CHAPTER 1
INTRODUCTION

1.1 Background of Study

Nowadays, society of the world is mostly depending on fossil fuels to meet their energy needs. Fossil fuels such as oil and natural gas are very important in daily life. Fuels for transportation (car, motorcycles, and taxi) and cooking gas are the example of needs related to fossil fuel. As fossil fuel is one of the main energy sources, noted also that it is non-renewable. Petroleum stock in earth is getting less every year due to the high consumptions. Because of this, new alternative energy must be search for that the production and prolongation of energy can be continuing for many years.

Currently, scientist and researcher all over the world starting to research and study about the renewable energy source. Renewable energy which is environmental friendly can be re-use and no limited of source and low cost. Energy such solar, wind, wave and biomass can be used as an alternative for fossil fuels.

This renewable energy can be utilized by many ways and techniques. For this project, solar energy can be stored using the Thermal Energy Storage (TES) system. TES is defined as temporary storage of thermal energy at high or low temperature. TES is one of the alternative solutions for existing energy problem. It will store energy during day where sun is available and use it when the energy availability is inadequate especially at night.

To store the solar energy, TES will use substance that calls Phase Change Materials (PCM). These PCMs is a latent heat storage type. Latent heat storage can store energy by phase change like solid to liquid or liquid to solid without any changing in the temperature. It also has various interesting properties such it's capability to hold a high energy storage density and store heat at constant temperature with respect to phase transition temperature.

1.2 Problem Statement

In Malaysia, the sunlight is available for 12 hours per day and there is no problem with the sources of solar energy. But the main problem here is to store the energy for a certain time before use it. For storing the solar energy, an appropriate technique is required to ensure the energy stored can be fully utilized efficiently for later use. By using the TES system, solar energy can be stored using phase change material (PCM). This PCM are very useful for storing energy without involving phase change. It can hold the energy for certain period of time and can be use any time of need.

1.3 Objectives

The main objectives of this research are:

i. Design a TES tank suitable to be used with existing trough collector.
ii. Development of TES tank and integration of system.
iii. Analysis of the results of the salt hydrates use as PCM.

1.4 Scopes of Study

i. To conduct a test or experiment to see if the TES working with the existing parabolic tough collector.
ii. To select the suitable salts hydrates to store enough energy to supply for household equipments.

1.5 Limitations

i. This TES tank will be a small scale project for example of energy storage. Calculation on determining the size coil required for heating and cooling will be shown.

ii. Only salt hydrates will be used as storage media.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

There are has several ways or methods of ES that can be used to store energy such mechanical energy storage, chemical energy storage, Biological storage, magnetic storage and thermal energy storage (TES). Concept of energy storage using flywheel is also a new thing. The flywheel must be design with "high tensile materials to reduce the price and volume of storage" " (Dincer & Rosen 2001, p.60) to store the energy of rotation. Another idea is by reversible chemical reactions and storage of hydrogen in metal hydrides. For this project, TES are the type storage that going to be research on. According to (Dincer & Rosen 2001, p.93), history of TES started during mid–nineteenth century, chemically-charged batteries were the main source for providing power for telegraph, signal lighting and other electrical devices. In 1896, an inventor, Homer T. Yaryan installed the first TES at one of his low-temperature hot-water district heating plants in Toledo to permit the capture of excess heat when electric demand is high. TES also were use to power street cars in the 1890s, including compressed air and high temperature water that was flashed into steam to drive an engine.

2.2 TES methods

PCM or latent heat storage is one of the most efficient ways of storing thermal energy. From (S.D. Sharma and K. Sagara, 2005), latent heat storage are based on heat absorption or release when a storage material undergoes a phase change from solid to liquid or liquid to gas or vice versa. Latent heat storage is one attractive heat storage technique due to its higher energy storage density, with a smaller charging/discharging temperature range, as compared to sensible heat storage system.

PCMs can be produced in various chemical formulations that are designed to melt and freeze at a selected temperature. They use the latent heat of the storage medium for thermal energy storage and have shown a promising ability to reduce the size of a storage system compared with water storage that uses sensible heat to store energy. According to Bo He (2004) in his doctoral thesis, the main criteria for a candidate PCM for thermal energy storage are:

- Phase transition process must be completely reversible and only temperature dependent;
- Phase transition temperature must match the practical temperature range of applications;
- Material should have a large latent heat and high thermal conductivity;
- Material is chemically stable such that no chemical decomposition occurs;
- Material must be non-toxic, non-corrosive and non-explosive;
- Material is available in large quantities at a low cost.

There several classes for PCM that generally are divided in two groups: organic and inorganic compounds. Inorganic compounds include salt hydrates, salts, metals and alloys. Organic compounds are categorized into paraffin and non-paraffin (Bo He, 2004).

Table 1: List of salt hydrates that can be used as a storage medium (Sources: Lane, 1983; Abhat, 1983; Garg et al., 1985; Buddhi, 1994; Hale et al., 1971; Sharma, 1999)

Phase Change Materials (PCMs)	Melting Point (^{0}C)	Heat of fusion (kJ/kg)
Potassium fluoride tetrahydrate	18.5	231
Calcium chloride hexahydrate	29.7	171
Sodium Sulphate decahydrate	32.4	254
Sodium orthosphosphate dodecahydrate	35	281
Zinc nitrate hexahydrate	36.4	147

Salt hydrates are attractive materials for use in thermal energy storage due to their high volumetric storage density (between 250-400 MJ/m3), relatively high thermal conductivity and reasonable cost. For example, Glauber salt ($Na_2SO_4 \cdot 10H_2O$) has been studied as early as 1952. It has a melting temperature of around 32.4 °C, a high latent heat of 254 kJ/kg (377 MJ/m3) and the thermal conductivity of 0.544 (W/m K)

Not all PCMs are suitable for TES storage medium. Each PCM has different thermodynamics properties. The properties such melting temperature is very important in selecting the suitable PCM. First, the PCM melting temperature must be in the operating range. Value of operating range is depending on the solar radiation temperature which is an average between 30^0C to 37^0C (day temperature). By having melting temperature in this operating range, it is easier for the process (phase change) to take place. Furthermore, extra energy (heat) generate from outside is not required if the melting temperature is over the operating temperature.

Table 2: Range of PCMs operating temperature for specific applications (Sources: Bo He, 2004)

Temperature range (^{0}C)	Applications
–20 to –10	Process and storeroom cooling and food freezing
2-15	Air-conditioning comfort cooling applications)
16-26	Building applications (heat storage for peak shifting in space heating, PCM wallboards and PCM concrete, as well as under-floor heating with PCM storage)
20 to 60	Solar and space systems, greenhouses

Another important characteristic of PCMs are its volumetric energy capacity which also known as latent heat of fusion. The latent heat of fusion determines the capacity of energy that one PCM can stored. Comparing with water being an energy storage, few disadvantages can be found such, it requires a large volume because of its low energy storage capacity and its wide temperature range over which the stored energy is delivered. Meanwhile, several PCMs such Glauber and calcium chloride hexahydrate salt can provide a high energy storage capacity with latent heat of 250 kJ/kg and 170 kJ/kg respectively. Such energy is delivered over a very narrow temperature range makes a PCM is lot better than water as energy storage.

