Design of Molten Salt Thermal Storage Tank

By

Mumtaz Hayati Binti Abd Rashid

Dissertation submitted in partial fulfillment

of the requirement for the

Bachelor of Mechanical Engineering (Hons.)

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Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

Mechanical Engineering Programme

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Approved by,

____

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JANUARY 2013

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 the unspecified sources or persons.

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MUMTAZ HAYATI BINTI ABD RASHID

ABSTRACT

Malaysia is located near the equator. Therefore, it receives equal hours of day and night. Malaysia also receives sunshine throughout the year. However it is not continuous. There are days where there is less sunlight due to rain, windy days, monsoon season and etc. The amount of sunlight days in Malaysia is about 60-70% in a year. The amount of solar irradiations receive by Malaysia is approximately 400 to 800 W/m^2. The sunshine during daylight provides us with great quantity of thermal energy. Therefore, solar thermal energy available throughout the day is important to be used for the night time and other sunless days. This paper is prepared to design a Molten Salt Thermal Storage Tank to store an amount of thermal energy for the night usage. This design is conducted based on the weather data obtained throughout year 2008 in Ipoh, Malaysia. The following objectives are to be met for the design of Salt Thermal Storage Tank:

1. To calculate the available amount of solar energy during the day time.
2. Select a suitable media (molten salt) to store thermal energy.
3. To design an underground thermal energy storage to store the excess energy during the daytime.

Designing a storage tank is to conserve the thermal energy that is produced by the sun during the day and use the stored thermal energy to be converted to electricity using turbines. This report includes the selection of material and the design of the thermal storage tank. Research and analysis have been done to determine the available solar radiations which will be used to calculate the available amount of heat energy that can be stored daily. The design of the Molten Salt Thermal Storage Tank is designed based on the calculations done using the available weather data. The results show the daily available power in Ipoh would be 3000Whr/m^2. This includes approximately 6 hours of sunshine daily. For this design, Sodium Nitrate ($NaNO_3$) is used as the heat transfer fluid. An insulated storage tank of volume 1.8 m^3 containing 0.85 m^3 of $NaNO_3$ is placed underground to reduce the heat loss. The amount of energy stored in the storage tank is 20 MJ daily.

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1 INTRODUCTION

1.1 PROJECT BACKGROUND

Malaysia is a tropical country where the temperature is mostly hot. It is located at a latitude and longitude of 3°7'N and 101°33'E with an altitude of 27m (89 ft). The temperature in Malaysia has an average of 27.5°C (82°F) and can reach up to 33°C (91°F) in Kuala Lumpur from February until June. Malaysia has the lowest temperature as low as 22°C (72°F) in January, February, July, September and December[2]. In Malaysia, there is two monsoon seasons, which are the Southwest Monsoon and Northeast Monsoon which occurs from May to September and November to March respectively. The Southeast Monsoon is particularly a season where it normally indicates relatively drier weather, while, the Northeast Monsoon season produces heavy rainfall especially to the east coast of Peninsular Malaysia and western region of Sarawak. An average range of sunshine hours in Malaysia is between 4.9 hours per day in November and 7.4 hours per day in February. In remainder, there are 2228 more sunshine hours every year and roughly 6.1 hours of sunlight per day.[1]

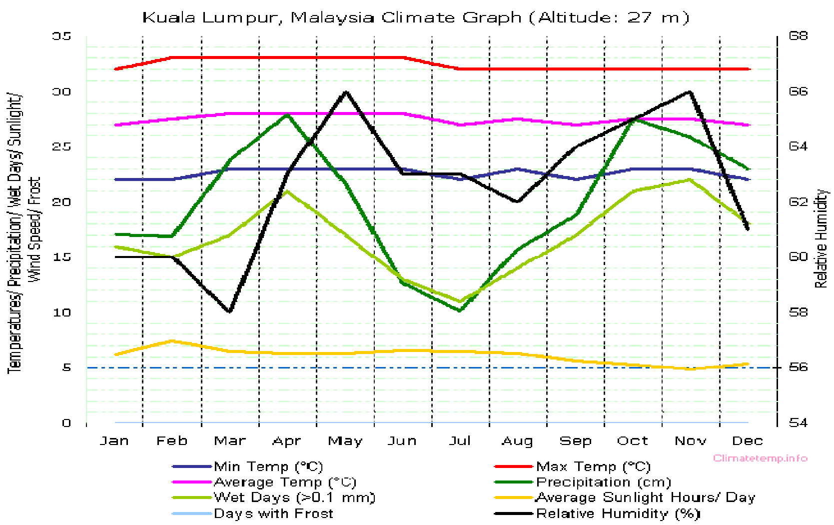

Figure 1: Graph of Malaysia Climate [2]

