Design of a Mini Thermal Storage System for Air- Conditioning Service

by

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Dissertation submitted in partial fulfilment of

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Bachelor of Engineering (Hons)

(Mechanical Engineering)

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Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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Approved by,

(Ir. Dr. Shaharin Anwar Sulaiman)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

NIK MOHD RADI BIN NIK MOHAMED DAUD

ABSTRACT

Thermal energy storage is a system that distributes chilled water or other media to multiple buildings for air conditioning or other uses. Thermal Storage System systems are useful for maximizing the thermal energy efficiency for meeting the fluctuating cooling demands by shifting energy use from on peak to off-peak hours by charging the Thermal Storage Tank during the off-peak hours and discharging it later during the peak hour. For this reason, they are now receiving much attention among the world. Due to that, this project aims to get initial understanding about thermal storage system by design a mini thermal storage charging (during nighttime) and discharging (during daytime) for air-conditioning system. This report discusses about the background of this project regarding thermal storage operating strategy, system operation and design of mini thermal storage system. The project is based on the thermal storage system at Universiti Technologi PETRONAS's Gas District Cooling but simpler and smaller. An analysis also was conducted on storage tank to characterize the thermal storage tank.

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CHAPTER 1 – INTRODUCTION

1.1 Background of Study

Thermal Storage System for space cooling is a relatively mature technology that is continuously improving. It has its roots in early nineteenth-century schemes but the Colorado Automatic Refrigerator Company, which began operating in Denver in late 1889, built the first Thermal Storage System (Takasago, 2010).

A Thermal Storage System distributes chilled water or other media to multiple buildings for air conditioning or other uses. Cool storage technology can be used to significantly reduce energy costs by allowing energy-intensive, electrically driven cooling equipment to be predominantly operated during off-peak hours when electricity rates are lower. In addition, some system configurations result in lower first costs or lower operating costs.

Cool storage technologies come in many different forms, each with their pros and cons. The storage media is most commonly water (with "cold" stored in the form of ice, chilled water, or an ice/water slurry), but other media (most notably eutectic salts) have also been used. Chilled water is used in this project as the storage media. Storage media can be cooled (charged) by evaporating refrigerant or a secondary coolant (typically a water/glycol mixture). Discharge is usually accomplished directly via circulating water or indirectly via secondary coolant. At least one system has been developed that discharges storage via circulating refrigerant.

1.2 Problem Statement

In Malaysia or most country in the world, the demand for air conditioning in offices reaches a peak during daytime, and air conditioners are rarely used during night time. If equipment is prepared in proportion to such demand, the availability factor of such equipment remains low. For this reason, thermal storage system for air conditioning that produces and stores the heat needed for air conditioning during nighttime when the demand for air conditioning is small and utilizes the stored heat at a peak during daytime is now receiving much attention. With this thermal storage system, large air conditioning systems that are made proportional to the peak during daytime will be unnecessary, and the basic charge of electricity contract can be saved. Moreover, as the system produces and stores heat by using an inexpensive nighttime electricity service, overall running cost is lowered. As for students, study about thermal storage tank is important so that in the future the may use the information to contribute for our country. However, many students find it is hard to study about temperature distribution inside thermal storage tank without an experiment.

1.3 Objective and Significance of the Project

The objective of this project is to design a mini thermal storage tank for experimental use so students can a study on characterization of thermal storage charging and discharging for air-conditioning system. The aim of the project is to provide a system that can store the heat needed for air conditioning during off-peak low utility tariff periods (charging cycle) and utilizes the stored heat during on-peak utility tariff periods (discharging cycle).

1.4 Scope of study

The scope of study involves research and study more about the mini thermal storage design requirements and material selection for the system. A design concept and its material should be produced by the end of the first semester. Complete technical drawings of the system that are up to the codes of standards also will be developed by the end of the second semester.

CHAPTER 2 –LITERATURE REVIEW AND THEORY

2.1 Thermal Storage System

2.1.1 Types of Thermal Storage System

There are many types of thermal storage system that are used in whole world. Commonly, thermal storage system divides into chilled water, ice and molten salt. Chilled water storage system rely on the sensible heat capacity of water and the temperature difference between supply and return water streams going to and from the cooling load (Takasago, 2010) while in thermal energy storage using ice, it makes use of the large heat of fusion of water (EPSLTD, 2011). Molten salt can be employed as a thermal energy storage method to retain thermal energy collected by a solar tower or solar trough so that it can be used to generate electricity in bad weather or at night (Pacheco, 2009).

In chilled water thermal storage system, a single tank is usually used to store both the chilled water and the warm water returning from the cooling load. Separation of the two water layer is maximized by placing the cooler, denser water at the bottom of the tank and the warmer water at the top of the tank. Specially designed piping networks called diffusers allow water to enter and leave the tank without causing significant mixing. The result is a layer of cold water separated from a layer of warm water by a thermocline. The chilled water storage requires greater storage volume than for any of the ice or eutectic salt options. However, using water eliminates the need for secondary coolants and heat exchangers and standard water chillers can be used without significantly degraded performance or capacity.

In ice-based thermal storage system, ice become medium in store and discharge heat. There are many types of iced-based thermal storage system. One of them is ice-harvesting system where harvesting ice generators is use to separate the function of making ice and storing ice. The systems form ice on coils or other refrigerant evaporating surfaces and periodically release the ice into a storage tank that contains a mixture of ice and water (KNEBEL, 1986). Another type of ice-based thermal storage system is the ice-on-coil systems. Ice-on-coil systems come in several variations. In all variations, ice is formed on a heat transfer surface generically referred to as a "coil" without being released during the charging mode and melted away during the discharge mode (Takasago, 2010). Coils are packed in various arrangements within a tank and surrounded by water. Ice is formed by transferring energy from water to an evaporating refrigerant or secondary coolant by passing through the coils (Suparos, 2008). In ice slurry systems, it produces small particles of ice within a solution of glycol and water, resulting in a slushy mixture that can be pumped (Takasago, 2010). In ice slurry systems, ice particles are generated by passing a weak glycol/water solution through tubing that is surrounded by an evaporating refrigerant contained within a shell. As the glycol/water solution is cooled by the evaporating refrigerant, ice particles form (EPSLTD, 2011). The last type of ice-based thermal storage system is the encapsulated ice systems which consist of water contained in plastic containers surrounded by coolant, all contained within a tank or other storage vessel (Tsuchiya and Hasegawa, 2010).

2.1.1 Operating Strategy

The operating strategy determines when the thermal storage systems charge and discharge water to give maximum savings in operational cost (PG&EC, 1997). Strategies for operation at less than design loads include chiller priority and storage priority control (DTSi, 2010). The main aims is to capitalize on off-peak low utility tariff periods to charge the Chilled Water Storage tank and discharge during on-peak utility tariff periods to cool the building. This will reduce the numbers of chillers running on-peak period thus lowering electricity cost and maximum demand charges. Basically there are two main operating strategies to adapt to which are full storage system and partial storage system (PG&EC, 1997), referring to the amount of cooling load transferred from on-peak periods.

In the full storage system, maximum saving is achieved by fully utilizing the tank during on-peak period (Gilani and Majid, 2006). During on-peak period, chilled water is discharged from the tank to cool the building without running any chillers.

Prior to discharging the chiller water from the tank, it will first need to be charged and this is done usually at night when the utility rate at the lowest (TNB, 2011). Figure 2.1 shows the capacity vs time of day in full storage system (DTSi, 2010).

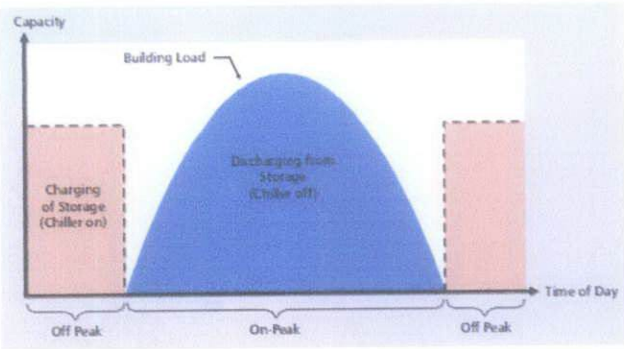


Figure 2.1: Full Storage System

Compare to the capacity vs time of day in partial storage system in Figure 2.2, full storage system requires more storage capacity and bigger plant equipment capacity thus incurring high capital cost investment compare to partial storage system.

In partial storage strategy utilizes both chiller and tank discharged to cool the building load at the same time (PG&EC, 1997, Gilani and Majid, 2006). Most of the building cooling load is met by discharging chilled water from the tank and utilizes little cooling from the chillers. This will give significant operation cost saving by using less number of chillers during on-peak period. Figure 2.2 shows the capacity vs time of day in partial storage system (DTSi, 2010). Compare to full storage system, partial storage system utilizes less storage capacity and smaller plant equipment thus lowering the capital cost investment of the system.

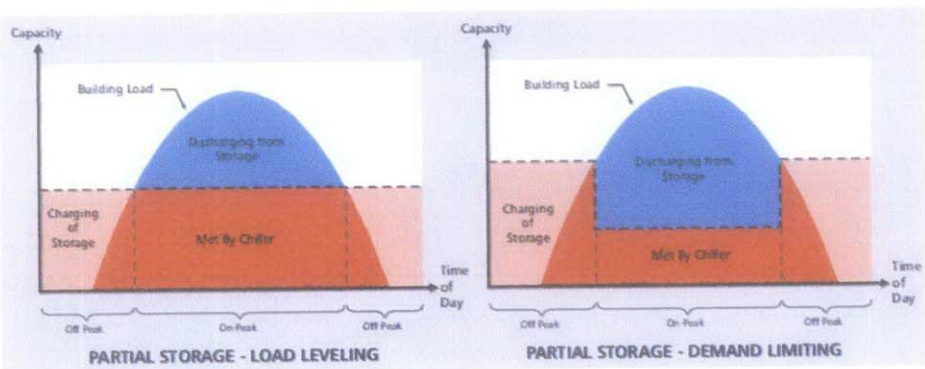
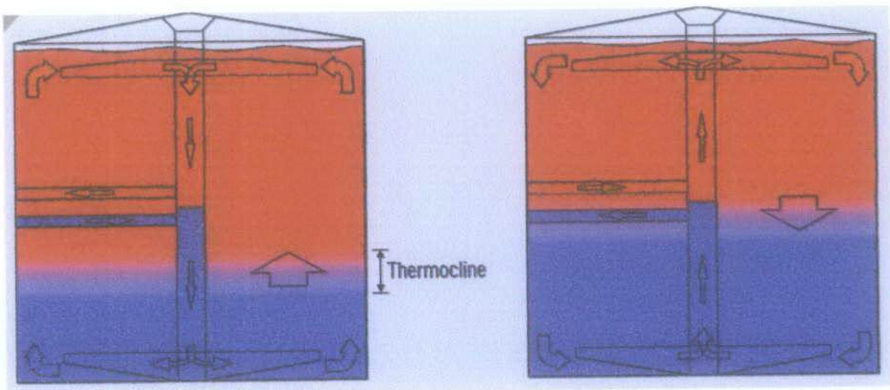


Figure 2.2: Partial Storage System

2.1.3 Chilled Water Storage System Operation

During charging mode operation, chilled water from chiller is pumped into tank bottom diffuser. The cold and dense water will remain at the bottom of the tank forming a layer of cold water. A thermocline layer is formed between the chilled water and the warm water, which prevents them from mixing. As more and more chilled water is pumped into the bottom of the tank the warm water is displaced and thermocline layer rises. The warm water exists through the top diffuser of the tank and returns to the chiller to form a continuous loop. The volume of water in the tank remains the same. The characterization of tank during charging cycle is shown in Figure 2.3.