The rate of charging and discharging are strongly depends on the thermal conductivities properties. Higher thermal conductivities can ensure more efficiency the heat transfer rate between the PCMs and liquids. For a comparison, salt hydrates have higher thermal conductivities than paraffin wax. Example, magnesium nitrate hexahydrate have thermal conductivity at 0.49 W/mK (liquid) and 0.611 W/mK (solid) while paraffin wax is at 0.167 W/mK (liquid) and 0.346 W/mK (solid).

There also other type of TES methods such using a sensible heat type of material. “In sensible TES, energy is stored by changing the temperature of a storage medium such as water, oil, rock beds, bricks, sand or soil” (Dincer & Rosen 2001, p.123). It consists of storage medium, a container and input/output devices. For the sensible materials, “it undergo no change is phase over the temperature range encountered in the storage process” (Dincer & Rosen 2001, p.124). Amount of heat stored in a mass of material can be formulate as (Bo He, 2004),

$$Q=mc_p\Delta T \qquad \text{or} \qquad Q=\rho c_p V\Delta T\ldots\ldots\ldots\ (1)$$

Where c_p is the specific heat if the storage material, ΔT is the temperature change, V is the volume of storage material and ρ is the density of a material. Value ρc_p determined the ability to store sensible heat for certain materials. As comparison, water has high value than rocks but, being liquid, it must be well contained. Each of the TES material has its own advantages and disadvantages. For an example, “rock is economically cost, but its volumetric thermal capacity is only half of water. Furthermore, rock only advantages that it can be used for heat storage at above 100 ^{0}C. (Dincer & Rosen 2001, p.124)

One type of TES sensible heats are solar pond which can be use to collects and stores solar energy. It contains layers of salt solutions with increasing concentration to a certain depth, below which the solution has a uniform high salt concentration. It has three layers water in the ponds;

i. The top layer, which has a low salt content.

ii. The bottom layer, which has a high salt content.

iii. An intermediate insulating layer with a salt gradient, which establishes a density gradient that prevents heat exchange by natural convection.

Basic process of what happen in the solar pond, when solar radiation is absorbed, the density gradient prevents heat in the lower layers from moving upwards by convection and leaving the pond. This means that the temperature at the bottom of the pond will rise to over 90 °C while the temperature at the top of the pond is usually around 30 °C. The heat trapped in the salty bottom layer can be used for many different purposes, such as the heating of buildings or industrial hot water or to drive a turbine for generating electricity (Dincer & Rosen, 2001).

2.3 Description of the TES tank.

There are several major things that very important while considering the designing and development of the TES tank. First, the process of involves inside the TES tank. Like, the direction of water flow, how the energy going to be stored and the whole systems in the tanks. Secondly, type of medium or materials that are PCMs type. For this project, salt hydrates are the PCMs type for the storage medium. Besides the parameters regarding the TES tank, the solar collector going to be used is also part of the TES tank systems. Since, the solar collector are already existed, this piping on TES tank will be integrate with the solar collector.

To design and develop a TES tank, it must have three main components which is;

a) Coil that act as a heat exchanger surface for transferring heat from the source (collector)

b) Container for PCMs.

c) Amount of PCM

Based on these three criteria, the first steps towards completing the tank are determining the size coil that going to be used in this project The size of coil which mean the length and its diameter will be determined by using the below equations that normally used for heat exchanger design (Incropera, DeWitt, Bergman and Lavine, 2007).

$$Q_T = U \text{ x } A \text{ x } \Delta T \text{.................. (2)}$$

Where Q_T = total heat to be transferred

U = overall heat transfer coefficient

A = heat transfer area

ΔT = mean temperature difference

The area, A in the equation are meant for the cylindrical coil which is A= πDL where D and L represent diameter and length of coil respectively. From both of this equation, the size of the coil can be determined to ensure that the amount of Q_T required can be transfer to the PCMs. By referring to below equation (Dr. Bell, K.J. and Dr Mueller, A.C., 2001), normally, the U are referring to A_0 the total outside tube heat transfer area, including fins and this equation are related to the individual film coefficients, wall resistance and also the fouling effect.

$$U = \frac{1}{\frac{1}{h_0} + R_{fo} + R_{fin} + \frac{\Delta x_w A_o}{k_w A_m} + R_{fi}\frac{A_o}{A_i} + \frac{1}{h_i}\frac{A_o}{A_i}} \text{................. (3)}$$

where h_0 and h_i = outside and inside film heat transfer coefficients

$R_{fo} + R_{fin}$ = outside and inside fouling resistance

Δx_w = wall thickness (finned section)

k_w = wall thermal conductivity

R_{fin} = resistance to heat transfer due to presence of fin.

The tank for this TES system will be designed as simple as possible and able to accommodate the size of the coil and also the amount of salt hydrate going to be used. Mechanical and chemical properties such thermal conductivities, melting point, density and corrosion resistance will be consider. Also, the availability of the tank material also important as part of the cost of the project.

For this project, a small amount of PCM will be set as fixed variable for the ease of designing the tank size. A small volume of PCM will be used since the project purpose are more to analyze the process happen during heating and cooling to the PCM. Furthermore, the amount of heat stored does not depend on how big the volume of PCM used. One of the PCM advantages are, smaller volume will have a larger energy capacity per unit volume.

2.4 Basic process in TES system

According to (Bo He, 2004), there are two types of storage processes for PCM storage, which is the static and the dynamic storage processes. In static storage process, the heat transfer between the heat transfer medium (fluid such water) and the storage material (PCMs) take places through a solid surface. The heat transfer conditions and the size of the available heat transfer surface area can be use to determine the power of the static storage system. One example of a static storage system is that the heat exchanger coil is submerged in the PCM while a heat transfer fluid is circulated inside the coil. Hot fluid can be used to charge the PCM by circulated in the tubes, causing PCM to solidify (solid to liquid). This configuration is widely used in ice-on-coil thermal energy storage. Another example of static storage is to use a plate heat exchanger layout where PCM is encapsulated in plates and the fluid flows in between these plates.

