaldehyde copolymer body and brass compression joints at two ends.
- One sensor for hot flow (SC-1) and another for cold flow (SC-2).

4. **Temperature sensor:**

- Thermocouple with J shaped, it has a length of 100 mm and 4 mm of diameter.
- It consists of 7 units: one for the boiler (ST-16) and the other six are distributed in the heat exchanger (ST-1, ST-2, ST-3, ST4, ST5 and ST-6).

5. **Flow control:**

- There are two control valves that made of brass: one to control cold flow (AVR-2) and other to control hot flow (AVR-1).

6. **Control of the direction of cold-water flow:**

- There are four valves that can provide either parallel or counter flow in the Heat exchanger which (AV-2, AV-3, AV-4 and AV-5) depending on the type of flow.

7. **Air purge system:**

- There are two sockets with screw of hexagonal type that located in the heat exchanger: one in the hot flow circuit (AP-2) and other in the cold flow circuit (AP-1).

8. **Draining valves:**

- There are 4 ball valves that allow the tubes to drain the water (AV-1, AV-6, AV7, and AV-8).

Table (4): Dimension and weights

	Base Unit	Heat Exchanger
Weight	30 Kg	20 Kg
Height	400 mm	200 mm
Width	1000 mm	1000 mm
Depth	500 mm	500 mm

3.3 Theory and Theoretical Calculations

In any heat exchangers system, it is necessary to calculate the heat capacity C that defined as the amount of energy required to raise the temperature by one degree Celsius or kelvin

$$\boldsymbol{Cmin, max} = \boldsymbol{CP} \times \dot{m} \qquad \textbf{(equ3.1)}$$

C_P = specific heat capacity measuring in J/g*c

$\dot{m}$ = mass flow rate

The heat capacities rate ratio will be dimensionless where C_{max} and C_{min} is equal to Cc/Ch or Ch/Cc, the value of cold and hot heat capacity ratio

$$\boldsymbol{C} = \frac{\boldsymbol{Cmin}}{\boldsymbol{Cmax}} \qquad \textbf{(equ3.2)}$$

$\boldsymbol{C}$ = heat capacity

$\boldsymbol{Cmin}$ = $\boldsymbol{C}$ cold or $\boldsymbol{C}$ hot

Cmax = $\boldsymbol{C}$ cold or $\boldsymbol{C}$ hot

In heat exchangers, there is an actual heat transfer rate for a heat exchanger, and the maximum possible heat transfer rate this defined as effectiveness which is useful to determine the heat transfer rate without knowing the outlet temperature of the fluid.

$\varepsilon = \frac{Tc\ outlet - Tc\ inlet}{\mathbf{Th\ inlet - Tc\ inlet}}$ or $\varepsilon = \frac{Th\ outlet - Th\ inlet}{Th\ inlet - Tc\ inlet}$ (eua3.3)

ε = effectiveness

$\mathbf{T_c}$ = Cold temperature

$\mathbf{T_h}$ = Hot temperature

It can be chosen depend on $Cmax$ and $Cmin$ equ3.1, if

$\dot{m}_h \times C_{p,h} < \dot{m}_c \times C_{p,c}$, $\varepsilon = \frac{(Th\ outlet - Th\ inlet)}{(Th\ inlet - Tc\ inlet)}$

$\dot{m}_h \times C_{p,h} > \dot{m}_c \times C_{p,c}$, $\varepsilon = \frac{(Tc\ outlet - Tc\ inlet)}{(Th\ inlet - Tc\ inlet)}$

Cmin and **Cmax** make no difference if it belongs to the cold or hot fluid. Effectiveness obey with dimensionless this is called **NTU**

$NTU = \frac{UAs}{Cmin} = \frac{UAs}{(mcp)min}$ **(equa3.4)**

NTU = number of transfer unit

U = The overall heat transfer coefficient

As = Heat transfer surface

As long as there is a larger surface there will be a larger amount of heat transfer coefficient.

$UA = NTU \times Cmin$ **(equ3.5)**

UA = the overall heat transfer coefficient multiplied by the surface.

NTU = number of transfer unit

$\mathbf{C_{min}}$ = smaller heat capacity rate

3.4 Product Subsystems and selection of Components

The figure shows the assembly of the project. As we can see there are various parts of the project including tank, pump, fitting, boiler, and controller. The base is the main part which is carrying all the parts. The Heat exchanger consists of two concentric tubes. Hot water flows through the internal tube and cooling water flows through the area lying between the internal and external tube. The exchanger has 6 thermocouples distributed strategically. There are 3 measures of hot water temperature (ST-2, ST-4, and ST-6) and 3 for measuring cold water temperature (ST-1, ST-3, and ST-5). The Controller is very important in our experiment and we can not operate our experiment without the controller. The Controller can be used to measure the temperature of the water tank through the PID in the software; it is limited to 60 C. Also, cold water is set by the control valve (AVR-2) on the base unit. Hot water flow is set by the pump's speed which is controlled in the software and by the bypass valve (AVR-1). Furthermore, points 1,2,3, and 4 in the figure represent the connections of the flexible tubes joining the exchanger to the base unit.

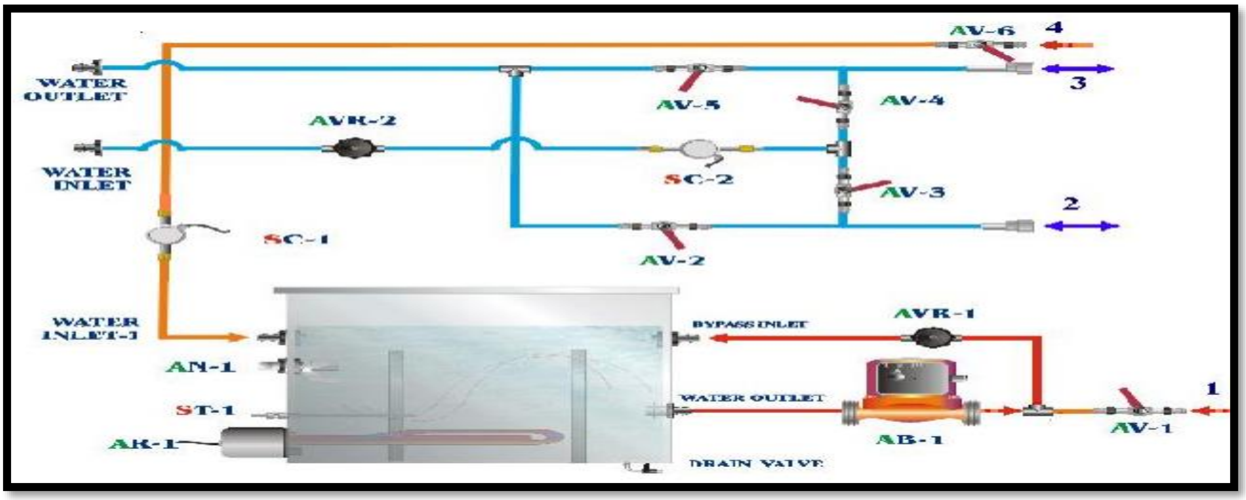

Figure (4): Exchanging heat Process.