When cooling is needed, chilled water is withdrawn from the bottom of the tank and pumped to the building air-handling unit for cooling. The warm water from the building air-handling unit is then pumped back to the top of the tank to form a loop. Now the tank takes over the function of the chiller to cool the building (full storage) or sharing the building load with the chiller (Partial storage). The characterization of tank during discharging cycle is shown in Figure 2.3.



Charging Cycle **Discharging Cycle**

Figure 2.3: Characterization of Thermal Storage Tank

2.2 UTP' Gas District Cooling Thermal Storage System

Thermal storage system at University Technology PETRONAS's Gas District Cooling has been taken as the reference in designing the mini thermal storage in this project. Thermal storage system at UTP's GDC consists of two 1,250 tons of refrigeration (RT) of steam absorption chillers (SACs) and four 325 RT electric chillers (ECs) and one 5,400 m3 storage Thermal Storage Tank with designed capacity of 10,000 RTh. The system operates on a temperature differential of 6°C, with chilled-water temperatures of 6°C and 12°C for the supply and return passages, respectively. The simplified flow diagram of the system is shown in Figure 2.4. (Majid and Waluyo, 2010)

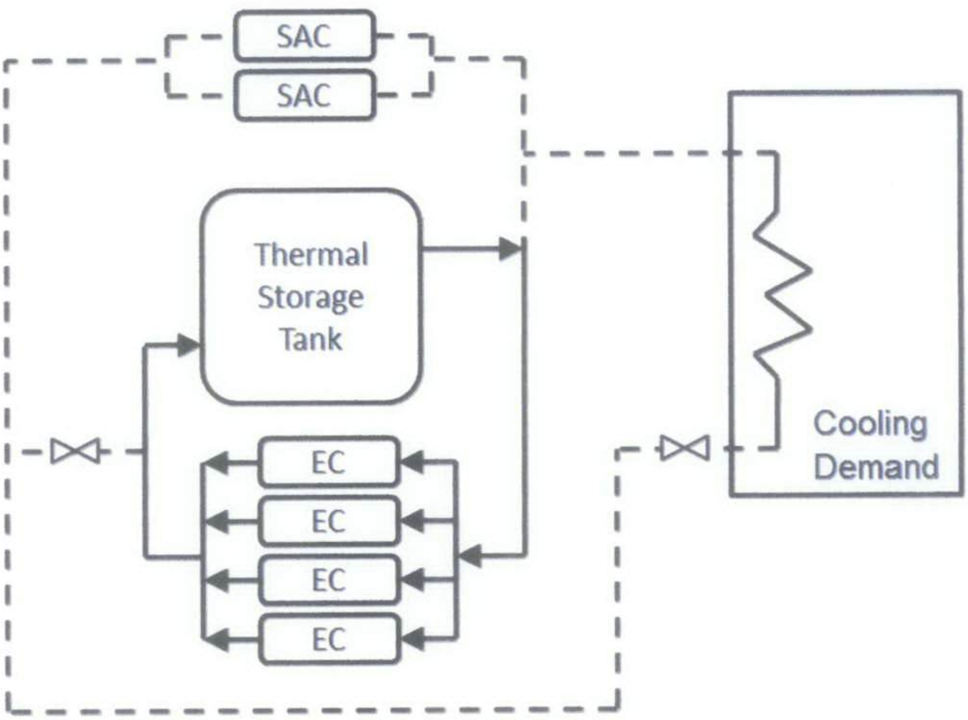


Figure 2-4: Flow diagram of the charging cycle at UTP GDC plant

The operating schedule for the chillers was designed to support the partial load strategy for the thermal storage system. The Steam Absorption Chillers are to operate during the day and the Electric Chillers to be operate during the night for charging the thermal storage tank. The Electric Chillers are designed to operate using the electricity supplied from Tenaga Nasional Berhad (TNB). This is to take advantage of the lower night tariff offered by TNB. The thermal storage tank was designed to supplement the chilled water requirements during the day (Gilani and Majid, 2006).

CHAPTER 3 - METHODOLOGY

3.1 Research Methodology

This project mainly is separated into two big parts, which will be conducted in two semesters. The first semester consists of start of the project until the development of the system while fabrication until the end of project will be conducted in 2nd semester. The project flow from the start of the project until the objective results are achieved is shown in Figure 3.1.

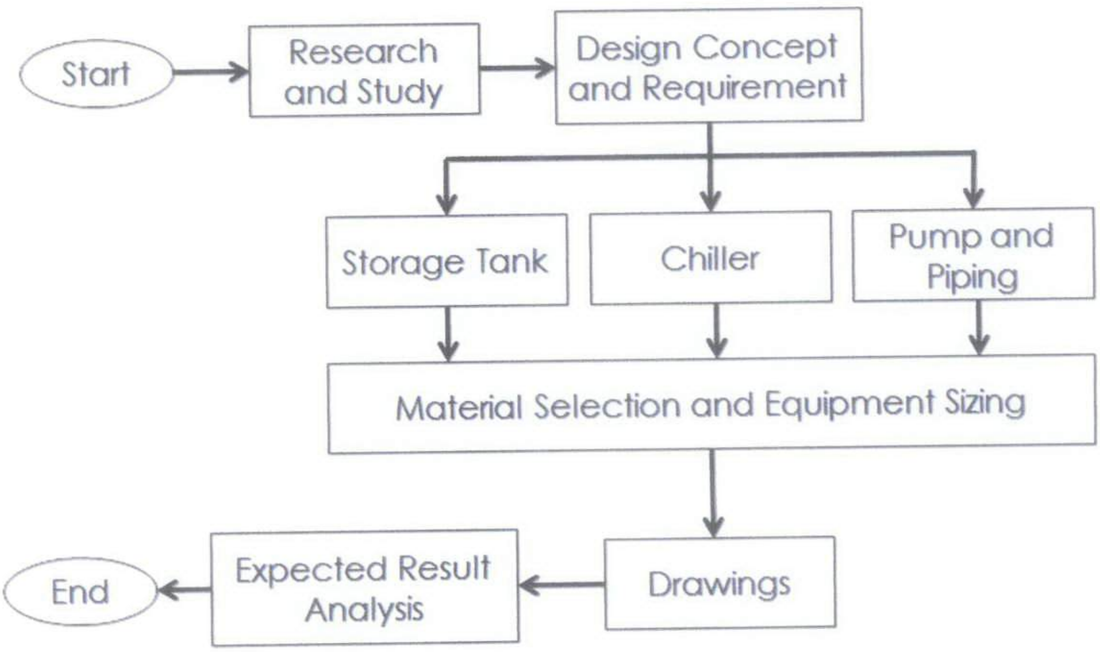


Figure 3.1: Flow chart of the project execution

During the first semester, the task will mostly consist of preliminary works, literature research and designing mini thermal storage system. Firstly research, collect and summarized data and experimental studies related to thermal energy storage charging and discharging design will be conducted from literature sources such as experimental studies, journals and reference books. Then, the first draft design of mini thermal storage system will be constructed from the researches. Next will be the material selection and developments of the system. The developments will posses redesign, analytical calculation and sizing of equipments in the system. A step-by-step redesign process will produce the final drawing of the system before the end of second semester.

3.2 Gantt chart And Key Milestone

Following the scope of work and methodology, this Gant chart in Figure 3.2 represents the timeline estimated to complete the project within the time constraints.

Activity	FYP1													
	MAY				JUNE				JULY				AUG	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Early stage documentation	■	■												
Research literature review		■	■	■	■	■								
Develop system design						■	■	■	■					
Material selection and sizing										■	■	■	■	
Submission of Interim report														■

Activity	FYP2													
	SEP				OCT				NOV				DEC	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Design Development	■	■	■	■										
Design Drawings					■	■	■	■	■					
Expected Result Analysis										■	■	■		
Oral presentation													■	
End stage documentation													■	■

Figure 3.2: Gantt chart and key milestone of project

3.3 Equipment Sizing

In sizing the equipment of the system, there are some equations used. For tank capacity, the equation used is:

$$Q = \text{mass flow rate} \times \text{liquid specific heat} \times \text{temperature difference.} \quad (3\text{-}1)$$

The other equation in determined equipment sizing show by the Table 3.1, Table 3.2 (George, 2000, Arnorld & Stewart), and Table 3.3 (Frank & Mark, 2006).

Table 3.1: Equation for Pipe Sizing

PARAMETER	EQUATION
1) Cross-sectional Area	$A = \Pi \times (\text{radius})^2$ or $\Pi \times (\text{Diameter}/2)^2$
2) Fluid Velocity	V = (Flow rates) / (Pipe cross sectional area)
3) Reynolds Number	$Re = \dfrac{\text{Density} \times \text{Pipe ID} \times \text{Velocity}}{\text{viscosity}}$
4) Friction Loss in 100 m length of pipe	$\Delta P/100ft = (0.00115)\dfrac{\text{Moody friction factor} \times \text{liquid flow rate}^2 \times \text{Specific Gravity}}{\text{Pipe ID}^5}$
5) Pressure drop	P = Friction Loss per 100m x equivalent length

Table 3.2: Equation for Insulation Thickness

PARAMETER	EQUATION
1) Heat Capacity	Q = mass flow rate x liquid specific heat x temperature difference
2) Heat Loss	$Qloss = \dfrac{\text{Temperature Difference}}{\text{Total Thermal Resistance}}$
3) Thermal Resistance	$Rt = \dfrac{\text{Log10 (Outer radius / Inner Radius)}}{2 \times \Pi \times \text{Thermal Conductivity} \times}$
4) Insulation Thickness	t = Insulation outer radius – inner radius

Table 3.3: Equation for Pump Sizing

PARAMETER	EQUATION
1) Static Head Gain	Head gain = density x gravity x elevation of suction side
2) Line loss	$\text{Line Loss} = (0.00115)\dfrac{\text{Moody friction factor x liquid flow rate}^2 \text{ x Specific Gravity x EL}}{\text{Pipe ID}^5}$
3) Suction Pressure	$P_{suction}$ = Vessel Pressure + Head gain at suction side – Line loss
4) Discharge Pressure	$P_{discharge}$ = Vessel Pressure - Head gain at discharge side + Line loss
5) Differential Pressure	Differential Pressure = Pdischarge - Psuction
6) NPSHA	Net Positive Suction Head Available = Head suction – Head Vapour

In sizing the pipe, some graph and table are used for determining the moody friction factor and equivalent length of pipe. They are chart for relative roughness, moody friction factor chart and equivalent table. In choosing the pipe size, the important requirement to follow is the fluid velocity must be between 0.5-5.0 m/s (PTS 38.31.11). The pipe size that meets the requirement which has the lowest pressure drop will be chosen.