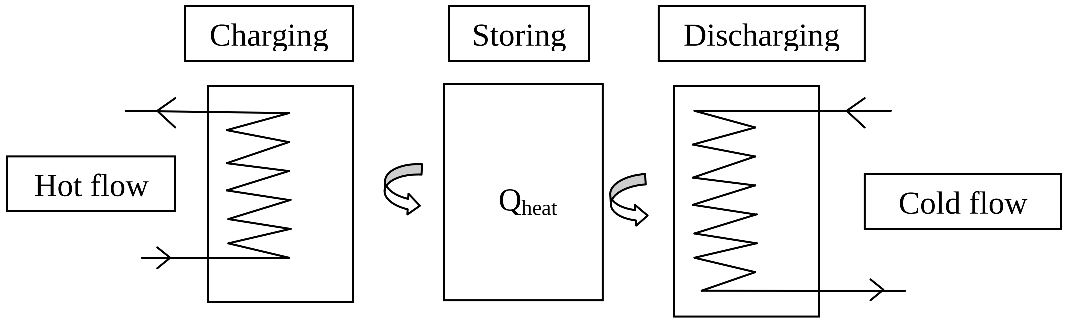

Figure 1: Description of basic process occurs in TES systems. (Source: Ibrahim Dincer and Marc A. Rosen (2002))

The storage system for this project is an example of static storage processes. A complete TES system in tank must undergo a cycle consists of charging, storing and discharging (refer figure 1). From this cycle, the storage medium will be the PCMs and heat exchanger will be the removal and charging elements. Charging process will happen during the liquid (water) from collector (after absorbing heat from solar radiation) will enter the heat exchanger systems and flow thru the container contain PCMs. Heat transfer from hot liquid will be transfer to the PCMs by conductions and PCMs will undergo phase change from solid to liquid (melting process). PCMs will melt due to its own melting temperature.

$$Q_T = m_w C_{p,water} (T_{w,i} - T_{pcm,i}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where Q_T = Amount of heat going to be stored (kW)

m_w = mass flowrate of water (kg/s)

$C_{p,water}$ = specific heats of water (kJ/kg ^oC)

$T_{w,i}$ = temperature of water coming in from solar collector (^oC)

T_{pcm} = temperature of PCMs at room temperature (27^0C)

By referring to equation 4(Sarr, Ahmet and Kaygusuz, Kamil, 2001), can be used to approximately determine the amount of heat transfer from hot water to PCMs at one time. This amount of heat maybe is not enough to solidify all the PCMs in the container. So, the water from solar collector needs to flow from solar collector into TES tank in certain period of time to solidify the PCM state from solid to liquids (refer to equation 5) (Sarr, Ahmet and Kaygusuz, Kamil, 2001).

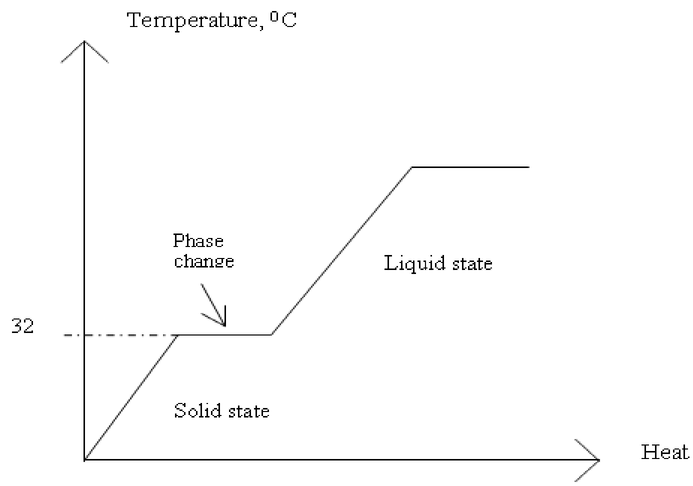

Figure 2: Phase change diagram for PCMs.

$$Q_T = Q_1 + Q_{melting}$$
$$= (m_{pcm}\, C_{pcm,solid\ r}\, \Delta T + m_{pcm} L) \,/\, \Delta t_m \ \ldots\ldots.(5)$$

Where Q_T = Amount of energy stored after PCM completely solidify (kW)

L = Latent heat of PCM (kJ/kg)

Δt_m = total time for PCM to solidify (s)

Moreover, for discharging process (refer equation 6) (Sarr, Ahmet and Kaygusuz, Kamil, 2001), the cold liquid form another source will be flow thru another heat exchanger system. Due to the temperature difference, heat transfer between PCMs and cold liquid will occur by conduction. Furthermore, PCMs undergo phase change from liquid to solid. This cycle will occur repetitive depends on the capacity of heat storage and can last for a longer time (refer figure 2).

$$Q_T = m_w\, C_{p,\,water}\,(T_{pcm,f} - T_{w,i}) \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

Q_T = Amount of heat transferred (kW)

m_w = mass flowrate of water (kg/s)

$C_{p,water}$ = specific heats of solid/liquids states of PCMs (kJ/kg ^{o}C)

$T_{w,i}$ = temperature of water coming in from solar collector (27^{o}C)

T_{pcm} = temperature of PCMs being stored (^{0}C)

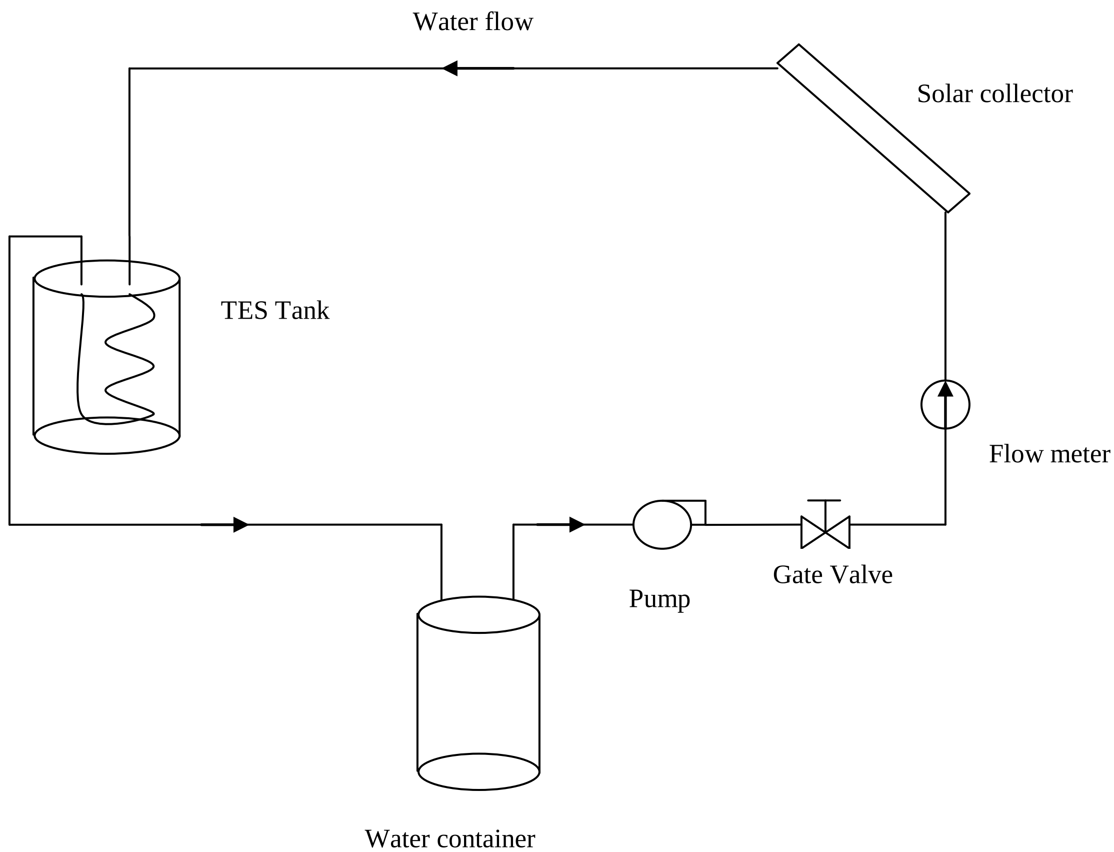

Figure 3: Schematic diagram of TES systems

This TES system shows the PCMs temporarily hold the energy for later use. Furthermore, TES tanks can used for variety of purposes such as heater during winter or provide hot water supply.