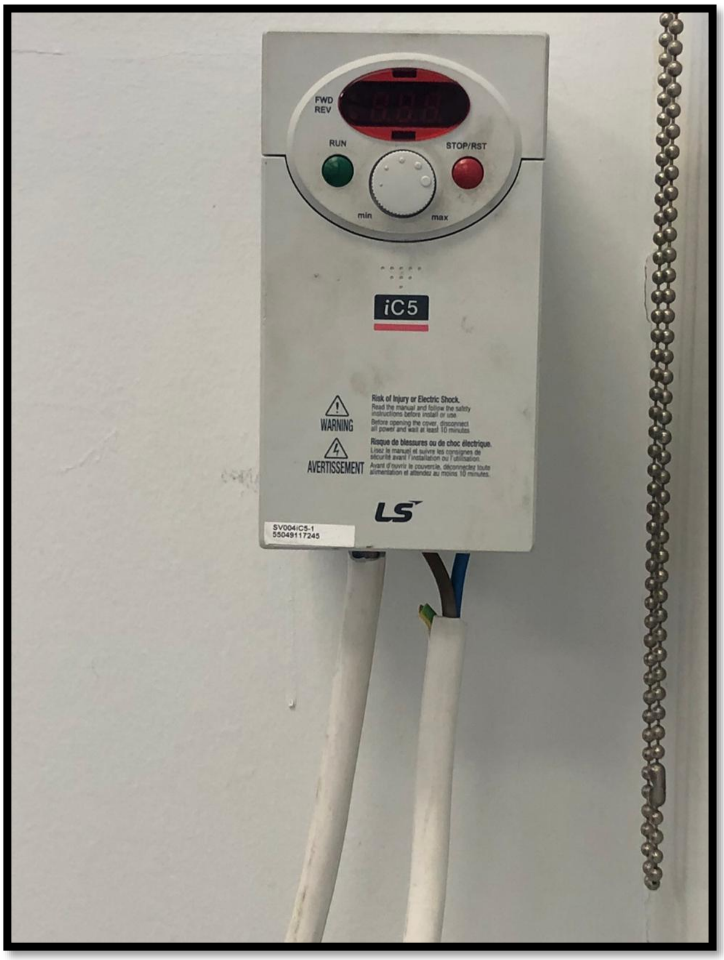

Figure (5): Cold flow rate Controller

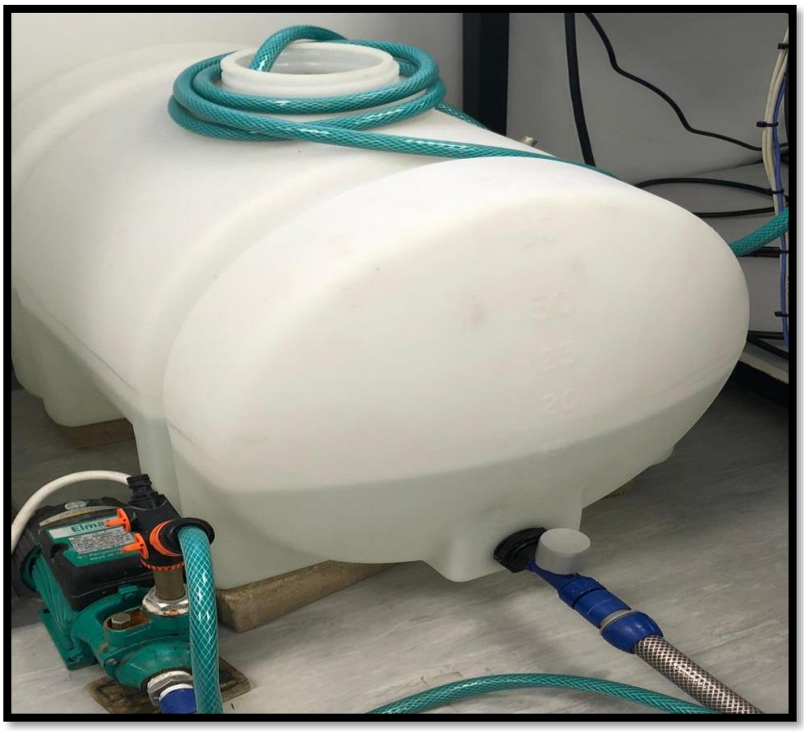

Figure (6): Cold fluid Tank (Distilled Water)

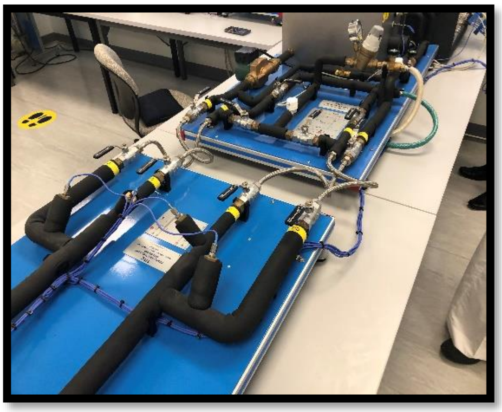

Figure (7): Base & Heat exchanger

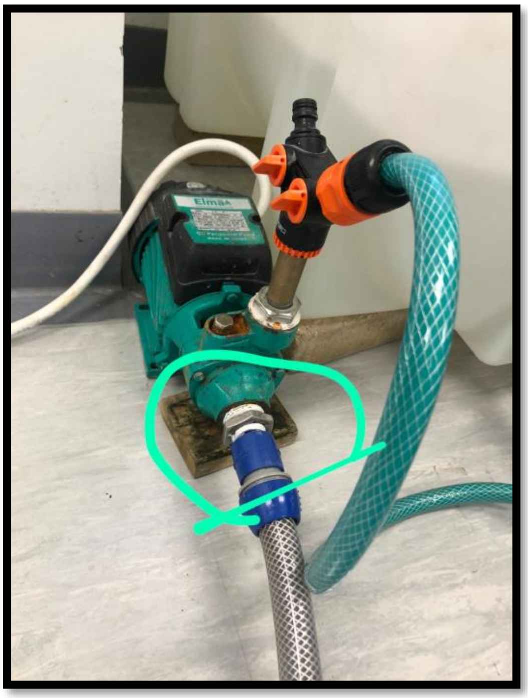

Figure (8): Cold Fluid Pump

3.5 manufacturing and assembly

Figure (9): Base Service Unit TIUS

The base service unit (TIUS) is made from stainless steel tank with a (30 l) size, provided with: Electric heating element that has a power of (3000 W) with a thermostat

(70 ºC), to heat the water, computer-controlled. PID temperature control. Temperature sensor ("J" type) to measure the temperature of the water. The Level controller it purpose is to adjust the level of the water in the tank. It has a stainless-steel cover to prevent any exposure to the hot water. There is a hole in this cover that allows us to see the water level and also to refill the tank. Draining water valve. Centrifugal pump with speed control from computer, range: 0 – 3 l/min. Two flow sensors, one for hot flow and the other for cold flow, range: 0.25 – 6.5 l/min. Control valves for the cold and hot flow. There are four ball valves that, depending on how we manipulate them, give us co-current or counter-current flux in the exchanger. Also, there are four flexible tubes to connect with different exchangers.

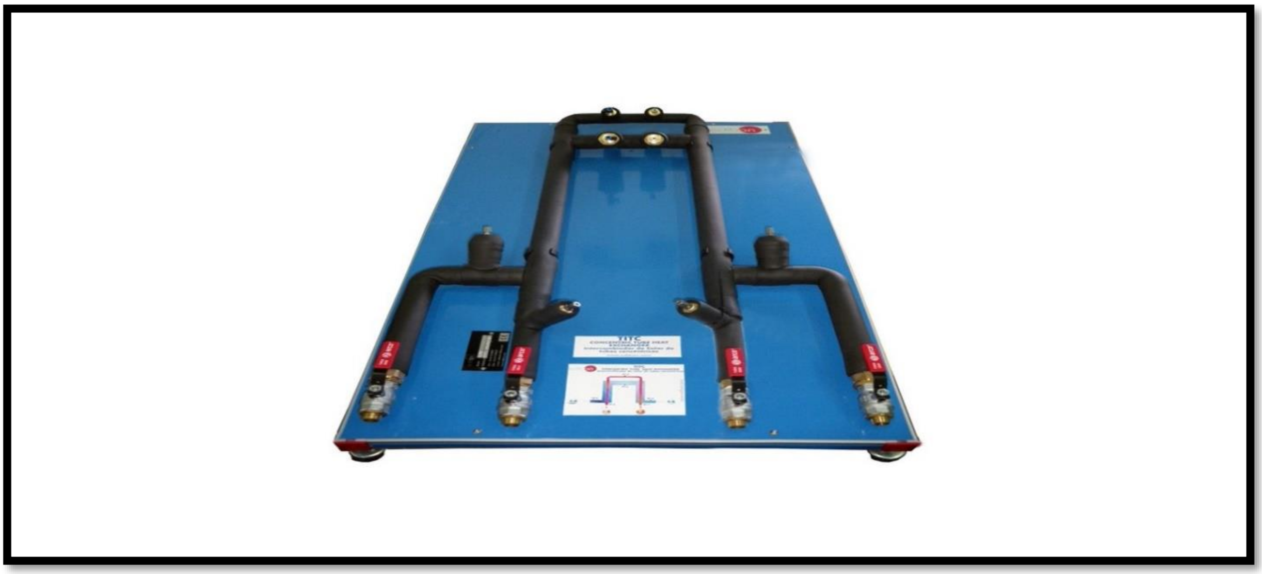

Figure (10): Concentric Tube Heat Exchanger for TICC

The TICC exchanger allows measuring hot and cold-water temperatures at different points of the exchanger. This type of heat exchanger is consisting of two concentric tubes, one is for the hot water circulating through the inner tube, the other for cold water which is the outer tube, and it has a ring-shaped area. This exchanger has two sections with the same length of 500 mm for each, where heat transfer takes place. Exchanger length: **$L = 2 \times 0.5 = 1$ m**, Internal tube: Internal diameter: **$D_{in} = 16 \times 10^{-3}$ m**, external diameter: **$D_{out} = 18 \times 10^{-3}$ m**. **Thickness = 10 m^{-3}**, heat transfer internal area: **A_h = 0.0503 m^2**, heat transfer external area: **A_c = 0.0565 m^2**, external tube: Internal diameter: **D_{int} =26 × 10^{-3} m**, external diameter: **D_{ext} = 28 × 10^{-3} m**, Thickness = 10^{-3} m and Six temperature sensors ("J" type): Three temperature sensors for measuring cold-water temperature: Cold-water inlet. Cold-water mid-position. Cold-water outlet. Three temperature sensors for measuring hot water temperature: Hot water inlet, hot water mid-position, and hot water outlet.

Chapter 4
System Analysis & Testing

4.1 Experimental Setup, Sensors, and data acquisition system.

In this part, the experimental setup was fabricated with the following equipment:

1. Concentric-tube of a counter-parallel flow heat exchanger.
2. Nanofluid (TiO_2) and hot water circulation units.
3. Heating unit for hot water.
4. Temperature measurement sensors.
5. Flow measuring sensors.
6. Flow controller.

The concentric-tube exchanger is provided with a length of 1000 mm. the inner brass pipe has an inner diameter of 16 mm and an outer diameter of 18 mm. the outer tube is made with brass with an inner diameter of 26 mm and an outer diameter of 28 mm.

The nanofluid circulation system is composed of the following items, tank, pump with bypass line, controller, flow sensor, fittings, frozen bottles, and heat transfer part. The pump is used to pump the nanofluid through the cold circuit. The Controller is used to adjust the speed of pump at a certain flow rate. Flow rate is acquired by the alteration of the return valve and measuring flow sensor. Fittings are used to make a connection between items. Frozen bottles were used to maintain the temperature of the nanofluid constant in the inlet section.

The hot water circuit system consists of the following elements, steel tank, pump with bypass line, flow sensor, and heat transfer section. Inside the steel tank, an electrical heater/resistance is used to heat the water to a certain temperature. Hot water leaves the steel tank and is driven by the pump into the heat exchanger. Flow rate is acquired by returning valve and measuring flow sensor.

Seven J-type thermocouples of 100 mm long and 4 mm in diameter were connected in the system. Six J-type thermocouples are used to measure inlet and outlet temperatures of hot water and nanofluid. One J-type was used to measure inlet and outlet temperatures of the hot water tank. However, the heat exchanger system was covered by a 10 mm thickness with insulation material to reduce heat loss.