For pump sizing, the informations that are needed in order to purchase a pump is liquid flowrate, pump suction pressure, pump discharge pressure, net positive head available and differential head. In determining the insulation thickness for tank and pipe, minimum heat loss is set to 0.5% of the tank's heat capacity. From the minimum heat loss, total thermal resistance can be calculated and then will be used to calculate the insulation thickness.

3.4 Project Activities

3.4.1 Mini Thermal Storage Design

The design of mini thermal storage is basically refer to the design of thermal storage system at UTP's GDC. However, the mini thermal storage is using fully operation strategy instead of partial storage strategy which is simpler and using less equipment.

The mini thermal storage system consists of one 1.05 m^3 storage tank with designed capacity of 50 RTh. The tank is design to receive 24°C and store 6 °C of chilled water. The tank has radius 1 m and height 1.4 m. The reason of chosen size of the storage tank is basically because of it is suitable to put in the lab for experiment work. The maximum design flow rates of tank are 8.4 m^3/hr. In one hour, there will be eight circulation or loop of chilled water. Bottom nozzle is made from 1 inch NPS located at elevation 0.1 m height, while upper nozzle is 1 inch NPS at elevation 1.2 m. The tank is made of stainless steel to prevent corrosion and entire tank is externally insulated with Ethylene Propylene Diene Monomer (EPDM) with thickness of insulation, 18.32 mm. The design of the tank will be taken as the requirement or design factor in designing others equipment.

3.4.2 Mini Thermal Storage Operation Mode

The mini thermal storage system is using the fully storage operating strategy. The schematic flow diagram of mini thermal storage system is shown in Figure 3.3.

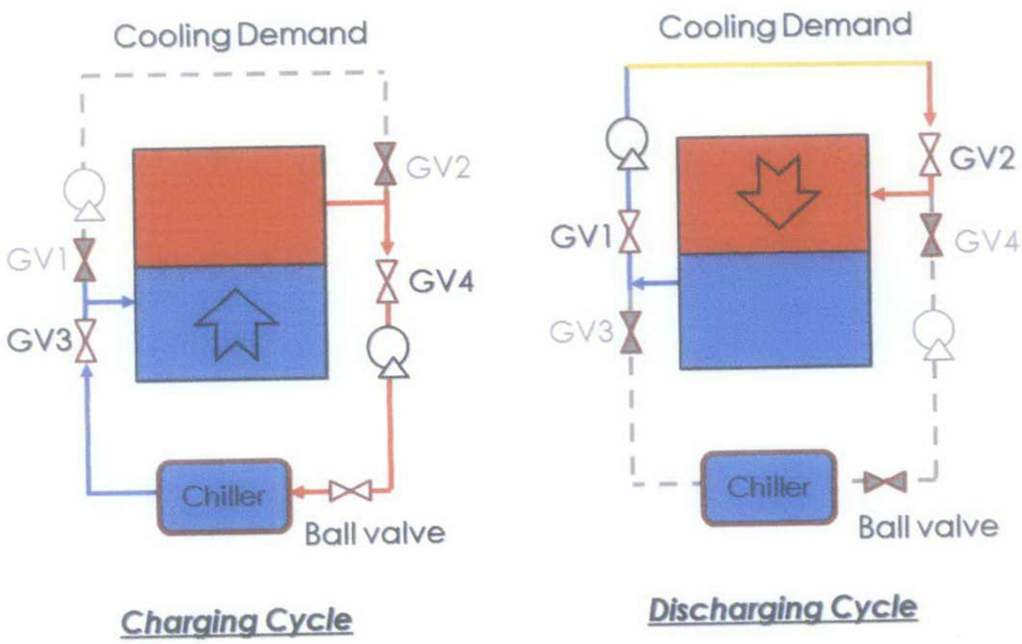


Figure 3.3: The schematic flow diagram of mini thermal storage system

During charging mode operation, Gate Valve 1 & 2 are closed. Chilled water from tank is pumped from upper nozzle into the chiller and then returns the tank through the bottom nozzle to form a continuous loop. During discharging mode operation, Gate Valve 3 & 4 are closed. Chilled water is withdrawn from the bottom of the tank and pumped to a cooling demand tank that is equipped with heating coils to represent the cooling load. The warm water from the cooling demand tank is then pumped back to the top of the tank to form a loop.

However, in this project, the study will be concentrated only for the charging cycle in case of there is not enough time to complete the project. If there is time, the study will be proceeding to the discharging cycle. However, the pipe line and cooling demand tank are still will be design and fabricated for further study.

3.4.3 Mini Thermal Storage's Chiller Design

Instead using two types of chillers like UTP's GDC thermal storage system, the mini thermal storage system is using one chiller. However, there will be a ball valve before chilled water enters the chiller (see Figure 3.4) to control the flow rates of chilled water to represent two types of chiller that are used in UTP's GDC thermal storage system.

In UTP's GDC thermal storage system, total capacity designs of Steam Absorption Chillers (SAC) are double of the Electric Chillers (EC). By reducing half of the flow rates chilled water that enters the chiller in mini thermal storage system, half design capacity of chiller will be get, because as volume flow rate decrease, the mass flow rate also decrease by half, and same goes to cooling capacity (Eq. 3-1). So, half open ball valve will represent the EC and fully open valve will represent the SAC. The design capacity of the chiller is 6.25 tons of refrigeration (RT) which is 1/8 from the tank design capacity for fully open ball valve.

The initial idea is to use aquarium chiller to operate as the chiller. However, after some survey on aquarium chiller supplier, the finding is aquarium chiller is only can reduce water temperature until 19°C. So, it can't be use as the required final temperature is 6°C. Because of that, two alternative chiller options have been considered. The first option is to purchase a freezer, drill holes on top for tubing, then connect the tubing with aquarium pump to move the fluid in tubing which will act as a chiller, and the second option is to move the water through a box of ice. Both option schematic arrangements are shown in Figure 3.4.

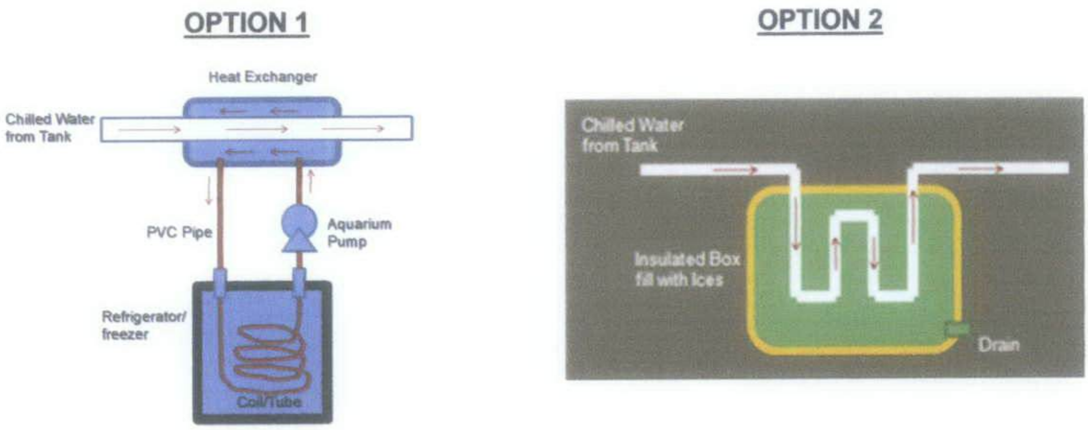


Figure 3.4: Mini thermal storage system's chiller design

The second option is cheaper and simpler than first option. However, the operation cost of second option is higher than the first one because the ice is needed to be change regularly during the experiment. For this project, the second option will be choose as the temporary chiller for mini thermal storage system because its fabrication took less time than the first option. On the other hand, the first option is still going to be design and fabricated for further study.

3.4.4 Equipment Material and Sizing

The equipment sizing has been conducted based on the tank design and requirement which shown in Table 2.2.

Table 2.2: Design basis of mini thermal energy storage

Storage Tank Capacity	RTh	50
Storage Tank Volume	m^3	1.05
Liquid Flowrate	m^3/hr	8.4

Steel pipe will be used as the pipe line in the system. Hydraulic calculation has been conducted for the system and the result is 1 inch NPS pipe is selected. The insulation of the pipe is ethylene propylene diene (k=0.25) with the thickness of 4.33 mm.

Sizing calculation on the pump requirement was performed for both pumps in the system with a few assumptions have been made. The distance between pump centreline to grade is 0.3m. The fittings at pump suction line consist of one 90° elbow, one tee-equal and one gate valve. For the pump discharge line, it consists of three 90° elbow, one ball valve, one gate valve and one tee-equal. Both pumps that are used in the system has similar characteristic.

Pump Sizing results:

Parameter	Unit	Max Design
Liquid Flowrate	m^3/hr	8.4
Pump Suction Pressure	bar (A)	0.74
Pump Discharge Pressure	bar (a)	1.54
NPSHA Available	m liquid	7.6
Differential Head	m	26.83

Refer to Appendix for Pump Sizing report.