For dynamic storage process, a direct contact is established between storage and the heat transfer medium. This storage system behaves as a hybrid storage system, i.e. utilizing all the thermal storage advantages of both the sensible heat of the heat transfer medium and the latent heat of the PCM (Bo He, 2004). There are several conditions in order to use the dynamic system. The conditions are:

- PCM is not soluble in the heat transfer fluid.
- There is a significant difference in density between the PCM and the heat transfer fluid.

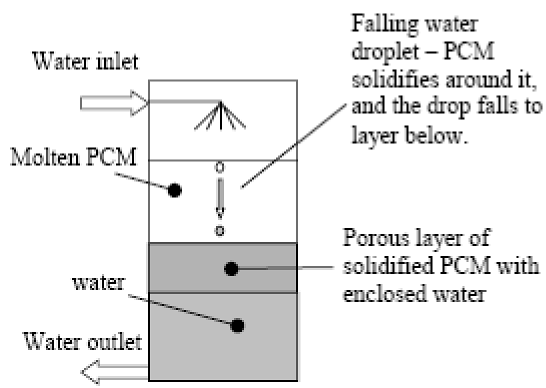

Fig. 4: Dynamic cool storage process during charging. (Sources: Bo He, 2004)

The paraffin PCM-water is an example of dynamic storage process. During the charging process, cold water is sprayed into the tank from the top and drained off from the bottom. When the average temperature of the liquid PCM reaches the freezing point, a PCM shell covers the water droplets and form a layer of water droplets covered by PCM at the interface between the PCM and water. In the discharging process, water at a temperature above the phase change temperature range of the PCM is sprayed into the system, and the frozen PCM will melt. The solid structure of the porous wax provides optimum conditions for the freezing and melting processes since it provides a large surface area for heat transfer.

CHAPTER 3
METHODOLOGY

3.1 Procedure identification

Overall project methodologies for both of semester have been developed to ensure smooth planning on steps to complete the design and development the TES tank. Part of planning consists of literature review, design and details technical drawings development. For second semester part are more on implement all the design into prototype and testing the prototype to ensure it capabilities to meet the project objective.

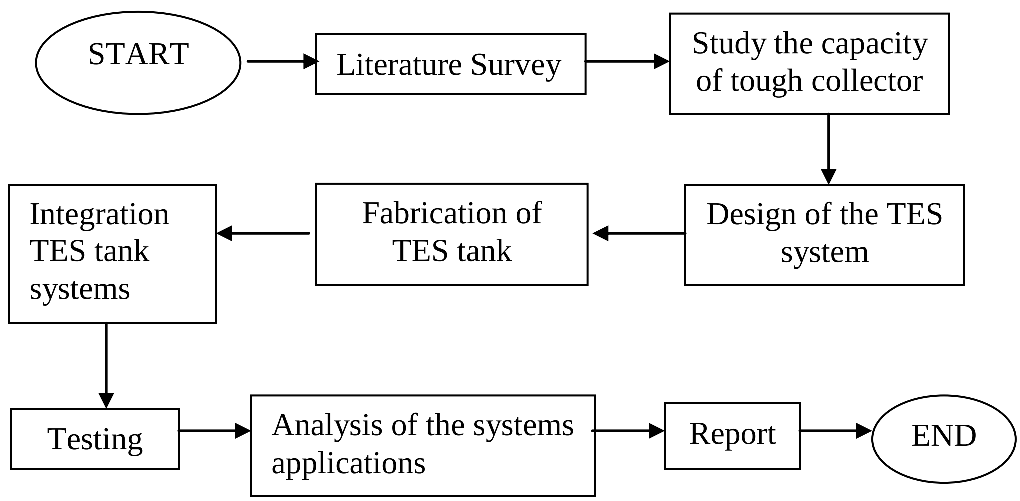

Figure 5: General Project Flow

The literature review involves the study of the basic theories that related to the process of the TES tank. To ensured the process of charging and discharging happen, a suitable PCMs need to be selected and tank need to be design based heat exchanger model with number of coil just to increase the heat transfer rate.

Based on above general project flow, two detailed step by step in completing this project have been construct. It divided into two parts which each part represent each semester project works.

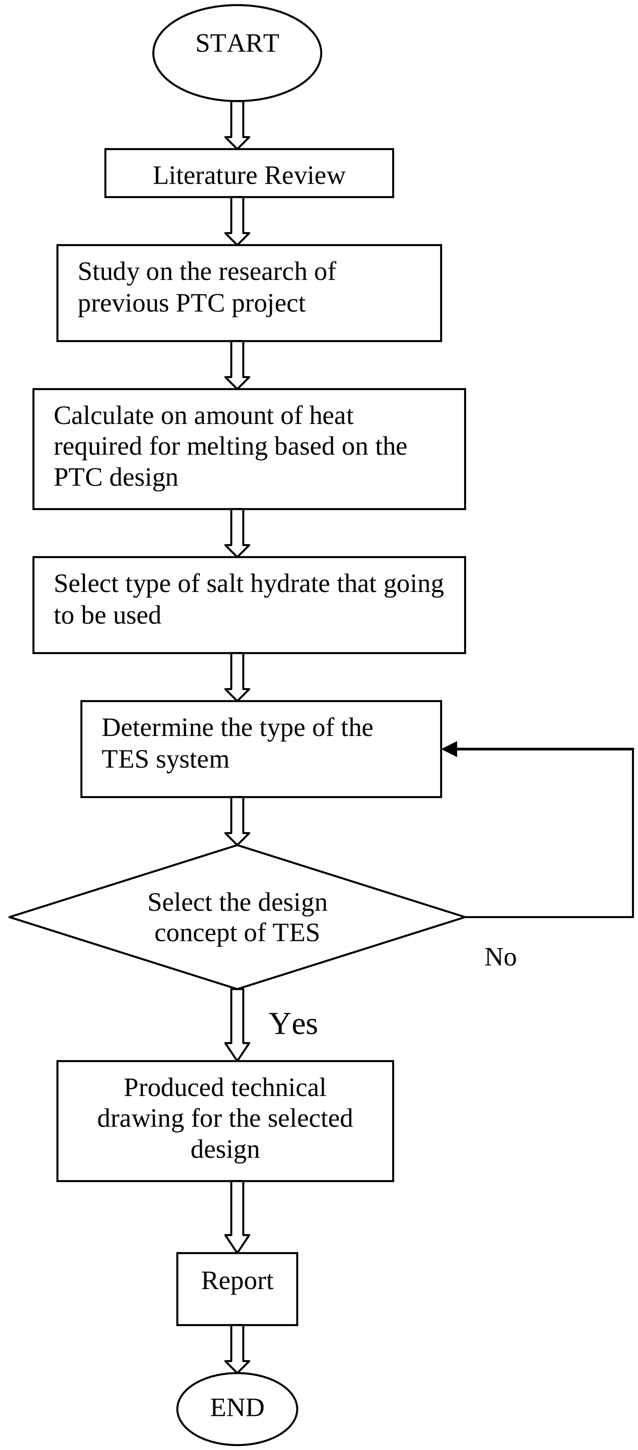

Figure 6: Project work flow for part one (1st semester).