4.2 Results, Analysis and Discussion.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1		T(h) in	T(h) Mid	T(h) out	T(c) out	T(C) Mid	T(c) in	Boiler	Hot Flow	Cold flow	C min	C max	C ratio	effectiveness
2	Time(s)	ST-1	ST-2	ST-3	ST-4	ST-5	ST-6	ST-16	SC-1	SC-2				
32	130	41.597188	38.72261	36.17984	22.61935	20.96204	19.53085	44.86788	2.554617	3.536516	0.17797165	0.2243691	0.793209	0.30950555
33	135	41.567502	38.70322	36.17701	22.61942	20.94672	19.51646	44.82108	2.568284	3.528568	0.17892379	0.2238648	0.799249	0.305856012
34	140	41.538188	38.67663	36.16104	22.59206	20.92359	19.49048	44.78988	2.56746	3.524394	0.17886638	0.2236	0.799939	0.304882065
35	145	41.518632	38.65888	36.12052	22.56598	20.92468	19.50441	44.70083	2.557852	3.533354	0.17819702	0.2241684	0.794925	0.308469572
36	150	41.522487	38.68457	36.13074	22.59025	20.93284	19.52505	44.66007	2.556874	3.522338	0.17812889	0.2234696	0.797106	0.3074975
37	155	41.512144	38.63887	36.10492	22.5651	20.92185	19.53889	44.54771	2.556571	3.54113	0.17810778	0.2246618	0.792782	0.310403424
38	160	41.520849	38.67629	36.11433	22.62224	20.9852	19.6327	44.44681	2.561435	3.523612	0.17844664	0.2235504	0.798239	0.309439408
39	165	41.514443	38.6453	36.09885	22.62258	21.01388	19.69514	44.35926	2.561376	3.52479	0.17844253	0.2236251	0.797954	0.311048236
40	170	41.529015	38.65859	36.1277	22.68968	21.10246	19.77595	44.33389	2.559072	3.5232	0.17828202	0.2235242	0.797596	0.311312073
41	175	41.51772	38.64373	36.09031	22.7324	21.17275	19.8217	44.32229	2.556654	3.527827	0.17811356	0.2238178	0.795797	0.314347467
42	180	41.557425	38.67455	36.14561	22.8293	21.2357	19.89657	44.39748	2.557995	3.527367	0.17820699	0.2237886	0.796318	0.313747799

Figure (11): 1% mass fraction – 1.5 (l/min) – Counter flow

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1		T(h) in	T(h) Mid	T(h) out	T(c) out	T(C) Mid	T(c) in	Boiler	Hot Flow	Cold flow	C min	C max	C ratio	effectiveness
2	Time(s)	ST-1	ST-2	ST-3	ST-4	ST-5	ST-6	ST-16	SC-1	SC-2				
32	135	42.94005	40.87749	38.90614	27.99138	25.79342	23.4435	45.05777	2.555509	1.522632	0.096601	0.178034	0.5426	0.429903602
33	140	42.96891	40.89618	38.93715	28.00846	25.82006	23.44153	45.12914	2.546706	1.511044	0.095866	0.177421	0.540332	0.432832394
34	145	42.96161	40.90785	38.94049	28.03876	25.83883	23.45779	45.18052	2.552511	1.509969	0.095798	0.177825	0.53872	0.435988525
35	150	42.93726	40.89858	38.91558	28.06148	25.8559	23.48441	45.16455	2.555311	1.514709	0.096098	0.17802	0.539818	0.435869041
36	155	42.89114	40.88182	38.92378	28.08534	25.89379	23.48703	45.06565	2.558175	1.513364	0.096013	0.17822	0.538735	0.439875233
37	160	42.86266	40.86001	38.90713	28.07351	25.90956	23.52993	44.95493	2.542979	1.514892	0.09611	0.177161	0.542502	0.433215304
38	165	42.81489	40.86258	38.93062	28.13734	25.95804	23.57216	44.87242	2.552574	1.514018	0.096055	0.177829	0.540151	0.439214162
39	170	42.80133	40.81772	38.87307	28.15182	25.95042	23.57017	44.79251	2.548375	1.521615	0.096537	0.177537	0.543756	0.43813965
40	175	42.77273	40.81948	38.86365	28.16148	25.97535	23.60658	44.71732	2.562802	1.520156	0.096444	0.178542	0.540176	0.43995555
41	180	42.74334	40.78413	38.82155	28.16599	25.97965	23.60375	44.64078	2.541389	1.513016	0.095991	0.17705	0.542169	0.439653617
42	185	42.77109	40.79457	38.81187	28.17609	25.98494	23.62655	44.65006	2.556439	1.517243	0.096259	0.178099	0.540483	0.439684142

Figure (12): 1% mass fraction – 3.5 (l/min) – Counter flow

This is a short sample of the results. However, in this part, we are interested in knowing the relationship between the heat capacity ratio and effectiveness. We can observe from the above data, efficiency increases when heat capacity ratio decrease and vice versa, that means they have a non-proportional relationship.

Figure (13): Concentric-tube heat exchanger

Figure (14): Nanofluid circulation system

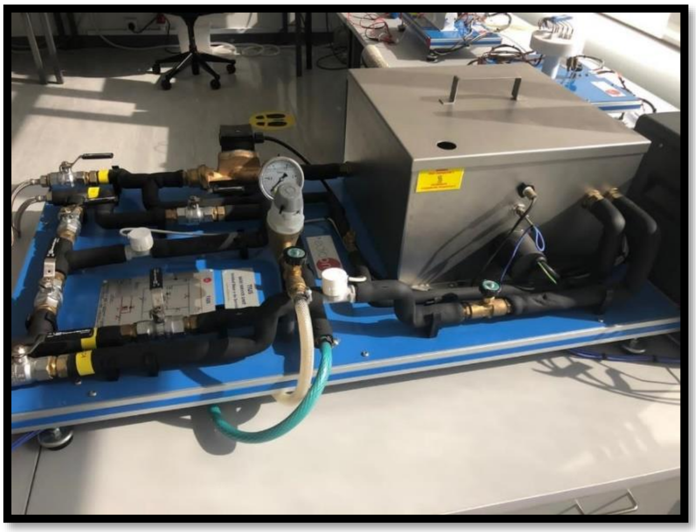

Figure (15): Heating unit

Figure (16): Cold flow rate Controller

Chapter 5
Project Management

5.1 Project Plan

Our Project includes several tasks distributed between the team members. Each task is given to one or more members to be done. Here is table 5.1 to see the tasks and duration while table 5.2 shows the assigned members.

Table (5): Tasks and their durations

#	Tasks		Start	End	Duration
1	Chapter 1: Introduction		23/09/2020	26/09/2020	4
2	Chapter 2: Literature review	Project Background	27/09/2020	02/10/2020	6
		Previous Work			
		Comparative Study			
3	Chapter 3: System Design	Design Constraints and Design Methodology	03/10/2020	29/10/2020	27
		Engineering Design standards			
		Theory and Theoretical Calculations			
		Product Subsystems and selection of Components			
		Manufacturing and assembly			
4	Chapter 4: System Testing & Analysis	Experimental Setup, Sensors and data	30/10/2020	12/11/2020	14
		Results, Analysis and Discussion			

5	Chapter 5: Project Management	Project Plan Contribution of Team members Project Execution Monitoring Challenges & Decision Making Project Bill of Material & Budget	13/11/2020	26/11/2020	14
6	Chapter 6: Project Analysis	Life Long Learning Impact of Engineering Solution Contemporary Issues Addressed	27/11/2020	08/12/2020	12
7	Chapter 7: Conclusion & Recommendation	Conclusion Future Recommendation	09/12/2020	18/12/2020	10
8	Design of Prototype	Heat exchanger Fittings & lids Valves & Base	28/10/2020	15/11/2020	22
9	Parts Purchase		11/11/2020	18/11/2020	8
10	Testing		4/11/2020	26/11/2020	23

Table (6): Tasks and assigned members

#	Tasks	Assigned Members
1	Chapter 1: Introduction	Omar Rebhan
2	Chapter 2: Literature review	Khalid Alshamrani
		Turki Almatrook
		Khalid Alnajrani
3	Chapter 3: System Design	All
4	Chapter 4: System Testing & Analysis	Khalid Alnajrani
5	Chapter 5: Project Management	Omar Rebhan
6	Chapter 6: Project Analysis	Turki Almatrook
		Hussain Al-Malack
		Khalid Alshamrani
7	Chapter 7: Conclusion & Recommendation	Hussain Almalack
		Turki Almatrook
8	Design of Prototype	Omar Rebhan Khalid Alshamrani
9	Parts Purchase	All
10	Testing	All

5.2 Contribution of Team Members

Project tasks are assigned to one or more members according to the ability to do the task or the skills that members have in specific tasks. In table 5.3, we will show the tasks and the contribution percentage of each member.