3.4.5 Mini Thermal Storage Parts and Components Drawing

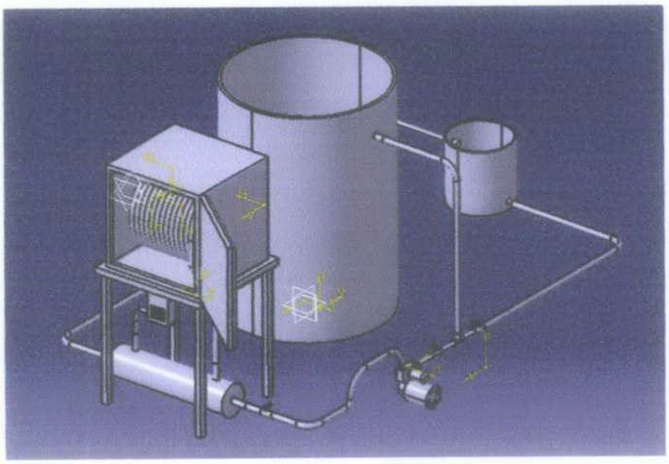


Figure 3.5: CATIA drawing of mini thermal storage system

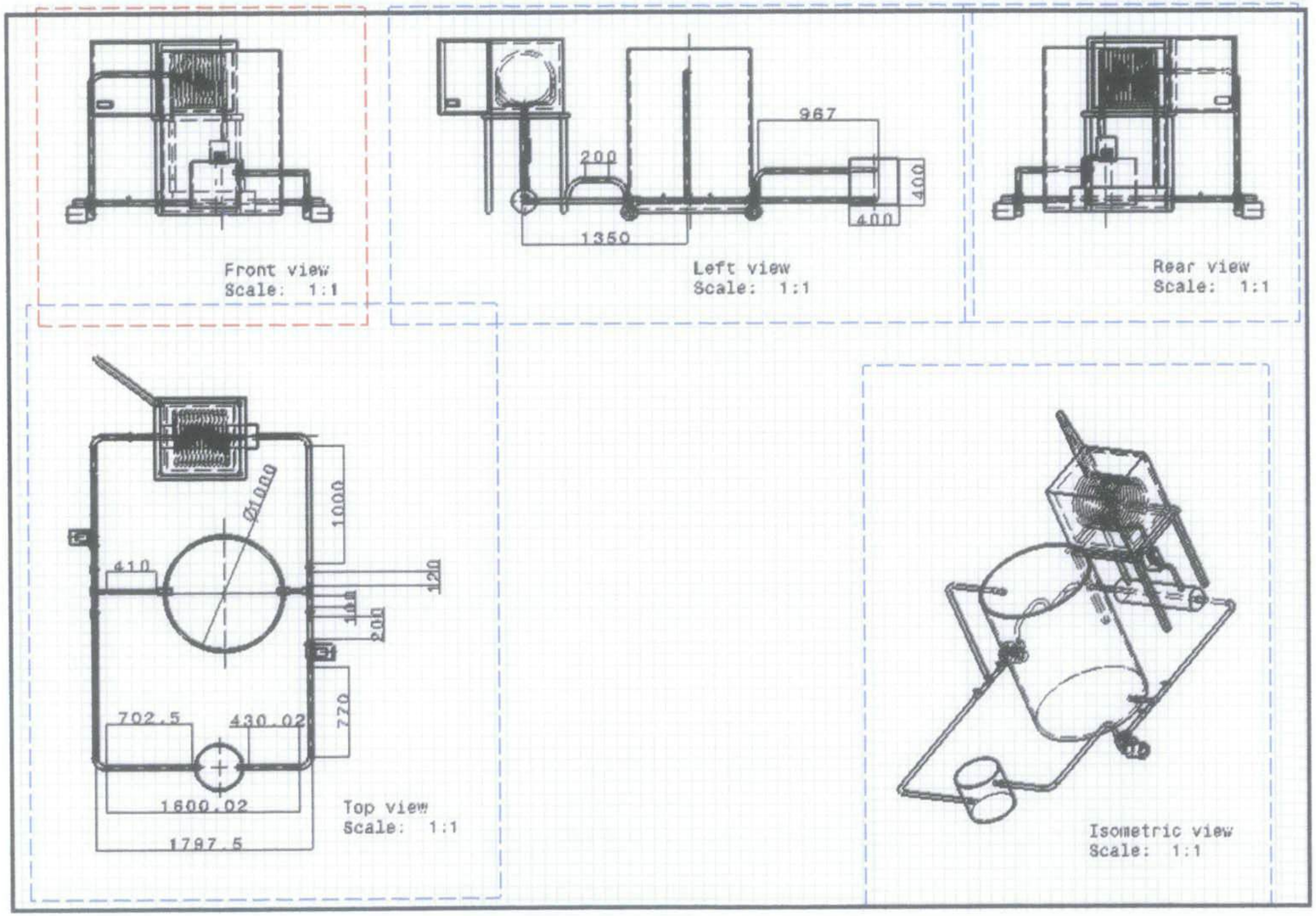


Figure 3.6: Mini thermal storage drawing

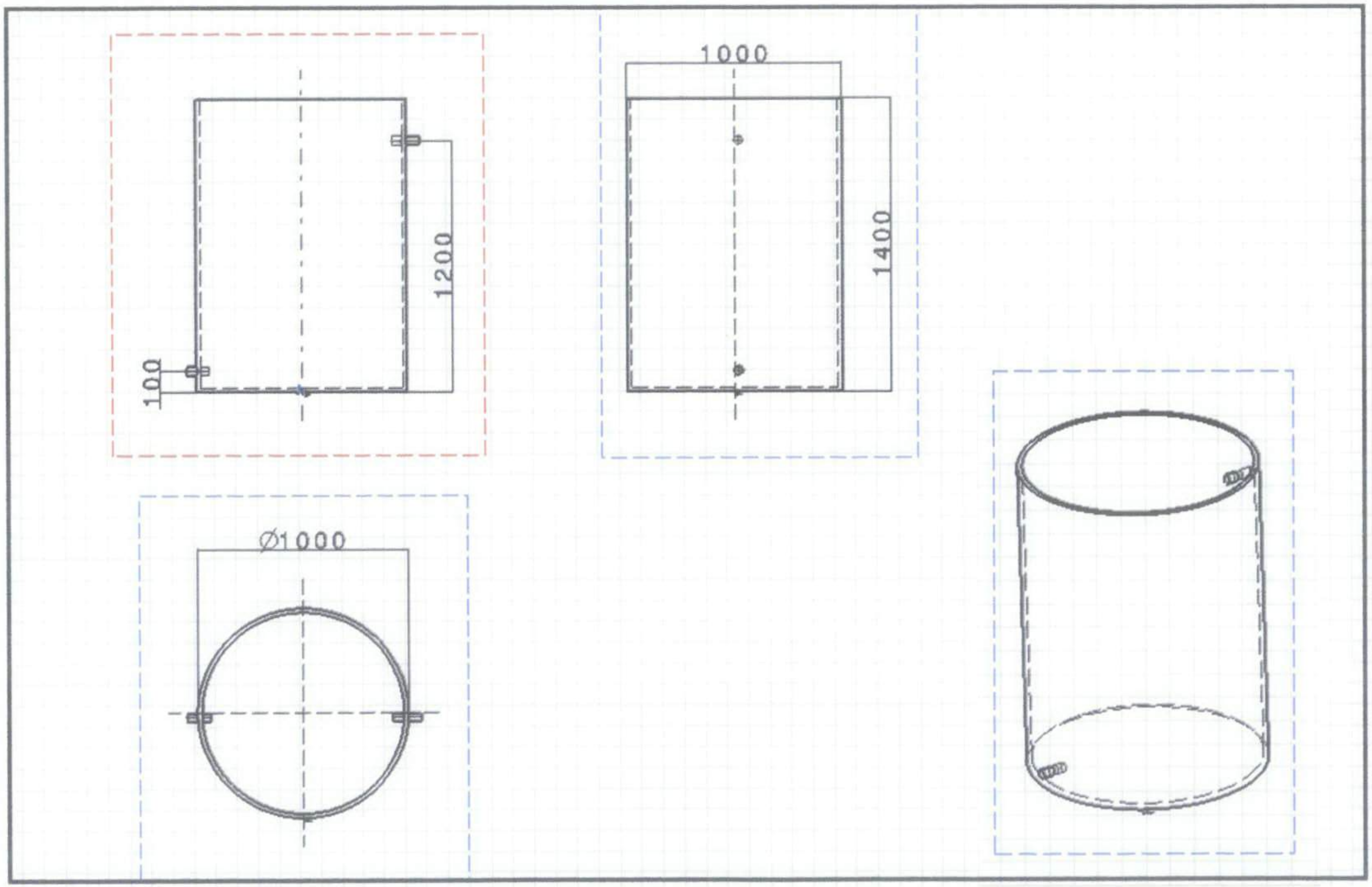


Figure 3.7: Storage tank drawing

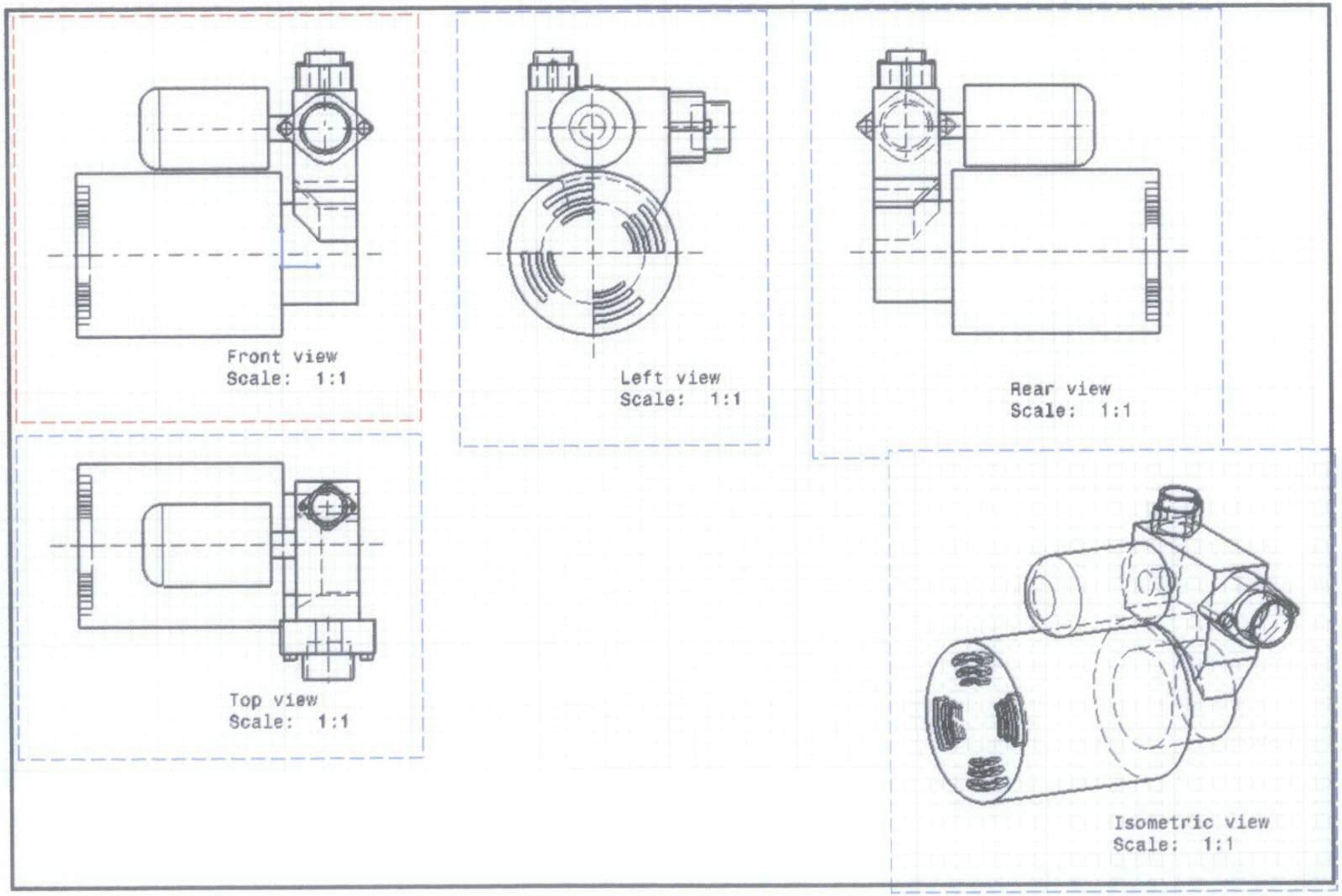


Figure 3.8: Pump drawing

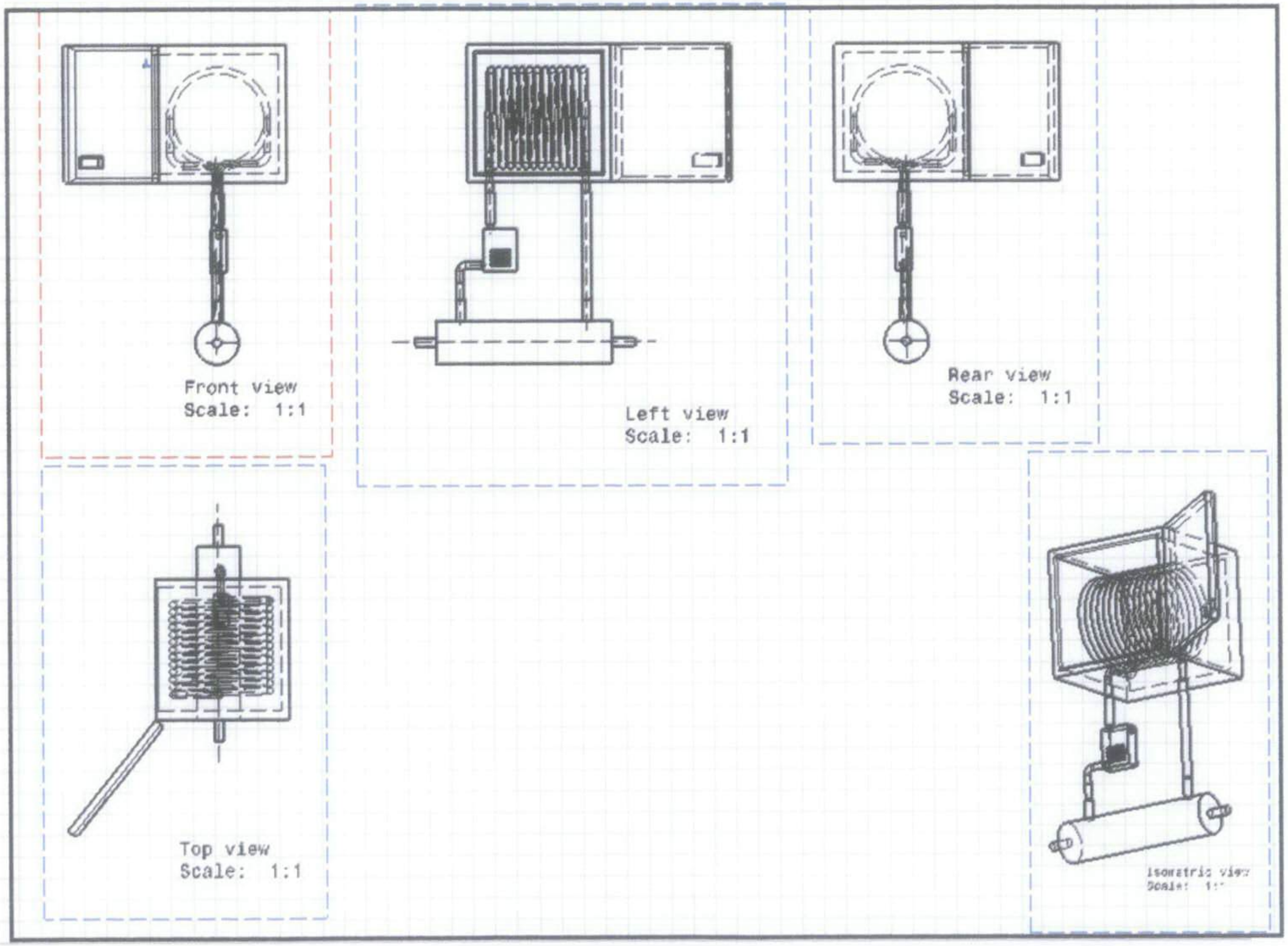


Figure 3.9: Chiller drawing

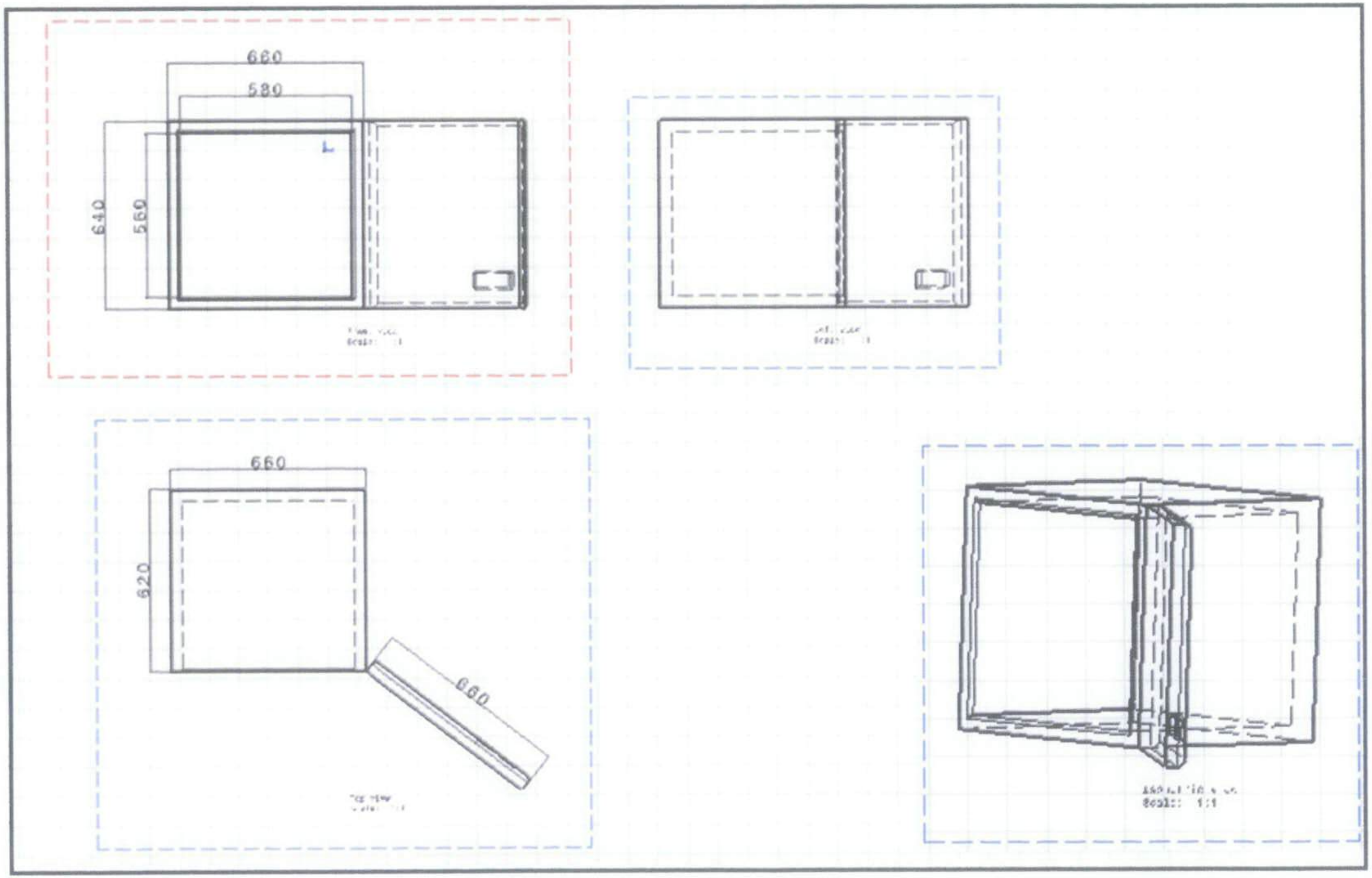


Figure 3.10: Freezer/refrigerator drawing

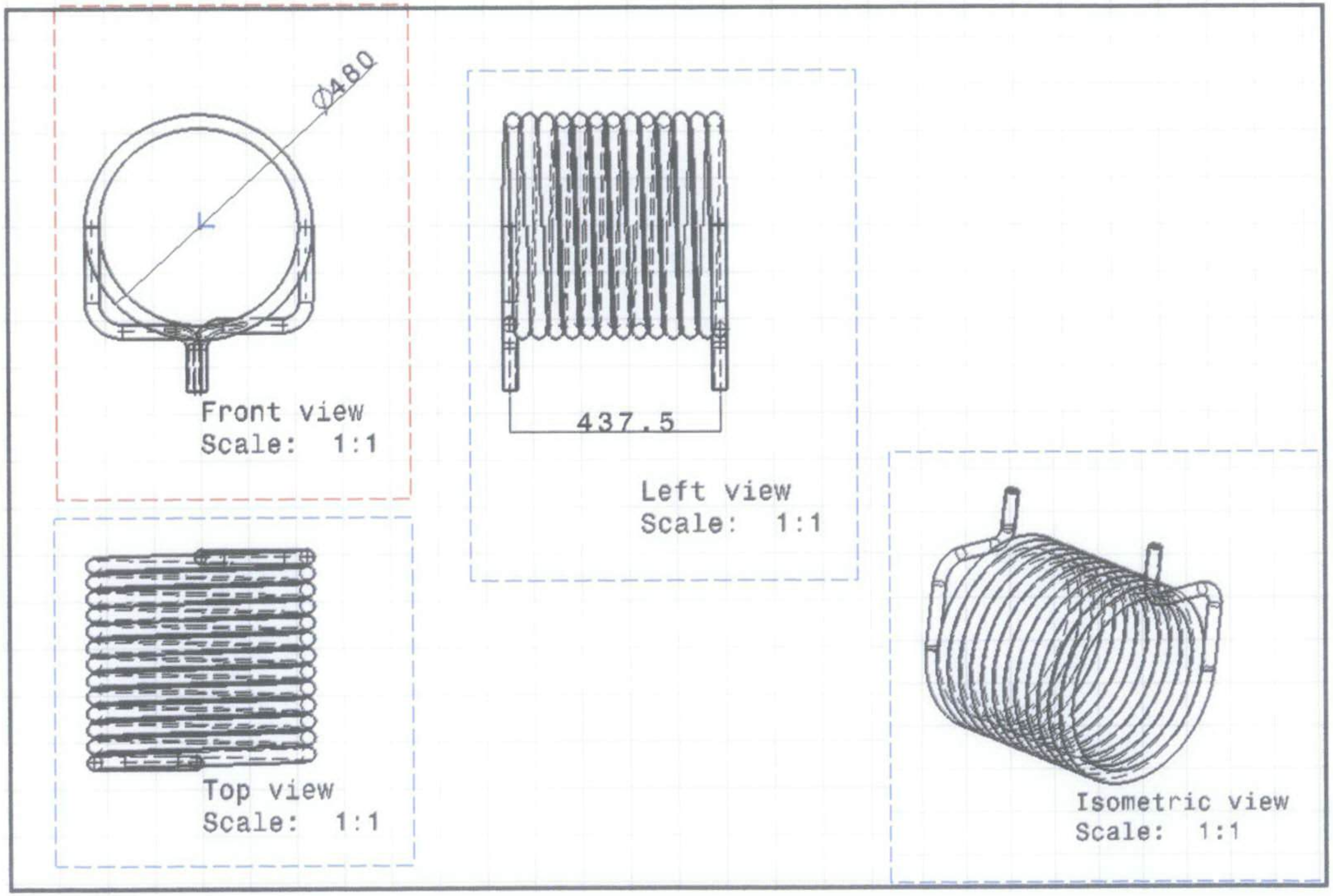


Figure 3.11 Tube drawing

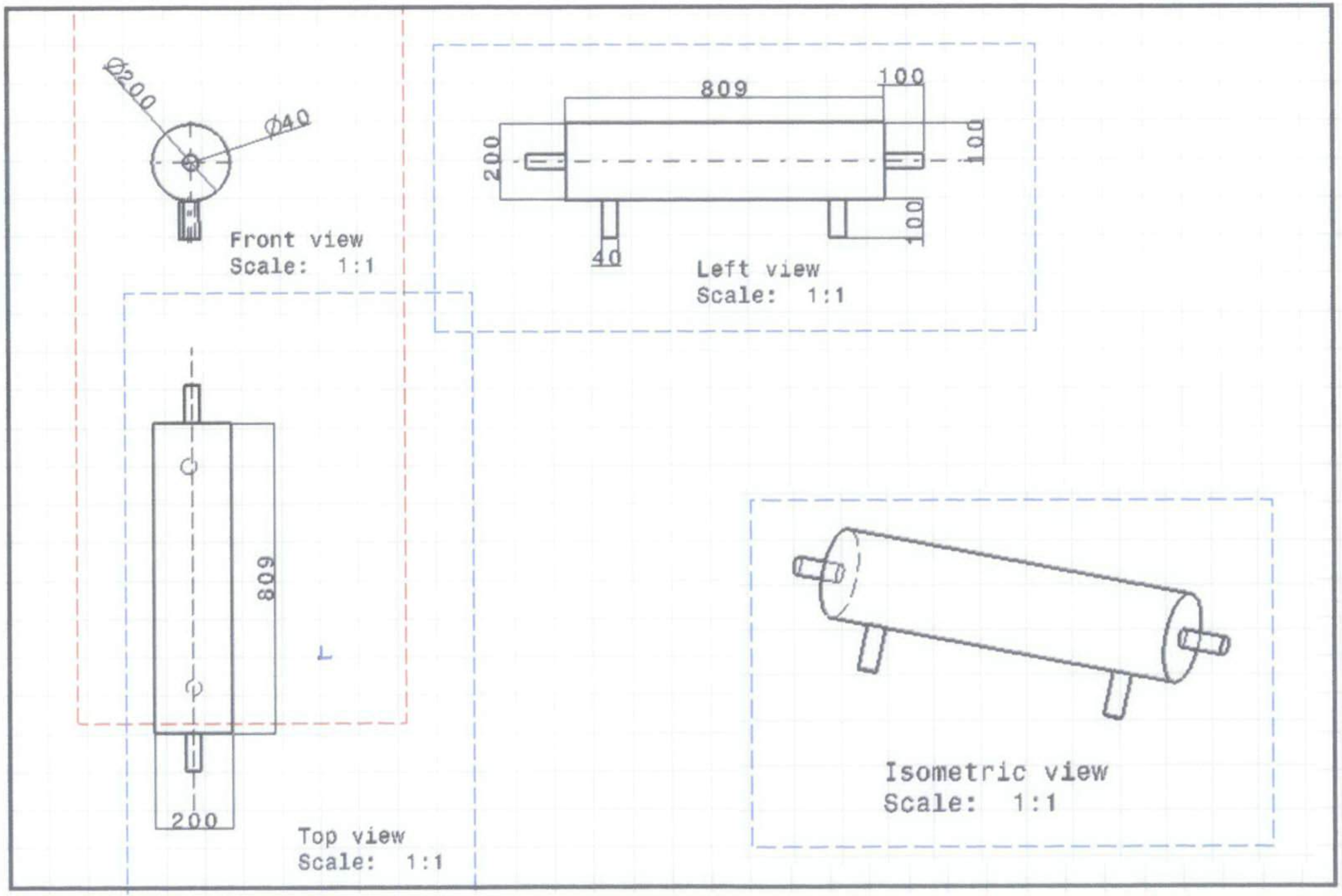


Figure 3.12: Heat exchanger drawing

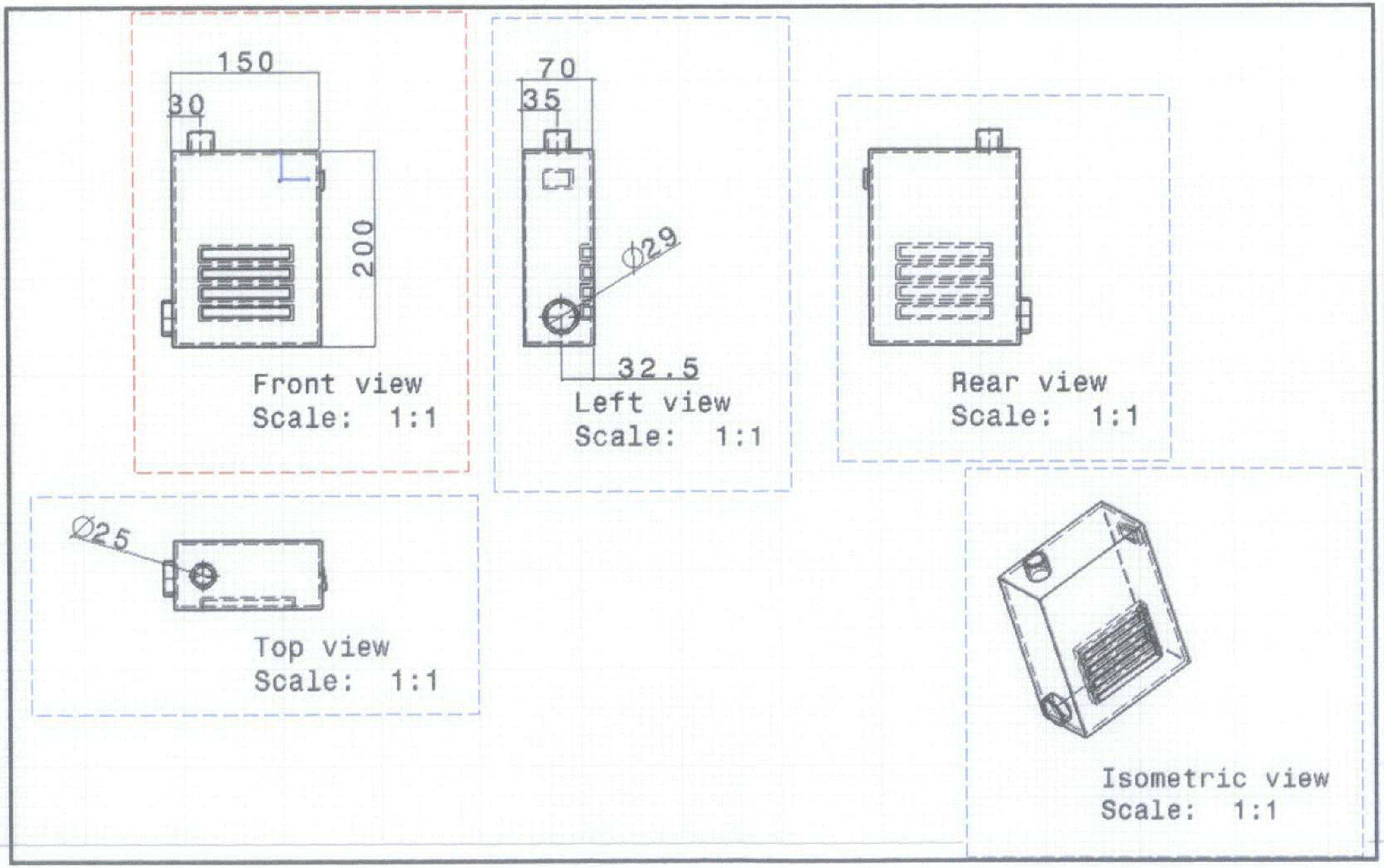


Figure 3.13: Aquarium pump drawing