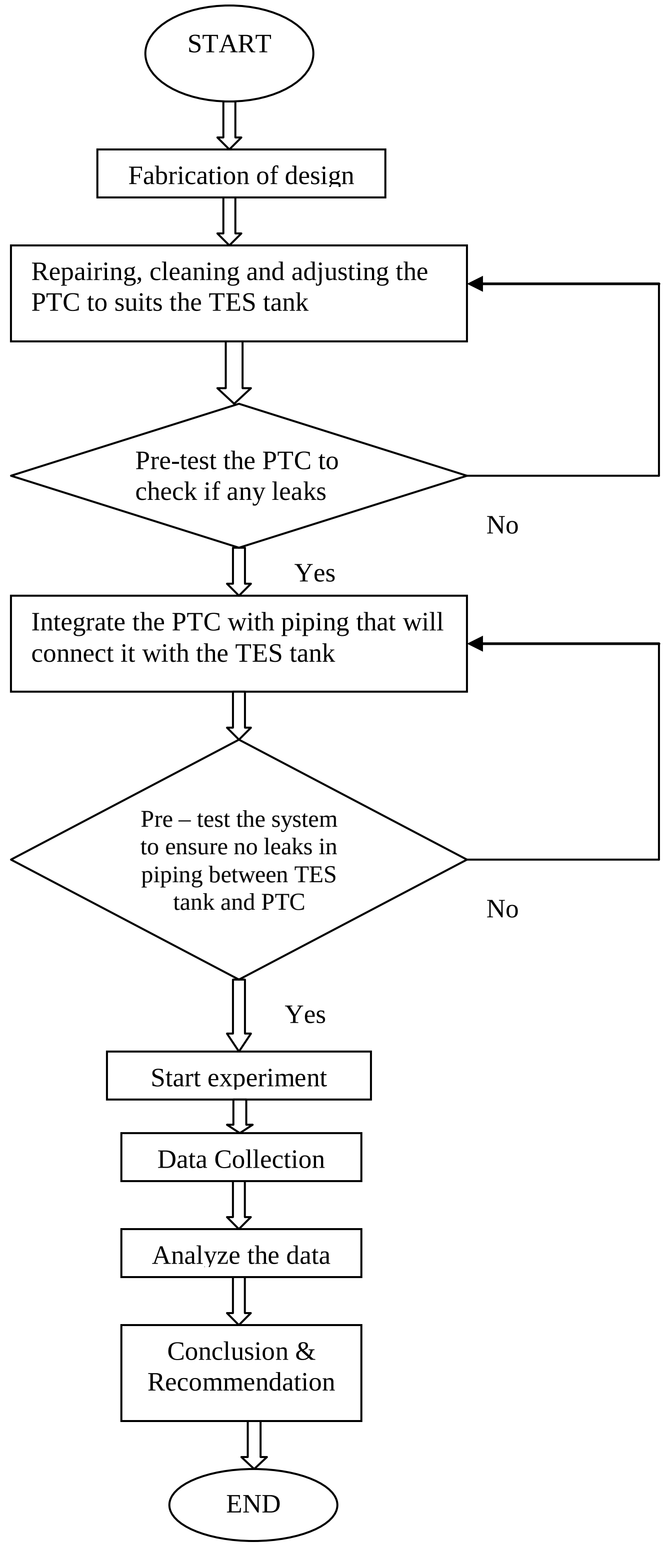

Figure 7: Project work flow for part two (2nd semester).

3.2 Experiment Procedure

An experiment procedure has been developed in purpose as a guideline for conducting the testing on the TES tank. Both experiments for charging and discharging process will be guided thru one procedure.

3.2.1 Procedure

1. Set-up the piping on PTC together with TES tank based on the schematic diagram (refer to figure)
2. Insert digital thermometer at inlet and outlet of the PTC.
3. Ensure all connection is completed. Use tape for any connecting tubes to ensure no leaking occurred during experiment.
4. Pre-test by running the system for one minute for checking purposes.
5. Start the experiment by setting initial flowrate at 40 litre/hour.
6. Take temperature reading at PTC inlet and outlet, TES tank outlet and PCM.
7. Repeat step 1 till 6 for discharging experiment but for step 1, the piping system will only involve the TES tank and the pump only.

3.3 PTC Design parameters

Since using on existing PTC, below are parameters of the PTC design. (Thesis refers to Tsen Wee Yew. (2006)]

- Width of the PTC 1.5m
- Focus length 0.375m
- Rim angle 90^o
- Turn of PTC -45^o to $+45^o$
- Absorber material copper
- Reflector material glass mirror
- Construction materials wood
- Flow rate control device Gate valve

- Overall project mobile on the caster wheel
- PTC integrated to a water system

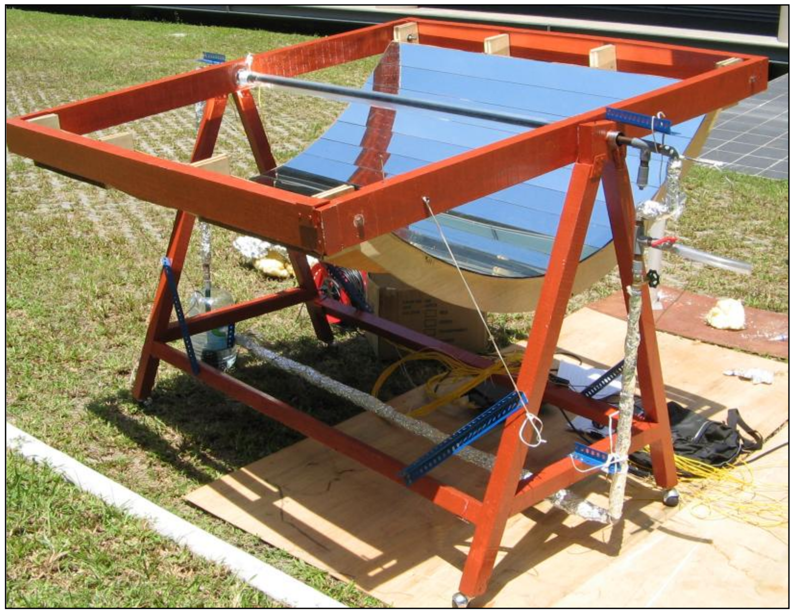

Figure 8: The existing PTC [(Thesis refer to Tsen Wee Yew.(2006)]

3.4 Project Work Activities

The location where the experiment was done is at Block 15. For charging process, the experiment was conducted behind the building at outside area. Area chosen is suitable since the sunlight ray is not covered by the adjacent buildings. To ensure the PTC can collect maximum of heat ray, the experiment were conducted at time 10.00 a.m till 2.00 p.m. where the position of sun is directly over our head. For discharging process, the experiment was conducted inside the building to avoid heat from sun that can affect the result of experiment.