As a true fact, the increase in temperature is due to the high content of Carbon Dioxide gas (CO_2) in the atmosphere and causing more and more of greenhouse effects. So in this term, I managed to find and come out with an advantage of this hot weather condition in Malaysia. I decided to use this solar energy system and transmit this energy to electrical energy. This would not only lessen the usage of core resources but also, help to conserve the earth and lessen the greenhouse effect.

1.2 PROBLEM STATEMENT

Since the daylight provides the maximum amount of radiation by the sun, it is needed for these radiations to be collected and stored for night usage. Malaysia is located near the equator; meaning that, Malaysia receives a lot of sunshine in a day and is available throughout the year. Also, due to this reason, Malaysia will experience a few days of minimal sunshine in a year. Designing a storage tank is to conserve the thermal energy that is produced by the sun during the day and use the energy stored.

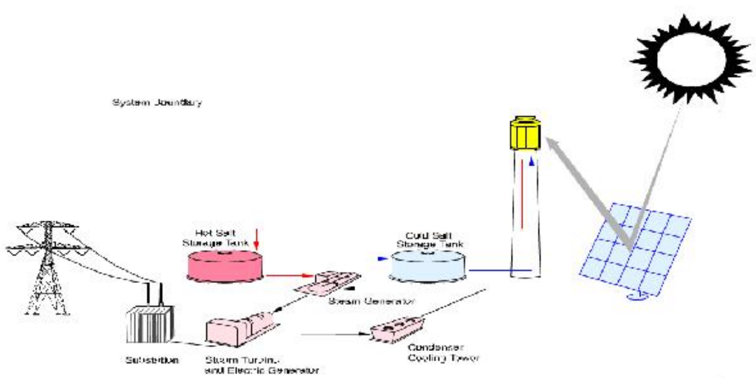

Figure 2: Solar Thermal Storage System [12]

Figure 2 shows a schematic drawing of the solar thermal storage system. As the solar radiation collected using the collector, heat gained is then transported using molten salt to the underground thermal storage tank. In the thermal storage tank, heat is transferred and stored using molten salt contained in the tank. The low temperature molten salt suspended at the bottom of the tank is pumped back to the collector to repeat the cycle. The heat in the storage tank is maintained using heater embedded to ensure the salt is above its solidus temperature. The heat exchanger is used to supply electricity to the generator.

1.3 PROBLEM IDENTIFICATION AND PROJECT SIGNIFICANCE

A tank needs to be produced in able to store thermal energy from the solar radiation collected by a tower using molten salt or any other chemical that may store thermal energy. This tank should be able to store the energy that will be used to be converted to electrical energy throughout the monsoon season in Malaysia, which occurs from November to March each year.

The significance of this project is to be able to understand the renewable source i.e. the solar energy and how it can be useful to humans. Therefore, doing a research on the solar energy and how it is able to be conserved while help to be one of a great source of power. Apart from that, individually it can add up the knowledge on energy consumption and also create awareness about the energy on earth.

1.4 OBJECTIVES OF THE STUDY

This project is aimed to meet the following objectives:

4. To calculate the available amount of solar energy during the day time.
5. Select a suitable media (molten salt) to store thermal energy.
6. To design an underground thermal energy storage to store the excess energy during the daytime.

1.5 RELEVANCE OF STUDY

The study is in the scope of energy conversion which relates to the subject studying in Final Year semester. In this way, it is able to know about how the energy on earth can be used wisely. Therefore, it will give ideas and understandings in the courses taken in the Final Year studies.

1.6 FEASIBILITY OF STUDY

This research can be done in the period of 8 months as it requires only the design of the storage tank and the driving mechanism of the thermal energy.