Table (7): Tasks the contribution of the members

#	Tasks		Assigned	Cont.%
1	Chapter 1: Introduction		Omar Rebhan	100 %
2	Chapter 2: Literature Review	Project Background	Khalid Alshamrani	34%
		Previous Work	Turki Almatrook	33%
		Comparative Study	Khalid Alnajrani	33%
3	Chapter 3: System Design	Design Constraints and Design Methodology	Omar Rebhan	20%
		Engineering Design Standards	Khalid Alnajrani	20%
		Theory and Theoretical Calculation	Turki Almatrook	20%
		Product Subsystems and selection of Components	Khalid Alshamrani	20%
		Manufacturing and assembly	Hussain Al-Malack	20%
4		Experimental Setup, Sensors and data	Khalid	100%

	Chapter 4: System Testing & Analysis	Results, Analysis and Discussion	Alnajrani	
5	Chapter 5: Project Management	Project Plan	Omar Rebhan	100%
		Contribution of Team members		
		Project Execution Monitoring		
		Challenges & Decision Making		
		Project Bill of Material & Budget		
6	Chapter 6: Project Analysis	Life Long Learning	Turki Almatrook	34%
		Impact of Engineering Solution	Hussain Al-Malack	33%
		Contemporary Issues Addressed	Khalid Alshamrani	33%
7	Chapter 7: Conclusion & Recommendation	Conclusion	Hussain Al-Malack	50%
		Future Recommendation	Turki Almatrook	50%
8	Design of Prototype	Heat exchanger Fittings & lids Valves & Base	Omar Rebhan Khalid Alshamrani	50% 50%
9	Parts Purchase		All	100%
10	Testing		All	100%

5.3 Project Execution Monitoring

while we were working on our project, we had many duties and activities to enhance our project. These activities include meetings, experiments, and some important duties for the project during Fall semester 2021. Table 5.4 will present the activities list of the project.

Table (8): Dates of the activates and events

Time/Date	Activities/Events
One time a week	Assessment class
Weekly	Meeting with group members
Biweekly	Meeting with the advisor
25 Oct 2020	Finishing first prototype
12 Nov 2020	Midterm presentation
4 Nov 2020	First test of the system
19 Nov 2020	Finishing final prototype
24 Nov 2020	Test the system
18 Dec 2020	Final Submission of the report
17 Dec 2020	Final presentation

5.4 Challenges and Decision Making

During this project, we faced some difficulties that may form obstacles to complete doing our experiments. The below problems are the main challenges that we have faced:

1) Equipment and devices problems.
2) Testing issues.

5.4.1 Equipment and devices problems

We used several devices and tools in our project. However, we succeed in solving some technical problems that happened during the conduction of the experiments. Those problems we found out are related to the Nano-fluid use and one of the sensors.

- Nano-fluid (TiO_2).

In Nano-fluid experiments, we discovered that the data given by the TITC software is much better comparing with using water in the whole experiments, especially in the efficiency. Nano-fluid when it goes inside the pipes, it sticks. That may obstruct the flow of cold fluid inside the tubes.

- Cold fluid Sensor.

The cold fluid consists of cold distilled water mixed with a certain amount of nano-fluid. During entering the cold fluid into the pipes loaded with nano-particles, those particles stick on the sensors which gives us wrong readings for the cold flow rate (L / min). We solved this problem by cleaning the pipes using tube water then repeat the experiments.

5.4.2 Testing issues

At the beginning of our experiments, we used distilled water without Nano-particles to make sure that the equipment is installed well. We did a test on the heat exchanger and found out that the temperatures for the cold and the hot fluid are close to each other. Thus, we decided to put frozen water bottles inside the tank to decrease the cold in and out temperatures. Then, we repeated the procedure and we got better results before starting the Nano-fluid experiments.

5.5 Project Bill of Materials and Budget

The table below shows the parts and materials needed to run our projects and their costs in Saudi Riyals (SR).

Table (9): Bill of Materials

Part / Material	Cost (SR)
Nano-fluid (TiO_2) – 500 ml	1500 SR
Pump 1 HP	350 SR
Hose	54.50 SR
Hose Couplings (2 pieces)	98.50 SR
Hose Connectors (2 pieces)	43.50 SR
Adapter (4 pieces)	30 SR
Brass Nipple	10.44 SR
CPVC Male Adaptor 1 Brass (2 Pieces)	10 SR
CPVC Male Adaptor 3/4 Brass	4 SR
CPVC Bushing 1 (2 Pieces)	4 SR
CPVC Coupling ¾	4 SR
CPVC Glue original 1/8 LTR	13.04 SR
Total	**2121.98 SR**

Chapter 6
Project Analysis

6.1 Life-long Learning

Working on a project such as heat exchangers can be ended with a variety of knowledge about the skills required to do a successful project. During project time we achieve a higher level of time management, decision-making, and cooperating to reach the most appropriate scientific for ideal work. This part will illustrate all the skills and knowledge we have gained during project time.

6.1.1 Software Skills

In our project, we have gained skills from some software, like Solid Work and Microsoft Excel. As it is known these two programmed have been used many times, but during the project, we have used them at an advanced level. To demonstrate, in Microsoft Excel we have used some complex way for applying many equations to gathering thousands of data.

6.1.2 Negotiation and Persuasion Skills

During our project, we had to make a decision about the appropriate components specification to reach a perfect prototype. Selecting a pump that can handle nanoparticles was a bit hard until we have contact with an expert to ensure the pump will not have a leakage and flow rate problem. The attention of that point provides us any possible loss of nanoparticle that is hard to get and expensive.

6.1.3 Project Management

In our project, we agreed to avoid any random work from the beginning. Because our project mostly stands for hundreds of experiments that take time, we have decided to be two groups scheduled as a day working and a day off. While the day off the group has to analyze the data to ensure there are no unusual and wrong results.

6.2 Impact of Engineering Solutions

Heat exchangers have various impacts in terms of economy, and environment whether it is a positive or negative impact. In this section, we will be discussing the impacts of the heat exchanger and the use of Nano-fluid in it.

6.2.1 Economically

The benefit of using heat exchangers economically wise that they don’t need additional equipment, such as air conditioning or air compressing unit to fully operate. And using the Nano-fluid will increase the efficiency without additional equipment.

6.2.2 Environmentally

Heat exchangers have a crucial role in pollution prevention and the decrease of the environmental effect of industrial processes, by reducing energy consumption or recovering energy from processes in which they are used.

Heat Exchangers are used: [5]

1- In pollution prevention or control systems that decrease volatile organic compounds (VOCs) and other air pollutant emissions.

2- in systems that decrease pollutants in wastewater discharges, the amount of discharge, and thermal pollution.

3- used to recover energy in facilities that incinerate municipal solid waste and selected industrial hazardous wastes. Heat exchangers are also used in the heating, cooling, and concentration of process streams that are part of many other pollution prevention or control-related processes.

6.3 Contemporary Issues Addressed

In Saudi Arabia, we face serious environmental issues which are Desertification, Air pollution, Water pollution. The First issue is air pollution in Saudi Arabia originally comes from crude oil that can lead to an effect on the human body. As a result, air pollution in Saudi Arabia also affects desertification because of the increasing temperature. The Second issue, desertification in Saudi Arabia is a major problem.

About 98% of Saudi Arabia's land-mass is desert According to UNCCD (United Nations Convention to Combat Desertification). This is not only Saudi Arabia's problem, but every country in the Arab region is also facing the problem of desertification. Desertification decreases food production on large scale, especially the production of crops. Therefore, Saudi Arabia is highly dependent on imports for its food [4]. The Third issue, air pollution in Saudi Arabia affects the health and life of man, animals, and plants alike. Polluted water is also harmful to agriculture as it adversely affects the crops [6].

Chapter 7

Conclusions and Future Recommendations

7.1 Conclusions

Projects benefit the people and assist them in their lives. From this project, the team gained communication skills, gained experience in the field of our study, and learned many things related to heat exchangers. Moreover, the project had good results outcome and boosted our confidence to do more projects. our project consists of various areas of engineering including; fluid mechanics, thermodynamic, and heat transfer which helped us improve our knowledge in these areas. Also, we improved our skills regarding engineering software such as SolidWorks, and how to operate heat exchangers. The team faced a couple of challenges through the project, and that helped us improve. The team faced an issue with the temperature measurement sensor after using the nano-fluid, the sensors stopped working due to the nano fluid. So, we had to clean the pipes with water in order to clean the sensors from the nano-fluid that stuck in them.

7.2 Future Recommendations

As we have concluded with our project in a way that followed by the advisor, there are some elements that can help others to avoid any inapposite layout or technical issue in the future. The first idea is to deal with more amounts of nanoparticles each time we use a different volume for a different experiment so, when the experiment is completed the nanoparticle will stick on the sensor, which leads to incorrect data. The second recommendation is to use a more effective way to cool down the cold-water tank instead of using frozen bottles; this can be reached by using an air conditioner, which will help to set up the inlet cold temperature as required.

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Appendix A: Monthly Progress Reports

	SDP – Monthly MEETING REPORT
	Department of Mechanical Engineering **Prince Mohammad bin Fahd University**

SEMESTER:	**Fall**	**ACADEMIC YEAR:**	**2020 / 2021**
PROJECT TITLE	**Title design of experiments to study the performance of Concentric Tube Heat Exchanger**		
SUPERVISORS	**Dr. Essam Jassim**		

Month: October

#	ID Number	Member Name
1	Khalid Alnajrani	201602350
2	Omar Rebhan	201602958
3	Turki Almatrook	201602430
4	Khalid Alshamrani	201502449
5	Hussain Almalack	201600661

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	Abstract & Acknowledgment	2	100%	
2	Chapter 1 and 2	All	100%	
3	Parallel & Counter flow Experiments (Water)	All	100%	
4	Calculation related to the Water experiments	1,2 and 4	80%	
5	Chapter 3	All	100%	

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

#	Task description	Team member/s assigned
1	Midterm Presentation	All
2	Parallel flow Experiments (Nano-fluid)	All
3	Data collection	All
4	Result and discussion	All
5	Comparison between the experiments	All

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

Outcome MEEN4: an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
MEEN4A. Demonstrate an understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental and societal context	Fails to demonstrate an understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Shows limited and less than adequate understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Demonstrates satisfactory understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Understands appropriately and accurately the engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts

Outcome MEEN5: an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
MEEN5A: 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	Properly and efficently makes team work plans and allocate resources and tasks
MEEN5B: Ability to participate and function effectively in team work projects to meet objectives	Fails to participate and function effectively in team work projects to meet objectives	Shows limited and less than adequate ability to participate and function effectively in team work projects to meet objectives	Demonstrates satisfactory ability to participate and function effectively in team work projects to meet objectives	Function effectively in team work projects to meet objectives
MEEN5C: 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	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 (MEEN4A)	Criteria (MEEN5A)	Criteria (MEEN5B)	Criteria (MEEN5C)
1	Khalid Alnajrani	4	4	4	4
2	Omar Rebhan	4	4	4	4
3	Turki Almatrook	4	4	4	4
4	Khalid Alshamrani	4	4	4	4
5	Hussain Al-Malack	4	4	4	4

	SDP – Monthly MEETING REPORT
	Department of Mechanical Engineering **Prince Mohammad bin Fahd University**

SEMESTER:	**Fall**	**ACADEMIC YEAR:**	**2020 / 2021**
PROJECT TITLE	**Title design of experiments to study the performance of Concentric Tube Heat Exchanger**		
SUPERVISORS	**Dr. Essam Jassim**		

Month: November

#	ID Number	Member Name
1	Khalid Alnajrani	201602350
2	Omar Rebhan	201602958
3	Turki Almatrook	201602430
4	Khalid Alshamrani	201502449
5	Hussain Almalack	201600661

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	Chapter 4, 5 & 6	All	100%	
2	Purchase Parts	All	100%	
3	Parallel & Counter flow Experiments (Nano-fluid)	All	100%	
4	Calculation related to the Nano experiments	All	80%	

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

#	Task description	Team member/s assigned
1	Chapter 7	2
2	Create brochures, banner, and Poster	All
3	Prototype Demo	All
4	Final Report Submission	All
5	Final Presentation	All

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

Outcome MEEN4: an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
MEEN4A. Demonstrate an understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental and societal context	Fails to demonstrate an understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Shows limited and less than adequate understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Demonstrates satisfactory understanding of engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts	Understands appropriately and accurately the engineering professional and ethical standards and their impact on engineering solutions in global, economic, environmental, and societal contexts

Outcome MEEN5: an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
MEEN5A: 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	Properly and efficently makes team work plans and allocate resources and tasks
MEEN5B: Ability to participate and function effectively in team work projects to meet objectives	Fails to participate and function effectively in team work projects to meet objectives	Shows limited and less than adequate ability to participate and function effectively in team work projects to meet objectives	Demonstrates satisfactory ability to participate and function effectively in team work projects to meet objectives	Function effectively in team work projects to meet objectives
MEEN5C: 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	Communicates properly and effectively with team members

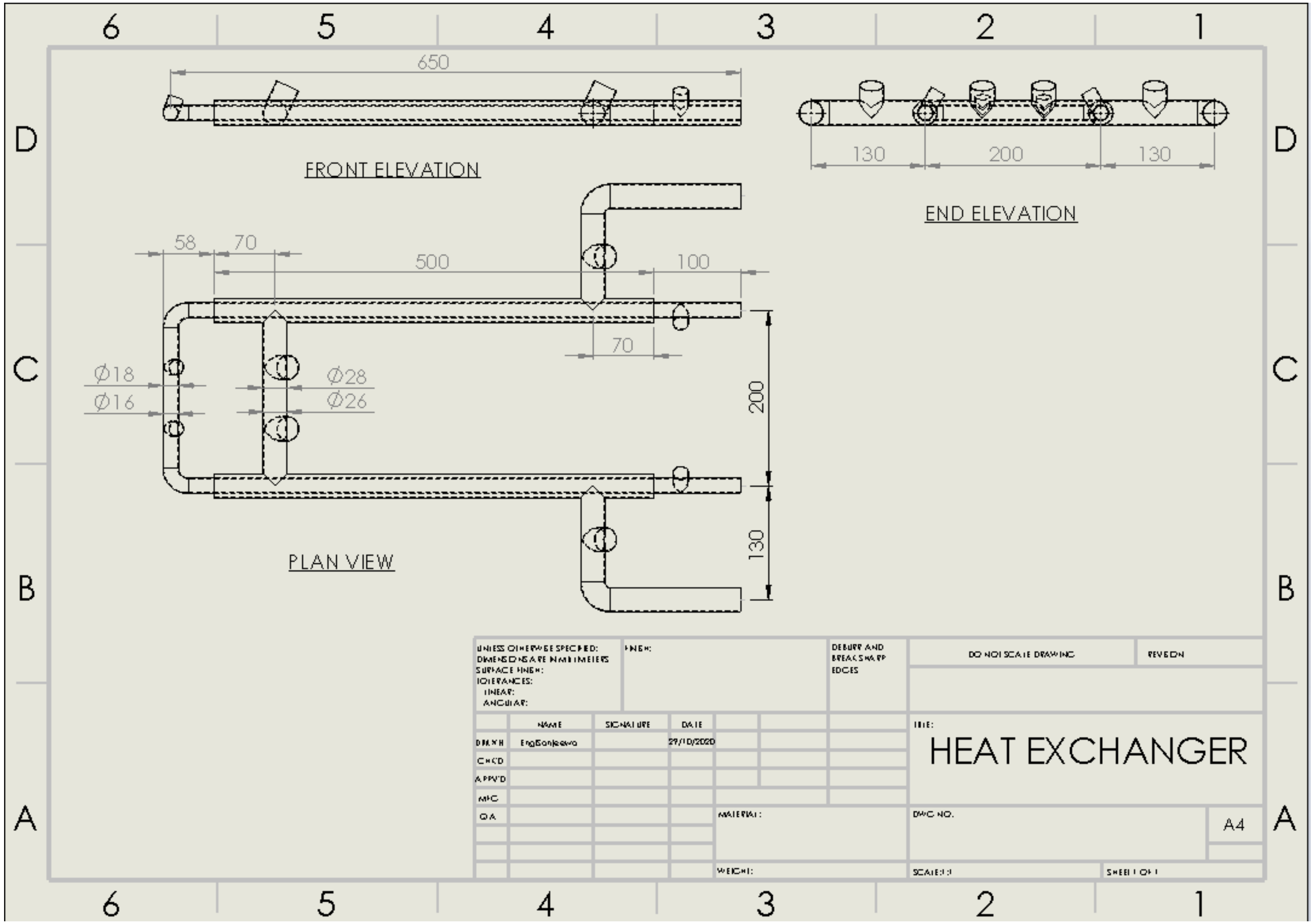
Indicate the extent to which you agree with the above statement, using a scale of 1-4 (1=None; 2=Low; 3=Moderate; 4=High)

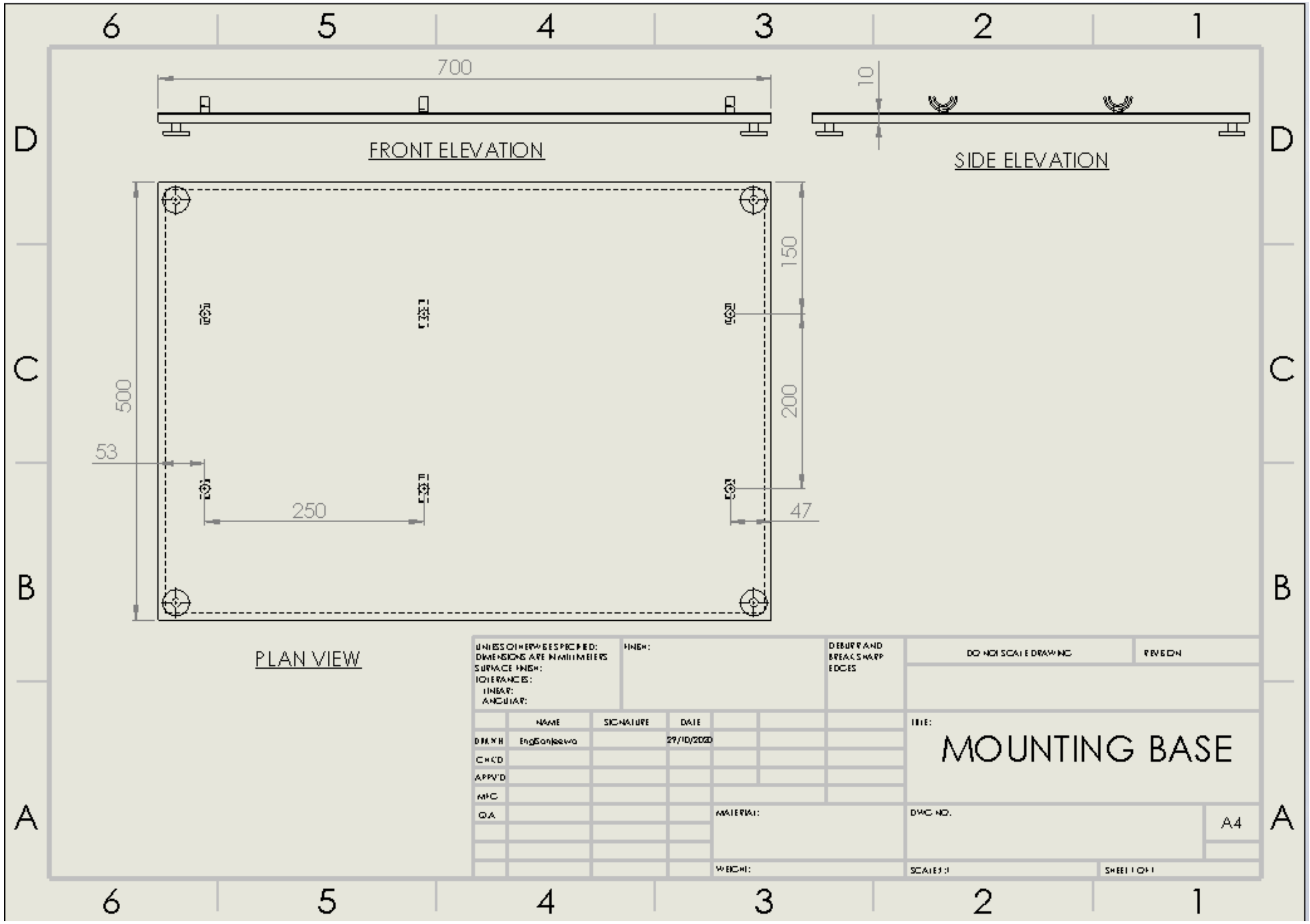
#	Name	Criteria (MEEN4A)	Criteria (MEEN5A)	Criteria (MEEN5B)	Criteria (MEEN5C)
1	Khalid Alnajrani	4	4	4	4
2	Omar Rebhan	4	4	4	4
3	Turki Almatrook	4	4	4	4
4	Khalid Alshamrani	4	4	4	4
5	Hussain Al-Malack	4	4	4	4