Below are the pictures that describe the activities were done during the experiment and also equipment that being used as part of obtaining the results of the experiment.

Figure 9: Experiment set-up during testing (Charging process)

Figure 10: Experiment set-up during testing (discharging process)

Figure 11: The pump (left side) and TES tank outlet (right side)

Figure 12: Pump with water container and control valve (head pipe)

Figure 13: The TES tank during the experiment

3.5 Tool and Equipments

i. AutoCAD – To design the tank and simulate.

ii. CATIA - To design the tank and simulate.

iii. Manufacturing lab – To fabricate and assemble the tank components.

iv. Flow meter – To set the water flow rate required

v. Digital thermometer – thermocouple (to measure the temperature of the water)

vi. Solar Panel – To generate power for pump by obtaining sources from sun ray

vii. Pump – to pump the water thru the system

Figure 14: Digital thermometer

Figure 15: Flow meter

Figure 16: Solar panel Equipment

CHAPTER 4
RESULT AND DISCUSSIONS

In this chapter, several calculations on determining the size of the coil will be shown and also calculation regarding the amount of heat transfer to the PCMs.

4.1 Designing Calculations

4.1.1 Calculation on length of coil to be used.

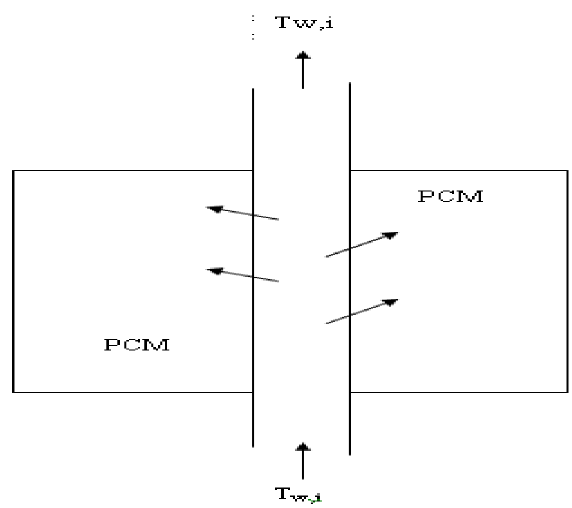

Figure 17: Diagram showing heat transfer form water to the PCM while charging

Assuming m_w = 0.1kg/s,
Calculate the length of coil required based on the charging process.

First, find Q_T that going to be transferred from water to the PCM (refer figure 17)

$$Q_T = m_w C_{p,water} (T_{w,i} - T_{pcm,i})$$
$$= 0.1 \text{ x } 4.179\text{kJ/kg x } (40\text{-}27)$$
$$= 5.4327 \text{ kW}$$

Using the heat exchanger design equation,

$$Q_T = U \text{ x } A \text{ x } \Delta T$$

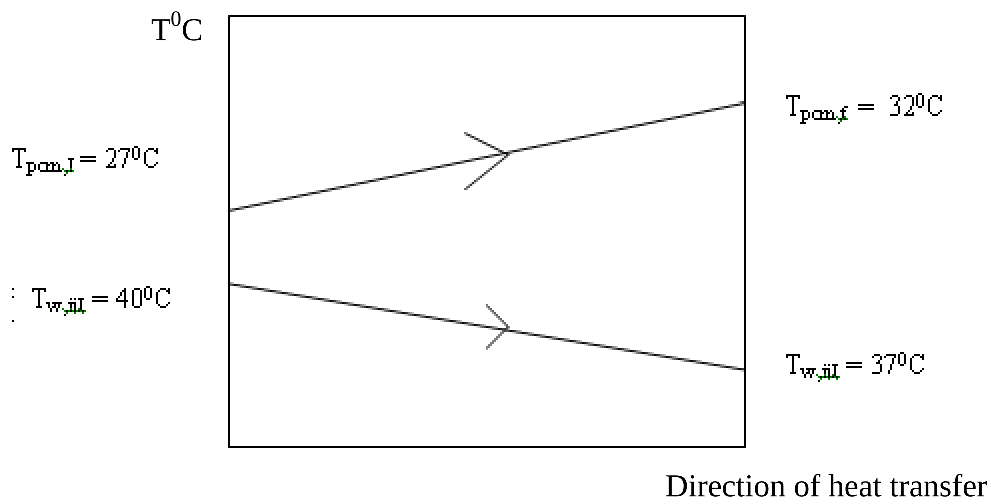

Figure 18: Temperature profile during the charging processes

Based on the temperature profile (refer figure 18),

$$\Delta T = \frac{(Tw,I - Tpcm,f) - (Tpcm.i - Tw,o)}{\ln[\,(Tw,I - Tpcm,f)\ (Tpcm.i - Tw,o)]}$$

$$= \frac{(Tw,I - Tpcm,f) - (Tpcm.i - Tw,o)}{\ln[\,(Tw,I - Tpcm,f)\ (Tpcm.i - Tw,o)]}$$

$$= \frac{(40 - 32) - (37 - 27)}{\ln[\,((40 - 32) / (37 - 27)]}$$

$$= 8.96$$

$$U = \frac{1}{\frac{1}{h_0} + R_{fo} + R_{fin} + \frac{\Delta x_w A_o}{k_w A_m} + R_{fi}\frac{A_o}{A_i} + \frac{1}{h_i}\frac{A_o}{A_i}}$$

Assumption: i) finned are not used in this project

ii) Fouling effect does not occur

$$U = \frac{1}{\frac{1}{h_0} + \frac{1}{h_i}}$$

$U_0 = h_i = h_w = \dfrac{Nu.k_w}{D_{pipie}}$ where Nu = nusselt no.

k_w = thermal conductivity (water)

D_{pipe} = diameter of coil (coil)

Assuming the Dpipe = 0.01m

$$Re = \frac{4m_w}{\pi D\mu} = \frac{4x0.5}{\pi 0.01x656.6x10^{-6}} = 96957$$

Water properties at 40^0C@ 313K

Pr = 4.34, μ = 656.6 x 10^{-6}, k_w = 0.632.

Nu = f(Re.Pr)

= $0.023Re^{0.8}Pr^{0.3}$

= 0.023 $(96957)^{0.8}$ x $4.34^{0.3}$

= 348.53

$$U_0 = h_w = \frac{Nu.k_w}{D_{pipie}} = \frac{348.53x0.632}{0.01} = 22027.1$$

Insert all the parameters into the heat exchanger design equation,

Q_T = U x A x ΔT

5432.7 = 22027.1 x π x 0.01 x L x 8.96

L = 0.876 m.

So, the L_{design} for coil is 3m. From this L_{design}, the coil turns will be determine based on the size of the container.