2 LITERATURE REVIEW

2.1 CRITICAL ANALYSIS OF LITERATURE

2.1.1 Solar Constant

Sun is the source of the solar energy. Sun provides two components to the earth namely heat and light. The properties of the sun are as the followings:

- Diameter: 1.27 x 10^4 km
- Distance from earth: 1.5 x 10^8 km
- Mass: 1.989 x 10^{30} kg
- Temperature at Surface: 5778 K
- Temperature at core: 1.6 x 10^7 K
- Age: 4.5 billion years old
- Consists of 70% of hydrogen and 28% helium gasses of its mass

Solar constant, I_{SC}, refers to the rate solar energy travels to the outside of the earth's atmosphere. This occurs at the mean distance between the sun and earth, measured by unit surface perpendicular to the solar beam. The standard value for the solar constant is 1353 W/m^2.[3]

2.1.2 Solar Radiation

The solar radiation travels to earth in two ways, directly and diffusion. The radiation travels to the earth directly means that there are no obstacles in the air. Meanwhile, radiation diffuses in the air to the earth due to a few reasons [3]:

- Absorption by air molecules in the air
- Scattered by gas molecules
- Reflected by the clouds

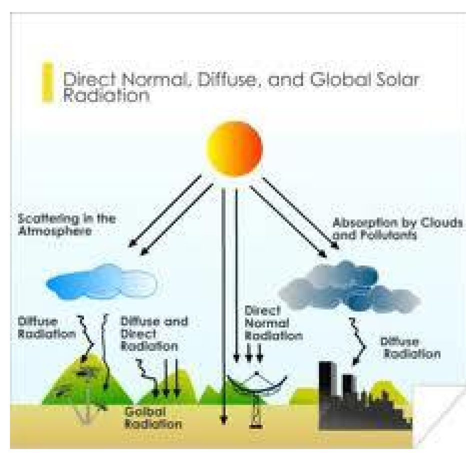

Figure 3: Radiation Path to Earth Surface[4]

2.2 THERMAL STORAGE

Thermal storage tank must be designed following the standard codes available. It is to be tested one and a half times rated pressure. Energy is collected by the solar collector and has to be stored for a long period of time. There are a few methods of thermal energy storage:

2.2.1 Chemical for Thermal Storage

i. Criterion for Chemical for Thermal Storage

The chemical selection for thermal storage tank depends on the following [5]:

i. High Density
ii. High Latent Heat of Fusion
iii. High Thermal Conductivity
iv. Small Temperature Difference

ii. Medium Selection

Storage can be accomplished in two methods: thermally (Sensible heat and Latent heat) or chemically (bond heat reaction).

i. *Sensible Heat:* A process of heating liquid or solid without changing the phase. The temperature change of the material determines the amount of energy stored. The highest possible heat capacity of the phase is the maximum energy.

ii. *Latent Heat:* A process of heating liquid or solid changing the phase. The mass and latent heat fusion of material determines the amount of energy stored. At melting point, this method of storage occurs isothermally.

iii. *Bond Heat:* Absorption and release processes in chemical bond reaction of one or more chemical compound, energy is stored. The most preferable reaction for thermal storage is endothermic reversible reaction. This is due to the ability of releasing heat when reversed. Chemical produced can be stored and transported easily.

Table 1: Methods of Thermal Storage

Storage Method	Form	Advantages	Disadvantages	Medium
Thermal	Sensible Heat Storage	1. Simpler in design	1. Often difficult to judge the correct thermal mass required for space heating requirements 2. energy cannot be stored or released at a constant temperature 3. Bigger in size 4. Low heat capacity storage 5. Non-isothermal behavior during heat storage (charging) and heat release (discharging) process.	Water, rock, pebbles, heat transfer oil, refractory and etc.
	Latent Heat Storage	1. Heat storage and delivery normally occur over a fairly narrow temperature range the phase change temperature. 2. Stores higher volume of energy 3. Provides a high-energy storage density 4. Store heat at constant temperature corresponding to the phase transition temperature of the heat storage substance.	1. Storage of heat cannot be detected from the temperature as the melting proceeds at a constant temperature.	Ammonia, Oxygen, Helium and etc.
Chemical	Organic Compounds	1. Posses wide range of high melting point 2. Non-toxic 3. Non-corrosive 4. Non-hygroscopic 5. Chemically stable 6. Compatible with most building materials 7. Have a high latent heat per unit	1. High cost 2. Low density 3. Low thermal conductivity compared to inorganic compound 4. Addressed by addition of a filler with a high thermal conductivity or the use of aluminum	Octadecane,Eicosane, Paraffin