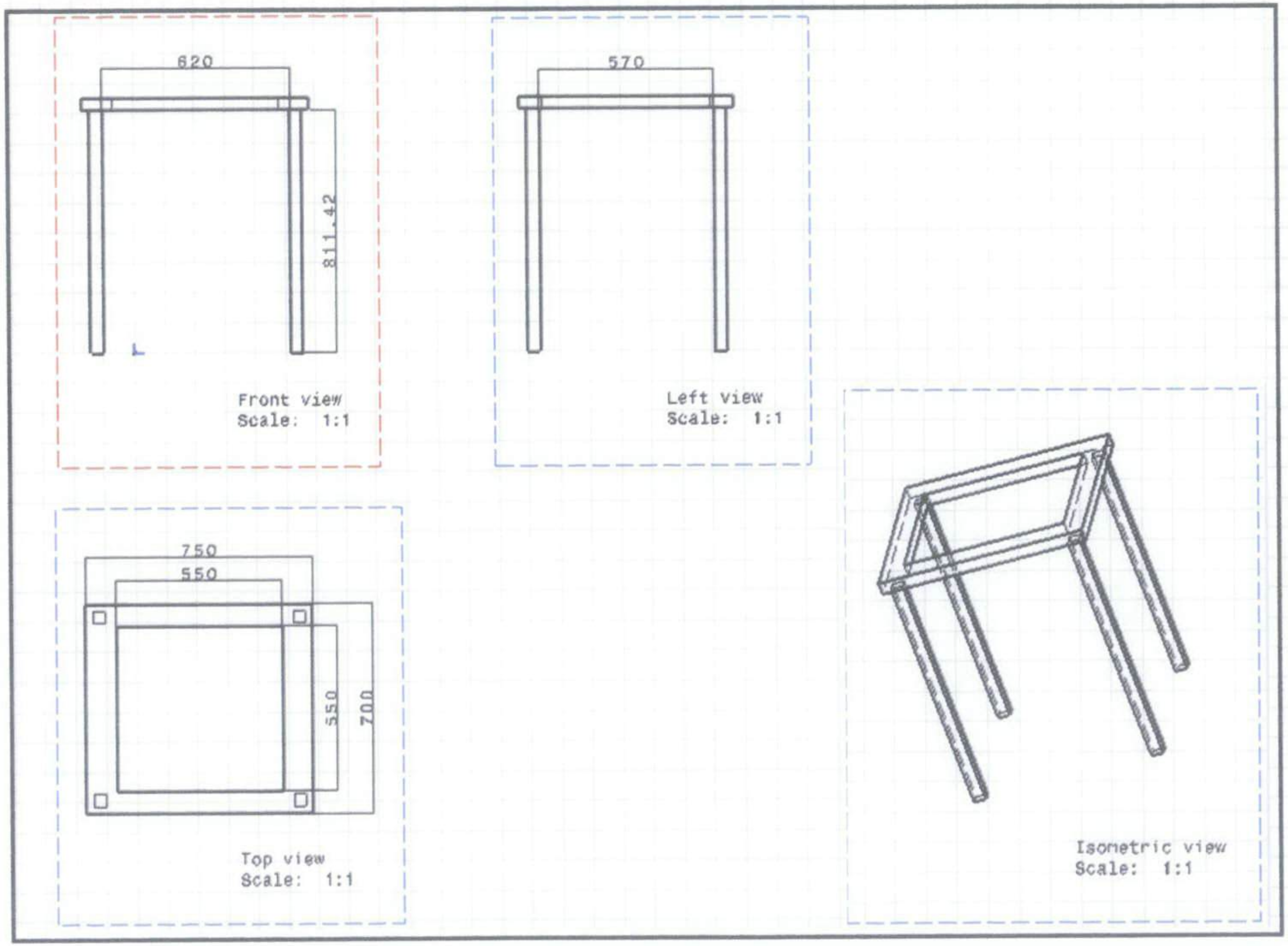


Figure 3.14: Chiller's table drawing

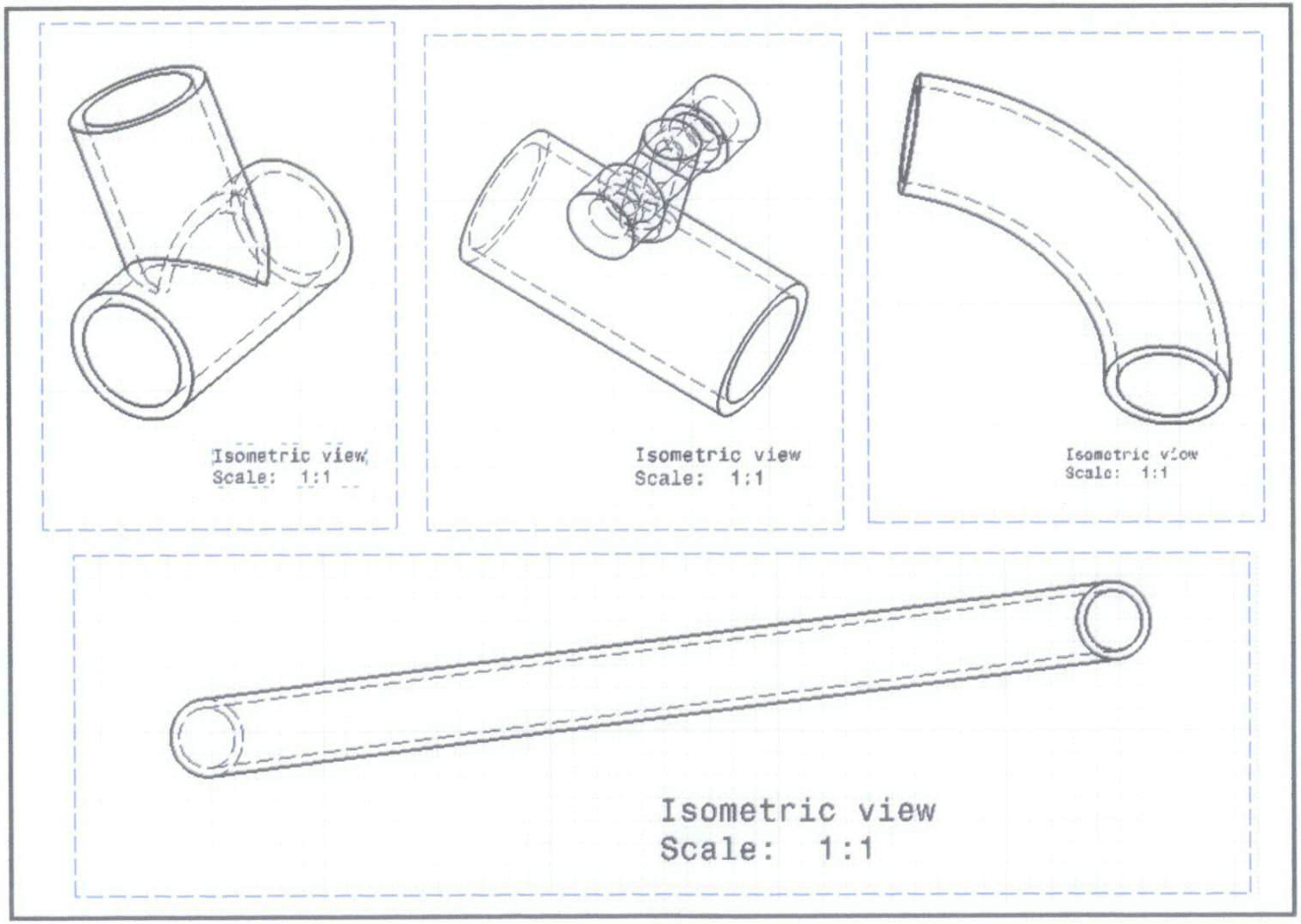


Figure 3.15: Other equipment drawing

3.4.5 Experiment Procedure

For future study, an experiment may be conducted on the storage tank after the fabrication to study the temperature distribution in the tank. Temperature distribution in the thermal storage tank consists of three regions. Top layer is warm water, bottom layer is cool water and in the middle is thermocline layer. Thermocline layer is a distinct layer which temperature changes more rapidly with depth than it does in the top and bottom layers. The temperature distribution in this three layers or regions of water will be study.

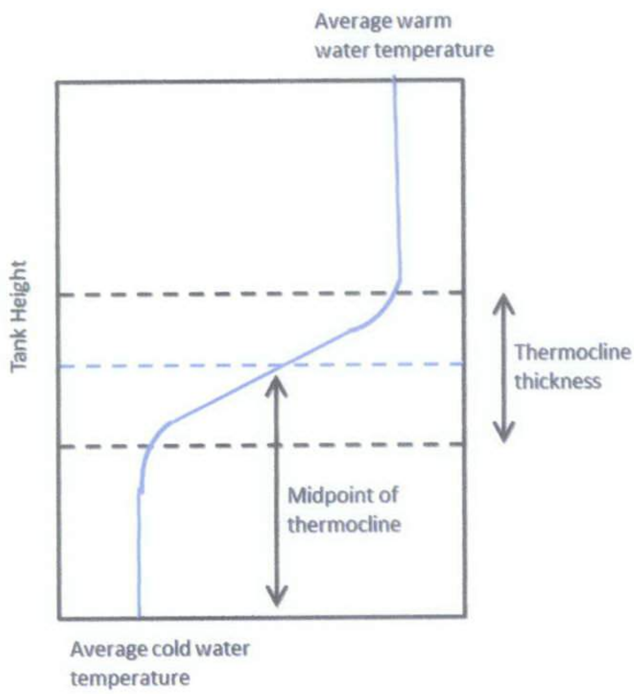