To determine the actual length that going to be used, L_{design} must be times with three (3) as a safety factor.

$$L_{actual} = L_{design} \text{ x } 3 = 0.876 \text{ x } 3 = 2.63 \text{ m}$$

So the L_{actual} for the coil is 2.63m and its diameter is 0.01 m.

4.1.2. Calculation on tank size

The tank size will be determined from the amount of PCM used.

$m_{pcm} = 5kg$

$\rho_{pcm} = 1485 \text{ kg/m}^3$

$$m_{pcm} = \rho_{pcm} \text{ x } V_{pcm}$$

$$V_{pcm} = m_{pcm} / \rho_{pcm}$$

$$V_{pcm} = 5 / 1485$$

$$V_{pcm} = 3.37 \text{ x } 10^{-3} \text{ m}^3$$

From the $V_{pcm} = 3.37 \text{ x } 10^{-3} \text{ m}^3$, assuming the total volume for tank will be,

$V_{tank} = 4 \text{ x } 10^{-3} \text{ m}^3$.

By taking the D_{tank} = 15 cm and t_{tank} = 5mm, the only parameter need to find are the length, *l* of the tank.

$$V_{tank} = 4 \text{ x } 10^{-3} \text{ m}^3$$

$$4 \text{ x } 10^{-3} = \pi j^2 l$$

$$4 \text{ x } 10^{-3} = \pi \text{ x } (0.075)^2 \text{ x } l$$

$$L = 0.226\text{m}$$

$$= 23\text{cm}$$

So, the size of the storage tank will be length, *L* = 23cm, *D* = 15cm and t = 5mm. Based on the coil and tank size, the final design of the TES tank can be produced.

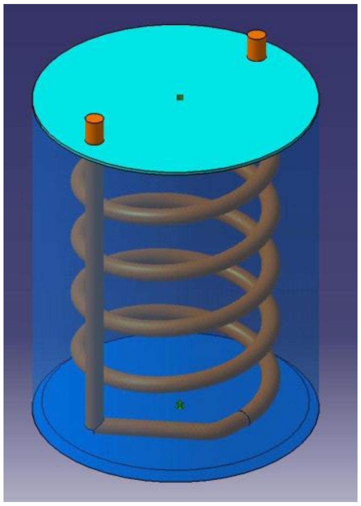

Figure 19: Computer modeling of designed TES tank

4.2 Result of the prototype testing

The experiment was conducted at 20 of April 2009 from local time 1000 to 1500. Solar radiation at that time was about559.9 w/m2. The testing was one of the objectives that require for testing the performance of the salt hydrate using this TES tank. Several parameters are being measured and taken for analysis. Parameters taken such temperature inlet of PTC, temperature inlet of TES tank and temperature outlet of TES tank.

For the testing, two different flowrate have been set to 20 l/h and 60 l/h in order to compare the charging and discharging time required for the PCM. Few observations have been made during the experiment and the data taken have been analyzed.

Figure 18 and 19 are showing the TES tank before the experiment and during the ongoing testing respectively.

Figure 20: TES tank with PCM before testing

Figure 21: TES tank condition at 30 ^{0}C (Phase change of PCM during the experiment)

Below are the graphs that represent the data taken from the experiment for charging process.

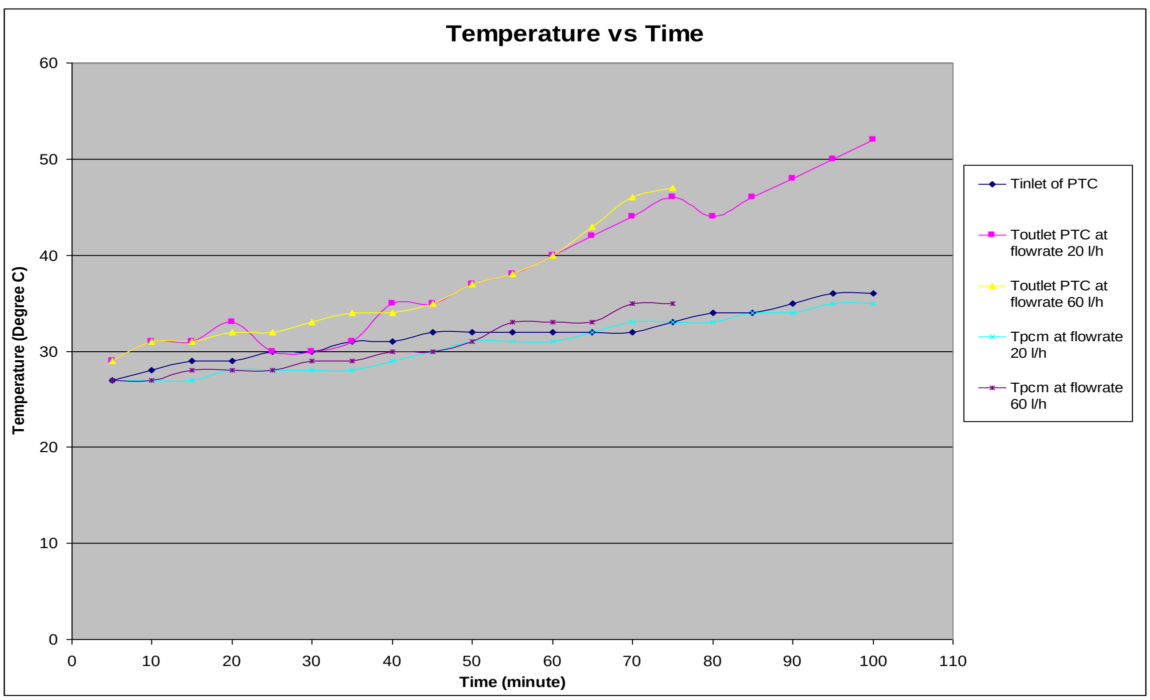

Figure 22: Graph of T_{inlet} of PTC, T_{outlet} PTC at flowrate 20 l/h and 60 l/h, T_{PCM} at flowrate 20 l/h and 60 l/h versus time

Figure 22 represents the temperature outlet of PTC at different flowrate versus time. For temperature inlet of PTC for both flowrate are been assuming same since the water came into the PTC is directly came for the water container and have no effect on the TES tank. Temperature outlet PTC is also known as temperature inlet of TES tank since it is directly connected. With higher water flowrates, it can absorb more heat form the sun as it pass through the pipe glass of PTC. Higher flow rate can increase the heat transfer in the TES tank. It also shown by the T_{PCM} which is less time required to achieve the melting temperature by using higher flowrate. At flowrate 60 l/h, 75 minutes are the time required to melt the PCM compared with flowrate 20 l/h which the time are 105 minutes.

Below are the graphs that represent data taken during the experiment for discharging process.