Appendix B: Engineering Standards (local and international)

Component	Engineering standards
Heat exchanger	ISO9001
Tank	AS/NZS 4766
Pump	PTC 8.2 - 1990
Boiler	ASME B31.1
fittings	ASTM D2846
controller	ASME A112.18.1
Flow sensors	PTC 19.5 – 2004(R2013)

Appendix C: CAD drawings and Bill of Materials

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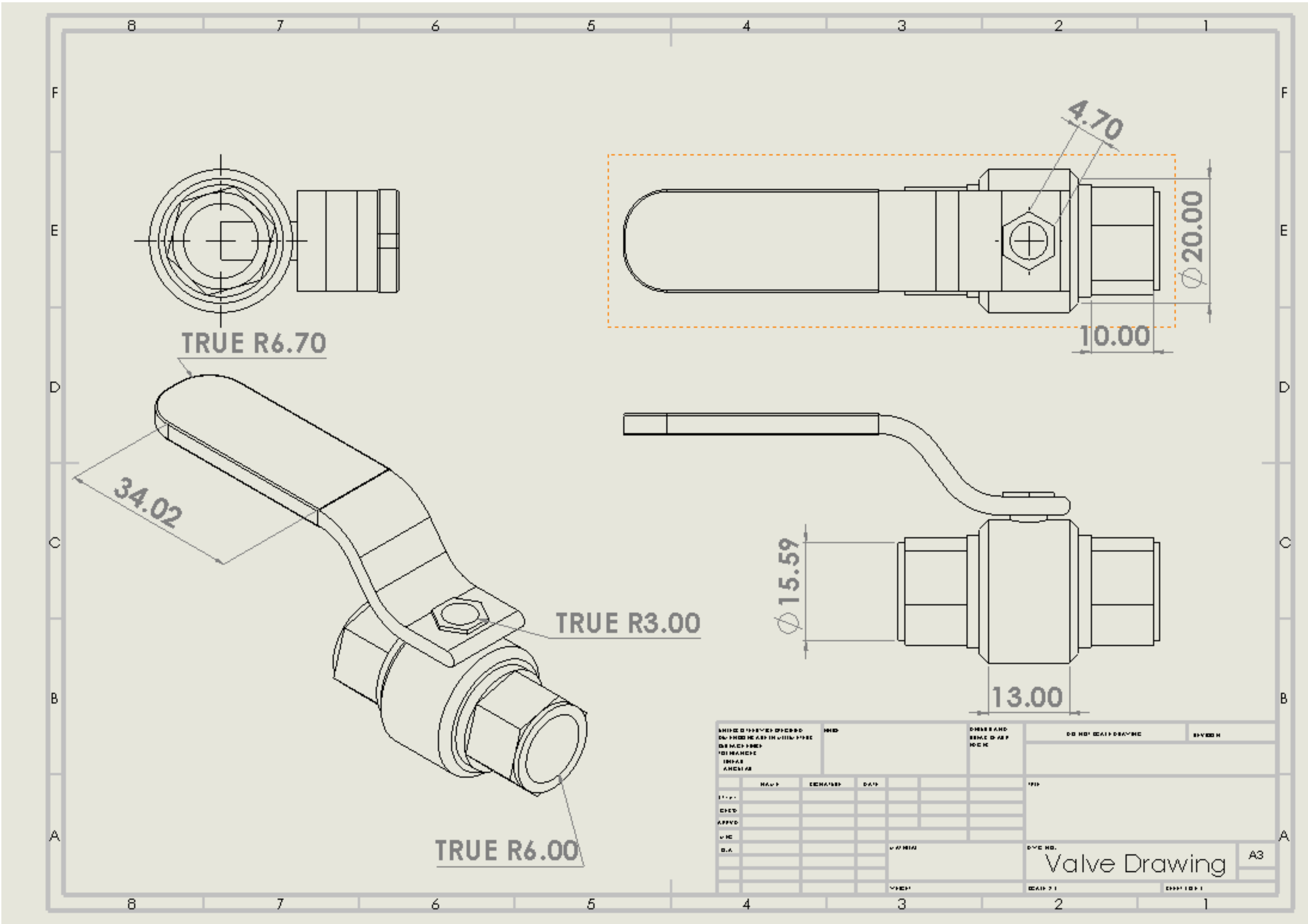
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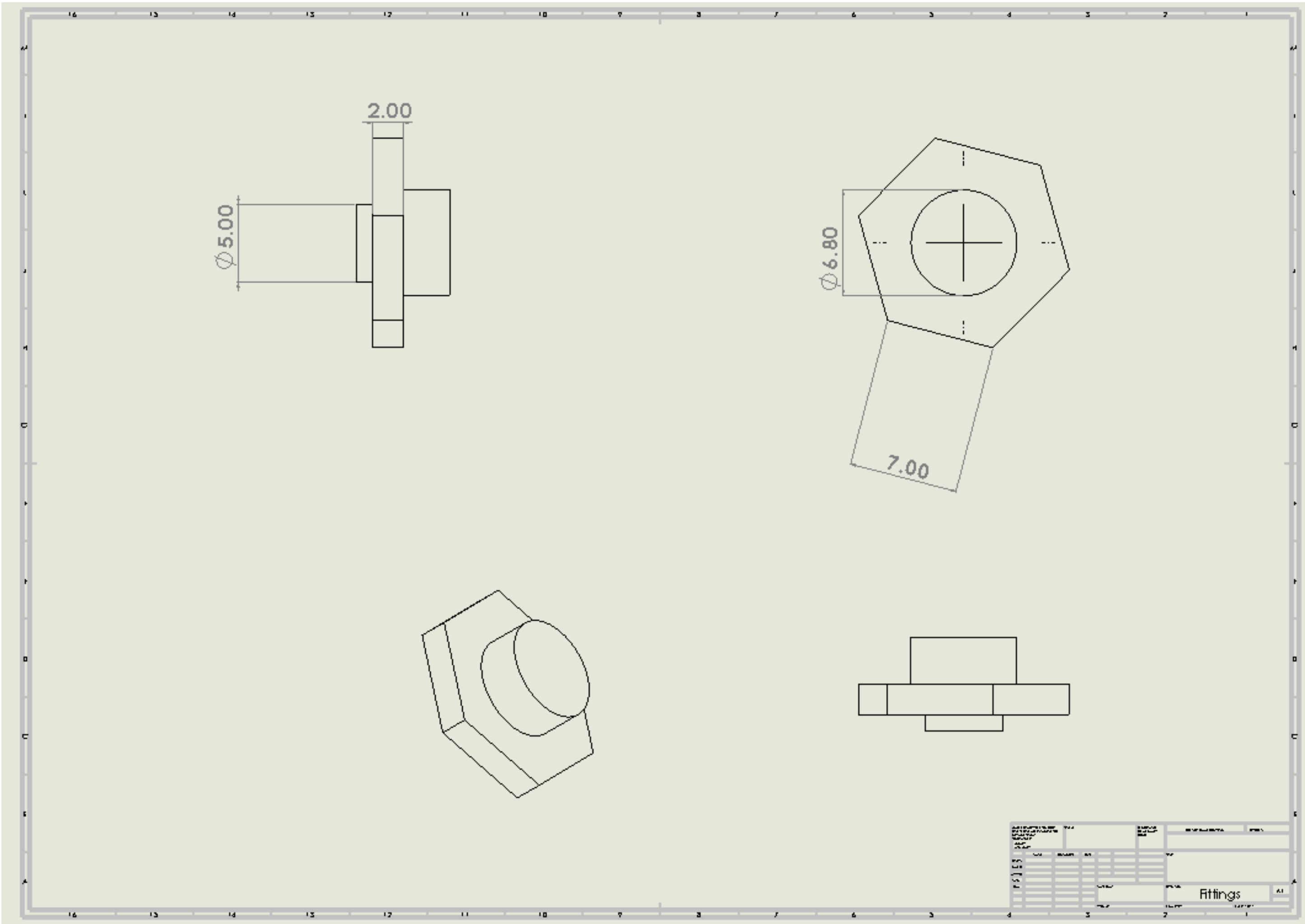
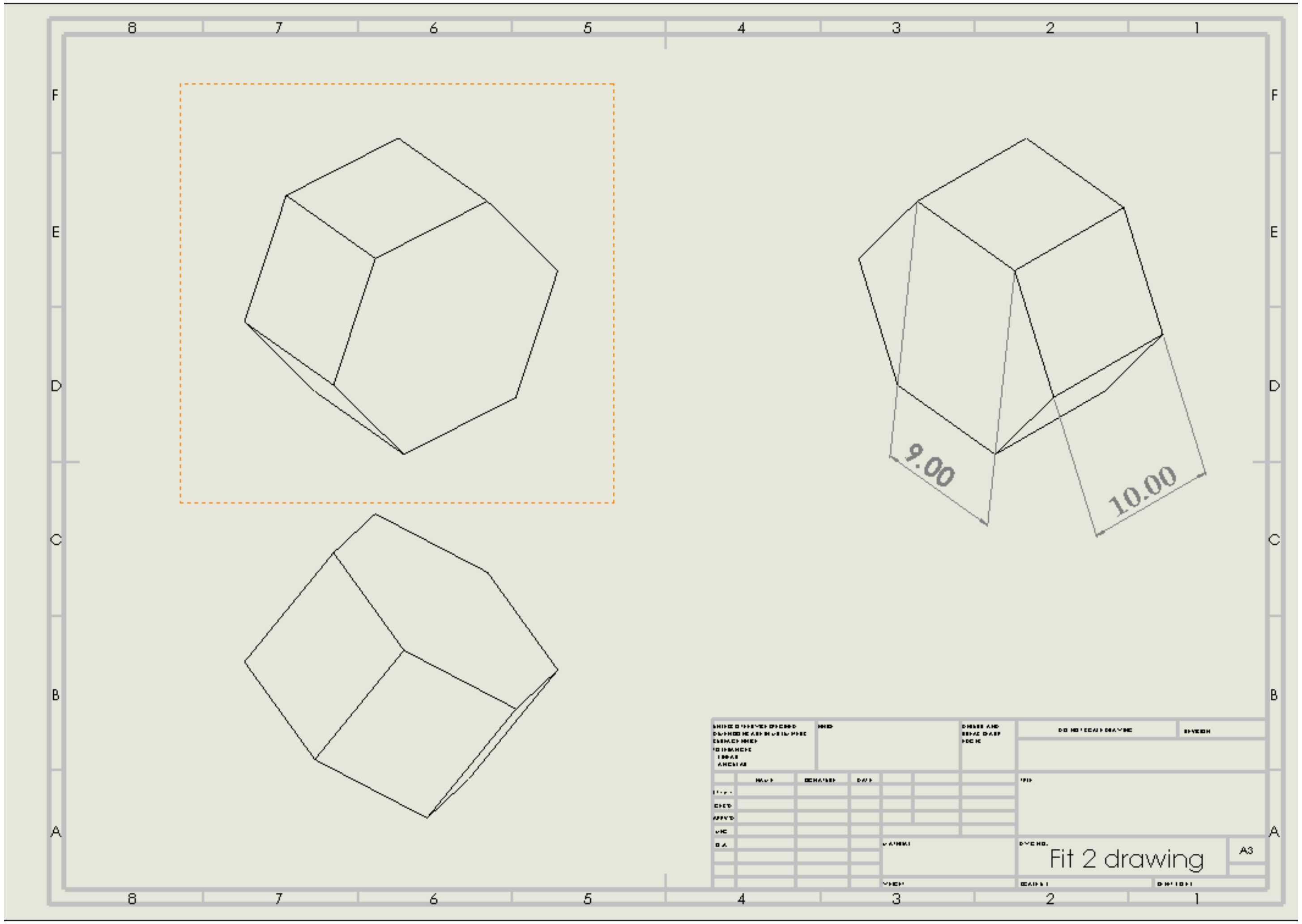
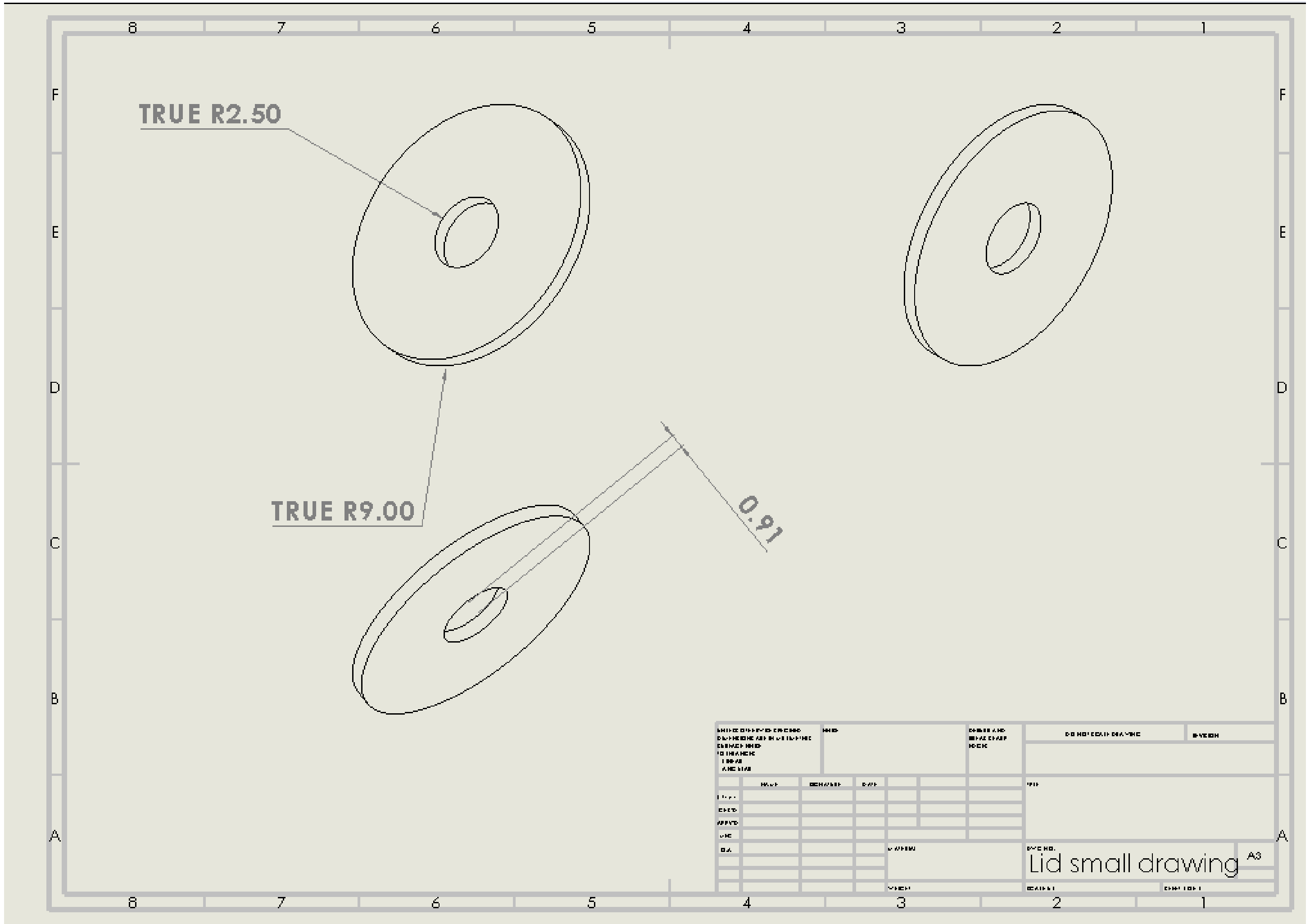
Valve Drawing
A3