Figure 3-16: S-curve of tank temperature profile

The storage tank will be equipped with 20 thermocouples, installed at approximately 0.07 m vertical interval, to measure the water temperatures. The lowest temperature sensor is located at 0.05 m height. Charging cycle will be operated continuously for 7 hours with fully open ball valve (8.4 m^3/hr). All temperatures are hourly recorded with acquisition data system. The experiment will be repeated with half open ball valve (4.2 m^3/hr) in the next day. Graph for tank height vs temperature will be plotted for both cases (Figure 3.4). Finally, the results will be analyze to compare the temperature distribution between the two case (ball valve fully open & half open).

3.4.5 Estimated Result

The estimated result from the experiment is shown in the graph Temperature vs Tank Height (sensor elevation) in Figure 3-7 and 3-8. The estimated result is based on the temperature distribution inside the UTP's GDC thermal storage tank. Basically, the estimated result is only to show how the shape of graph that should get from the experiment.

The result is done by theoritical calculation with a few assumptions have been made which are average warm water temperature is 24°C, average cold water temperature is 6°C, thermocline thickness is constant which is 10 cm in case 1 and 20 cm in case 2 and thermocline position increase with constant value for each hour.

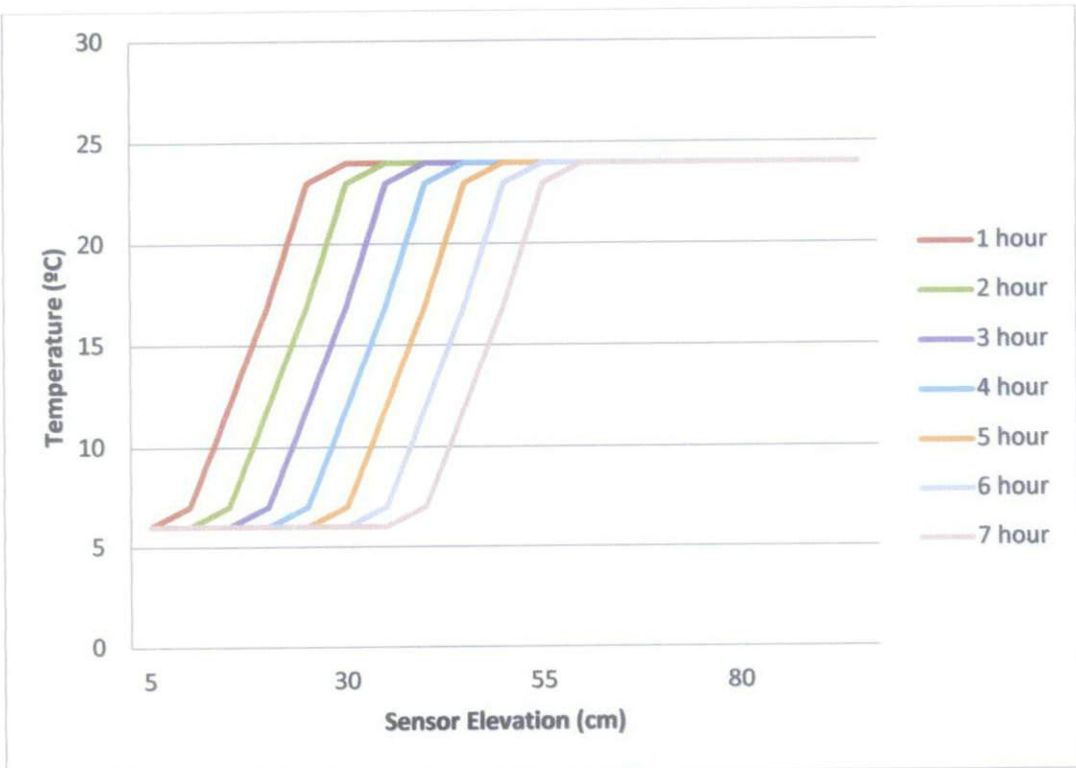


Figure 3-17: Storage tank temperature profile for Case 1: half open valve (2.4 m^3/hr)