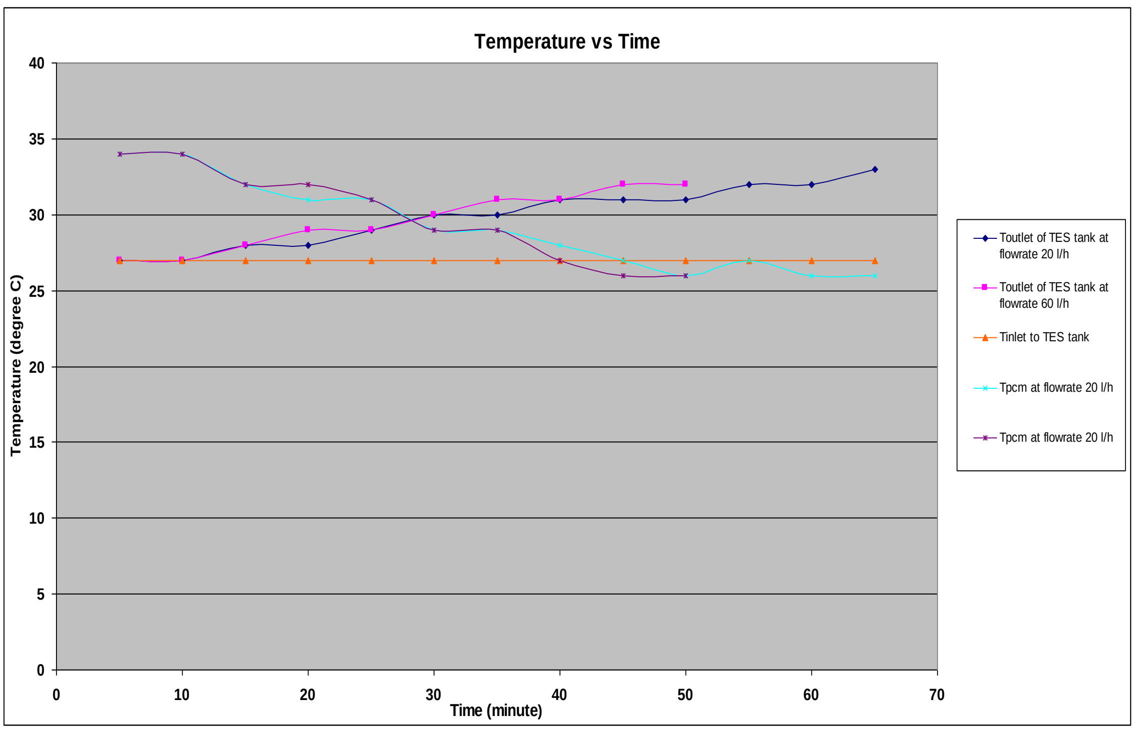

Figure 23: T_{inlet} of TES tank, T_{outlet} TES tank and T_{PCM} at flowrate 20 l/h and 60 l/h versus time

Figure 23 represents the temperature of the inlet and outlet of TES tank and also T_{PCM} at flowrates 20 l/h and 60 l/h. For discharging, the inlet temperature will be the same which is 27^0C (room temperature) since the initial temperature must be lower than the

PCM temperature. The graphs shown that at flowrates 60 l/h, less time is required for PCM phase to change (liquid to solid). It requires about 50 minutes compared to flowrate at 20 l/h which is 65 minutes. One of the reasons is that higher flowrate means higher capacity of water coming in that may have effect on amount of heat can be absorbed from the PCM. It also quicken the time for the phase change to occur as it absorbing more heat.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

As a conclusion, this experiment shows that higher flowrate influence the time required for charging and discharging. Based on the result obtained, for flowrate at 60 l/h, time required for PCM to solidify is 75 minutes with highest temperature of inlet TES tank / outlet PTC is 46 0C. As for flowrate 20 l/h, the time required for PCM to solidify, is 100 minutes with the highest temperature of inlet TES tank / outlet PTC is 52 0C. As for discharging, the temperature if inlet TES is constant which is at ambient temperature (27 0C) as the time for the PCM to change phase (liquid to solid) is 50 minutes and 65 minutes for flowrate at 60 l/h and 20 l/h respectively. From this experiment, it shows that with higher flowrates, less time required for charging and discharging since higher capacity of water (flowrate) can absorb more heat as flowrate at 60 l/h required less time compared to flowrate at 20 l/h.

5.2 Recommendations

Few recommendations have been made for future study of this project. This recommendation can be a guide in order to improve the capability of the TES tank itself by adding some parameters that might have effect on the heat transfer rate on the charging and discharging process.

- Fin can be added up to increase the heat transfer area
- Minimize the lengths of tube used that connect the PTC with the TES tank to minimize the heat loss during the way.
- Try to use another type of PCM such paraffin, fatty acids or another type of salt hydrates

- Try different methods of storing PCM such encapsulation of PCM or use with PCM with other liquids such oil for direct contact method.

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APPENDIXES

Gantt chart for 1st Semester

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10		11	12	13	14
1	Selection of Project Topic											**Mid-semester break**				
2	Preliminary Research Work															
3	Submission of Preliminary Report															
4	Project Research Work (designing)															
5	Submission of Progress Report															
6	Seminar															
7	Project Research work continues (production of fabrication drawing)															
8	Submission of Interim Report Final Draft															
9	Oral Presentation															

Gantt chart for 2nd Semester

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10		11	12	13	14
1	Project work continue											**Mid-semester break**				
2	Submission of Progress Report 1															
3	Project Work Continue															
4	Submission of Progress Report 2															
5	Seminar															
6	Project work continue															
7	Poster Exhibition															
8	Submission of Dissertation (soft bound)															
9	Oral Presentation															
9	Submission of Project Dissertation (Hard Bound)															

Experiment Data

i) Charging process

t(min)	T_{inlet} PTC	m= 20 l/h T_{outlet} PTC	m=60 l/h T_{outlet} PTC	m=20 l/h T_{pcm}	m=60 l/h T_{pcm}	m=20 l/h T_{outlet} TES tank	m=60 l/h T_{outlet} TES tank
5	27	29	29	27	27	27	27
10	28	31	31	27	27	27	27
15	29	31	31	27	28	28	28
20	29	33	32	28	28	29	29
25	30	30	32	28	28	29	30
30	30	30	33	28	29	30	31
35	31	31	34	28	29	31	32
40	31	35	34	29	30	31	32
45	32	35	35	30	30	34	33
50	32	37	37	31	31	34	34
55	32	38	38	31	33	34	37
60	32	40	40	31	33	35	38
65	32	42	43	32	33	35	39
70	32	44	46	33	35	35	39
75	33	46	47	33	35	36	39
80	34	44	-	33	-	37	-
85	34	46	-	34	-	37	-
90	35	48	-	34	-	39	-
95	36	50	-	35	-	40	-
100	36	52	-	35	-	40	-

ii) Discharging process

t(min)	T_{inlet} TES	m= 20 l/h	m=60 l/h	m= 20 l/h	m=60 l/h
		T_{outlet} TES	T_{outlet} TES	T_{pcm}	T_{pcm}
5	27	27	27	34	34
10	27	27	27	34	34
15	27	28	28	32	32
20	27	28	29	31	32
25	27	29	29	31	31
30	27	30	30	29	29
35	27	30	31	29	29
40	27	31	31	28	27
45	27	31	32	27	26
50	27	31	32	26	26
55	27	32	-	27	-
60	27	32	-	26	-
65	27	33	-	26	-