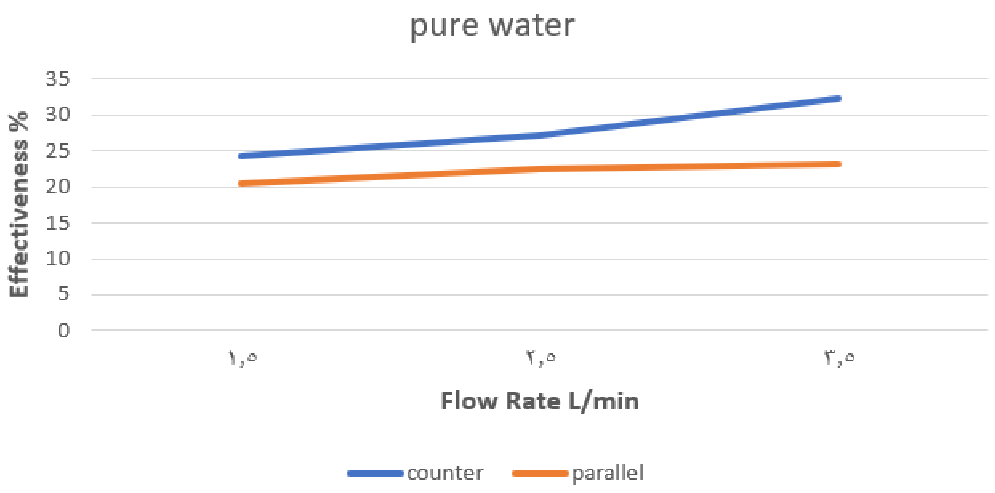

2.00
Ø5.00
Ø6.80
7.00
Fittings


9.00
10.00
Fit 2 drawing
A3


TRUE R2.50
TRUE R14.00
0.91
Lid Large drawing
A3


TRUE R2.50
TRUE R9.00
0.91
Lid small drawing
A3

Appendix D: Datasheets

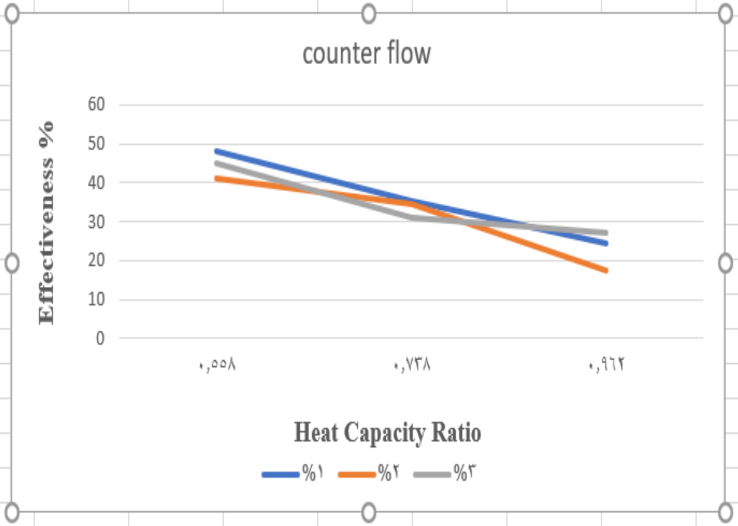


Heat capacity ratio	effectiveness
0.558056065	47.96574619
0.738130637	35.20505416
0.962202137	24.34409142
0.545222538	41.28095169
0.779718718	34.48050002
0.936251935	17.38900502
0.539265655	44.99637022
0.796744169	31.17227424
0.878517693	26.96214675