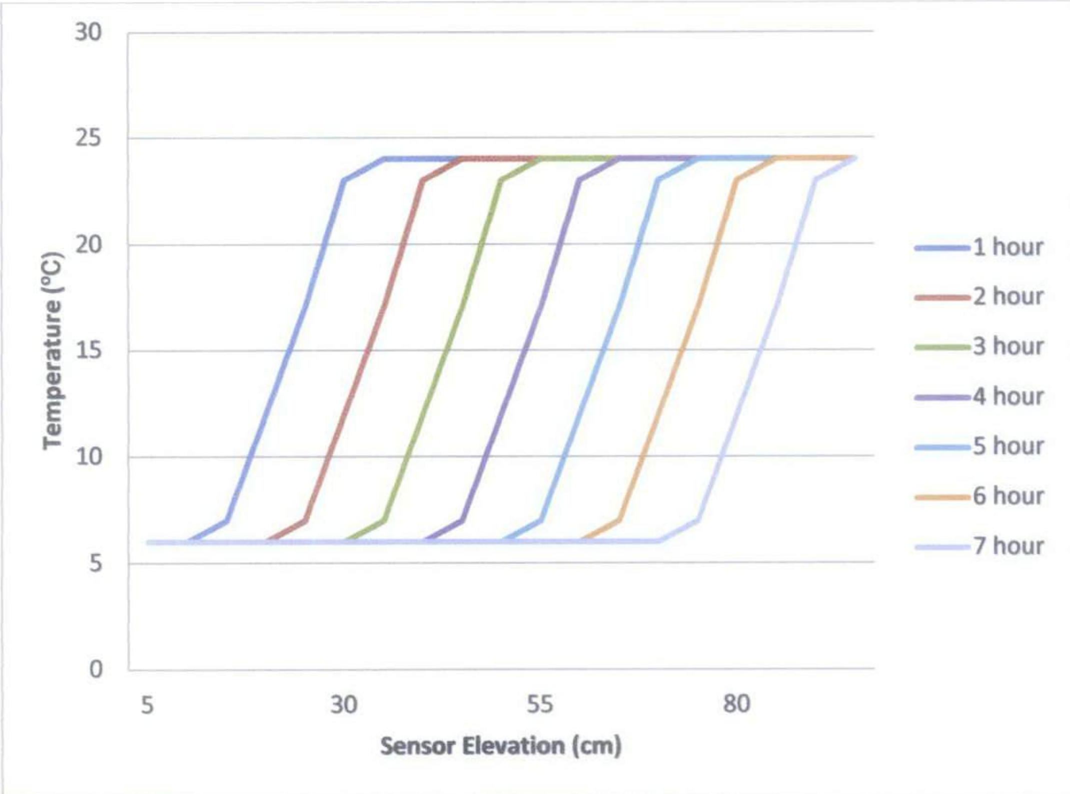


Figure 3-18: Storage tank temperature profile for Case 2: fully open valve (4.8 m^3/hr)

From the graph, the increase of thermocline layer height for the fully open valve case is expected faster than half open valve case for the same hour. This shows that the steam absorption chiller has better cooling ability than the electric chiller.

CHAPTER 4 – CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

Thermal storage system is the current solution to significantly reduce energy costs by allowing energy-intensive, electrically driven cooling equipment to be predominantly operated during off-peak hours when electricity rates are lower. In addition, some system configurations result in lower first costs or lower operating costs. Upon completion of this project, students may use this information to fabricate the system and conduct an experiment to get better understanding about the temperature distribution inside the thermal storage tank.

4.2 Recommendation

4.2.1 Recommendation on the project

The recommendation on this project is to use real chiller in the system so that the efficiency of the system can be increase. However, this may require highly more budgets because the cost to purchase real chiller is a lot expensive than the chiller that are going to use in mini thermal storage system.

The second recommendation on this project is the projects should continue using another operating strategy which is partial storage strategy with the study expanding to the discharging cycle and not charging cycle only. However, this only can possible if the final year project students are given more time to work on the project because 8 months is not enough to complete the project with desired result.

4.2.2 Recommendation based on the project

Currently at UTP's GDC thermal storage system, there are two types of chillers used which are Steam Absorption Chiller and Electric Chiller. The Absorption Chillers are to operate during the day and the Electric Chillers to be operate during the night for charging the thermal storage tank. The Absorption Chiller are operated by steam that produced by gas turbine. So, during night, when the absorption chiller are not operated, the steam produced is wasted as the turbine are operates twenty-four hour a day. Upon completion of this project, the comparison of two case that represent Steam Absorption Chiller and Electric Chiller will prove that the absorption chiller have more cooling capacity than electric chiller. So, the recommendation is to change the thermal energy storage at GDC so that the steam absorption chiller can be running at the night to charge the thermal storage tank. By doing this, the heat stored by thermal tank will be improved, and the size of the tank can be reduced. The steam also will be not wasted during night and the cost of operating also can be lowered.

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APPENDIX 1

Table A1.1: Pipe Sizing for Pump Suction Side

INPUT DATA					
		3/4" (19.05 mm)	1"(25.4mm)	1-1/4" (31.75mm)	1-1/2" (38.1mm)
Volume Flow Rate (m^3/hr@ P,T)		8.4	8.4	8.4	8.4
Density (kg/m^3 @ P,T)		997	997	997	997
Viscosity (cP @ P,T)		0.82	0.82	0.82	0.82
Pipe ND (in)		0.75	1	1.25	1.5
Pipe Internal Diameter (mm)		19.05	25.4	31.75	38.1
Pipe Roughness (mm)		0.00008	0.00006	0.00005	0.00004
Equivalent Length (m)		3.5479	4.2972	5.0465	5.7958
DETAILED CALCULATION RESULT					
Pipe Cross-sectional Area (m^2)		0.0003	0.0005	0.0008	0.0011
Fluid Velocity (m/s)		8.2	4.6	2.9	2.0
Reynolds No.		188475	141357	113085	94238
Moody Friction Factor		0.0164	0.0171	0.0177	0.0183
Pressure Drop (kPa/100m)		2887.5	713.9	242.8	100.9
Total Pressure Drop (kPa)		102.4	30.7	12.3	5.8

NOTE

1. Fluid velocity shall be 0.5-5.0 m/s (recommended by PTS 38.31.01.11 " Piping - General Requirement"

CONCLUSION

1" is selected for pipe sizing for economic consideration

Table A1.2: Pipe Sizing for Pump Discharge Side

INPUT DATA					
		3/4" (19.05 mm)	1"(25.4mm)	1-1/4" (31.75mm)	1-1/2" (38.1mm)
Volume Flow Rate (m^3/hr@ P,T)		8.4	8.4	8.4	8.4
Density (kg/m^3 @ P,T)		997	997	997	997
Viscosity (cP @ P,T)		0.82	0.82	0.82	0.82
Pipe ND (in)		0.75	1	1.25	1.5
Pipe Outer Diameter (mm)		26.67	33.40	42.16	48.26
Pipe Spec		Std	Std	Std	Std
Pipe Internal Diameter (mm)		20.93	26.64	35.05	40.89
Pipe Roughness (mm)		0.00008	0.00006	0.00005	0.00004
Equivalent Length (m)		4.1196928	4.7940628	5.786136	6.475492
DETAILED CALCULATION RESULT					
Pipe Cross-sectional Area (m^2)		0.0003	0.0005	0.0008	0.0011
Fluid Velocity (m/s)		8.2	4.6	2.9	2.0
Reynolds No.		188475	141357	113085	94238
Moody Friction Factor		0.0164	0.0171	0.0177	0.0183
Pressure Drop (kPa/100m)		2887.5	713.9	242.8	100.9
Total Pressure Drop (kPa)		119.0	34.2	14.1	6.5

NOTE

1. Fluid velocity shall be 0.5-5.0 m/s (recommended by PTS 38.31.01.11 " Piping - General Requirement"

CONCLUSION

1" is selected for pipe sizing for economic consideration

APPENDIX 2

Table A2.1: Pump Sizing

PUMP SIZING			
Number of Pumps Operating		1	
Pump Speed		1800	
Liquid Properties			
Liquid Pumped:			
Temperature	degC	6	
Density	kg/m³	977.00	
Viscosity	cP	0.9	
Vapour Pressure	bar(A)	0.02	at operating temperature
Flowrates			
Total Volumetric Flow	m³/h	8.40	
Total Volumetric Flow	US gpm	36.98	
Volumetric Flow (per pump)	m³/h	8.4	
Volumetric Flow (per pump)	US gpm	37.0	
Suction Side Hydraulics			
Suction Vessel Operating Pressure	bar(A)	1.01	
Elevation of Suction Vessel from Grade	m	0.7	
Vessel low liquid level	m	0.0	
Pump centreline elevation from grade	m	0.3	
Static Pressure Low Liquid Level to Pump	bar	0.04	
Suction Side Pressure Drop	bar	0.31	
Pump Suction Pressure	bar(A)	0.74	
Discharge Side Hydraulics			
Maximum Termination Pressure	bar(G)	1.20	
Elevation of Terminal Point	m	0.0	*- above pump centreline*
Discharge Side Pressure Drop	bar	0.34	
Pump Discharge Pressure	bar(G)	1.54	
Pump NPSH			
NPSH Required at the Pump	m	0.4	
NPSH Safety Margin	m	1.0	*Refer PTS 31.29.02.30*
Total NPSH Required	m	1.4	
Head at Pump Entry	m	7.7	
NPSH Available	m	7.6	*Sufficient NPSH Available*
Pump Design Data			
Pump Differential Pressure	bar	0.80	
Pump Differential Head	m	26.83	
Estimated Pump Efficiency	%	85	
Estimated Pump Power Required	kW	0.22	*N.B. This is power required per pump*

APPENDIX 3

Table A3.1: Insulation Sizing

Insulation Thickness		
Minimum Ambient Temperature	°C	27
Water Temperature:		
1st	°C	24
2nd	°C	6
Water Density	kg/m3	997
Water Specific Heat	J/kg.K	4180
Maximum Volume Flow Rate	m3/h	8.4
Mass Flow Rate	kg/h	8374.80
Mass Flow Rate	kg/s	2.33
Heat Capacity	W	175033.32
Minimum Heat Loss	W	875.17
Tank		
Stainless Steel Layer:		
Inner Radius	m	0.5
Outer Radius	m	0.505
Length	m	1
Thermal Conductivity	W/m °C	16
Thermal Resistance	°C/W	4.29868E-05
Polypropylene(Insulation) Layer:		
Inner Radius	m	0.505
Thermal Conductivity	W/m °C	0.12
Outer Radius	m	0.523
Tank Insulation Thickness	m	0.018
	mm	18.32
Pipe		
Steel Layer		
Inner Radius	m	0.027
Outer Radius	m	0.033
Length	m	3.050
Thermal Conductivity	W/m °C	16
Thermal Resistance	°C/W	0.000976348
Polypropylene(Insulation) Layer:		
Inner Radius	m	0.033
Thermal Conductivity	W/m °C	0.12
Outer Radius	m	0.037
Pipe Insulation Thickness	m	0.004
	mm	3.65