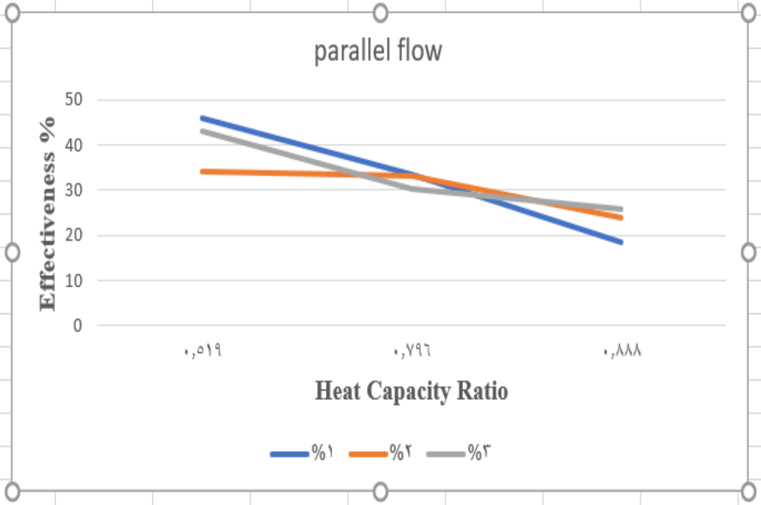
1% counter

2% counter

3% counter

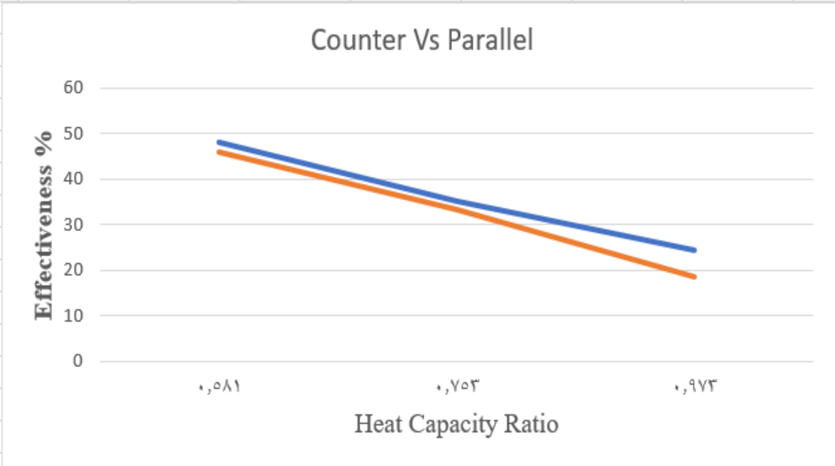


0.580535	45.90992	0.589898	34.0749	0.519295	42.96004
0.752734	33.43352	0.765103	33.05807	0.795601	30.20527
0.972994	18.41845	0.968407	23.8775	0.888357	25.66843



0.580535	45.90992	0.589898	34.0749	0.519295	42.96004
0.752734	33.43352	0.765103	33.05807	0.795601	30.20527
0.972994	18.41845	0.968407	23.8775	0.888357	25.66843

0.558056	47.96575
0.738131	35.20505
0.962202	24.34409
0.545223	41.28095
0.779719	34.4805
0.936252	17.38901
0.539266	44.99637
0.796744	31.17227
0.878518	26.96215



Appendix E: Operation Manual

To turn the prototype, the following steps should be followed:

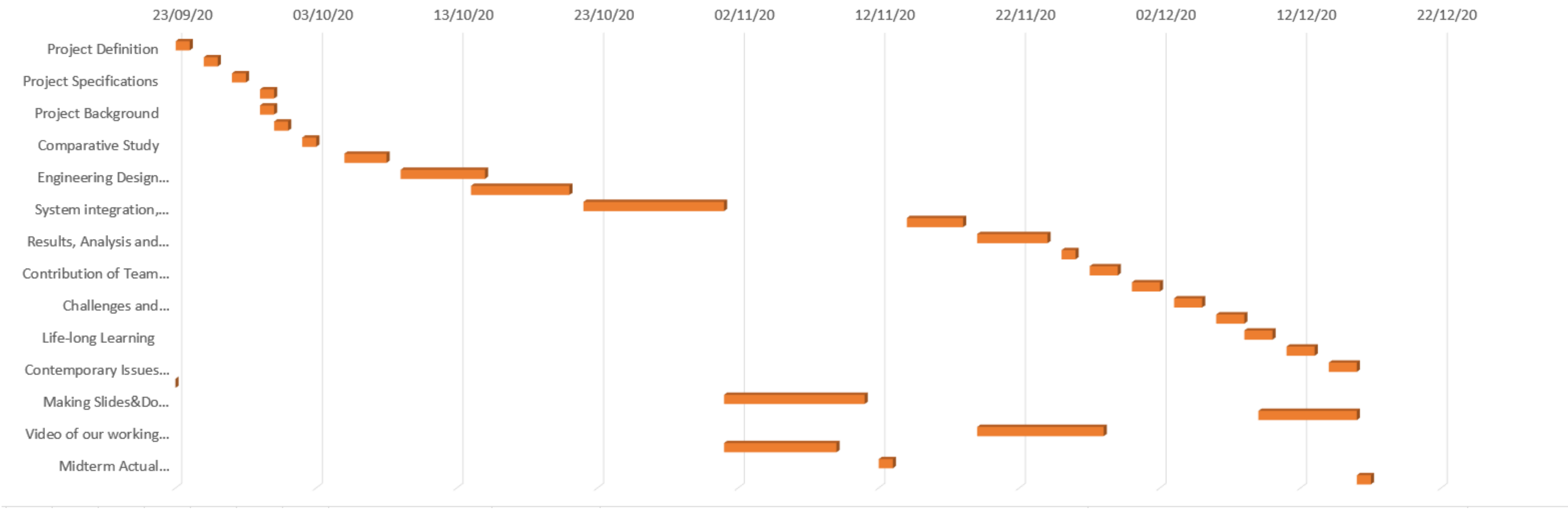
- Start on boiling the water until it reaches to 45^{O} C (ST-16).
- Turn on the heat pump on 7 then after 10-20 seconds we put it on 10.
- Observe ST-1 ($T_{\mathbf{hot,\ in}}$), ST-4 & ST-6 until it has a different to get more accurate data.
- Start on the cold flow rate Pump depends on the needed case 1.5, 2.5 or 3.5 (l/min).
- Click Take the data in the (TITC) Software to collect the data.
- Let it on for 5 minutes and make the data taken every 5 seconds.
- Turn off the pumps and start the next experiment.

The expected results from these processes are:

- Hot & Cold Temperatures (in & out Temperatures).
- Hot & Cold Flow rates (l/min).

Appendix F: Gantt Chart

Team 12 - Senior Project - Design of Experiments to study the performance of Concentric Tube Heat Exchanger				
Days To Complete	**Start Date**	**Tasks**	**Activity**	**Milestone**
1	23/09/20	Project Definition		
1	25/09/20	Project Objectives		
1	27/09/20	Project Specifications		
1	29/09/20	Applications	**Project allocation + Introduction**	
1	29/09/20	Project Background		
1	30/09/20	Previous Work		
1	02/10/20	Comparative Study	**Literature Review**	**Introduction**
3	05/10/20	Design Constraints & Design Methodology	**Design**	
6	09/10/20	Engineering Design Standards&Selected The Appropriate Items	**Equipment & Material selection**	
7	14/10/20	Main Calculations Required Detailed Calculations To Your Design	**Theory & Theoretical Calculations**	
10	22/10/20	System integration, describe , procedures and Implementation	**Prototype assemble**	**System Design**
4	14/11/20	Experimental Setup, Sensors and data acquisition system		
5	19/11/20	Results, Analysis and Discussion	**Testing & Analyses**	**ystem Testing & Analys**
1	25/11/20	Project Plan		
2	27/11/20	Contribution of Team Members		
2	30/11/20	Project Execution Monitoring		
2	03/12/20	Challenges and Decision Making		
2	06/12/20	Project Bill of Materials and Budget	**Project Management**	
2	08/12/20	Life-long Learning		
2	11/12/20	Impact of Engineering Solutions		
2	14/12/20	Contemporary Issues Addressed	**Project Analysis**	**anagement & Project**
7	11/09/20	Plan Of Project	**Gantt Chart**	
10	01/11/20	Making Slides&Do fake midterm presentation in online class room	**Midterm Presentation Preparation & Practice**	
7	09/12/20	Making Slides&Do fake final presentation in online class room	**Final Presentation Preparation & Practice**	
9	19/11/20	Video of our working prototype	**Prototype Completion**	
8	01/11/20	SDP05: Progress Report	**Monthly Progress Reports**	
1	12/11/20	Midterm Actual Presentation	**Midterm Presentation**	
1	16/12/20	Final Actual Presentation	**Final Presentation**	**Other**


23/09/20
03/10/20
13/10/20
23/10/20
02/11/20
12/11/20
22/11/20
02/12/20
12/12/20
22/12/20
Project Definition
Project Specifications
Project Background
Comparative Study
Engineering Design...
System integration,...
Results, Analysis and...
Contribution of Team...
Challenges and...
Life-long Learning
Contemporary Issues...
Making Slides&Do...
Video of our working...
Midterm Actual...