		weight 8. Melt congruently 9. Exhibit negligible super cooling which has plagued some inorganic compounds	honeycomb or matrixes 5. They are also subject to substantial changes in volume upon melting, which can result in the material detaching from the sides of its container when it freezes, which can affect the heat transfer process.	
	Inorganic Compounds (salt hydrates or molten salt)	1. Low cost compare to organic compound. 2. High latent heat per unit mass and volume 3. High thermal conductivity compared to organic compound 4. Wide range of melting point (7 - 117°C)	1. Suffer from loss of water when subjected to long term thermal cycling due to vapor pressure although prevented by airtight containerization. 2. Corrosion 3. Decomposition	1. Sodium sulphate decahydrate 2. Calcium chloride hexahydrate 3. Zinc nitrate hexahydrate
	Eutectics	1. More interesting point to their individual and separate compounds.	1. Costly	1. Palmatic acid 2. Mystiric acid 3. Stearic acid

Table 2: Comparison between the different methods of heat storage [8]

Property	Rock	Water	Organic PCM	Inorganic PCM
Density kg/m3	2240	1000	800	1600
Specific heat, kJ/kg	1.0	4.2	2.0	2.0
Latent heat, kJ/kg	-	-	190	230
Latent heat, kJ/m3	-	-	152	368
Storage mass for 10^6 J, kg	67 000	16 600	5300	4350
Storage volume for 10^6 J, m3	30	16	6.6	2.7
Relative storage mass	15	4	1.25	1.0
Relative storage volume	11	6	2.5	1.0

2.2.2 Storage Material

Table 3: Storage Tank Material [9]

Material	Density (kg/m3)	Heat Capacity (J/kgK)	Volumetric Heat Capacity (kJ/m3K)	Thermal Conductivity (W/mK)
Aluminum	2700	896	2419	204
Rock	2560	960	2458	0.48
Steatite	2680	1068	2862	2.5
Steel	7800	571	4454	50
Concrete	2000	880	1760	2.2
Copper	8960	380	3450	386

The table above shows the thermal properties of the material used for thermal storage tank. Both copper and steel have high densities and volumetric heat capacity of 8960 kg/m3, 7800 kg/m3, 4454 kJ/m^{3}K and 3450 kJ/m^{3}K respectively. Steel has 4454 kJ/m^{3}K of volumetric heat capacity while copper sustains 3450 kJ/m^{3}K. However, copper has higher thermal conductivity which is 386 W/mK compared to steel which has thermal conductivity of 50 W/mK. In building the thermal energy storage tank, it is important to make sure that the density, heat capacity, volumetric heat capacity and thermal conductivity to be at a high value. From this data, leaves two suitable choices: steel and copper. The tables below show the advantage and disadvantages of steel and copper to be considered in the design.

Table 4: Advantages and Disadvantages of Steel

Advantages	Disadvantages
• Has highest strength to weight ratio of any building material • Provides constant material quality • Fire resistant, does not burn and will not contribute fuel to the spread of fire. • Inorganic; it will not rot, split, crack or creep. • No twisting or warping. • Fire parapets can be eliminated. • Easily disassembled for repairs/alterations/relocation Vandal	• Heavy and thus expensive to transport, susceptible to corrosion. • Have a high expansion rate in changing temperatures, and this must be allowed for in the engineering. • Energy intensive to produce. • Susceptible to corrosion in outdoor atmosphere • Poor resistance to heat - Requires fireproof treatment • Ignites materials in contact and causes

resistant. • Produces less scrap and waste (2% for steel vs. 15-20% for wood). • Scrap is 100% recyclable. • Slower aging process with less maintenance. • Can be recycled • Cost effective and quick to build • Durable and safe • Environmentally friendly • Earthquake tested • Easy to transport • Cheap • Readily available • Can absorb energy form earthquake • Ductile • Toughness	fire • Susceptible to fatigue • Large variations in tensile strength exposes to excessive tension which reduces its overall strength • Susceptible to brittle fracture when lose ductility • Insurance costs are high • Prone to fracture • High maintenance cost and Fireproofing cost • Susceptibility to buckling • Brittle fracture • Poisonous to fish and marine orgasm • Less stable against fire

Table 5: Advantages and Disadvantages of Copper

Advantages	Disadvantages
• Good conductor, malleable and ductile so make it good for bending copper pipes into shapes. • It has an attractive look and very durable. • Good corrosion resistance • Leak-proof jointing system • Long lasting • Excellent pressure handling capability • Versatile • Low coefficient of linear expansion • Health benefit • Fire resistant • High electrical and thermal conductivity	• Expensive • Light • Low strength and hardness

Based on the literature review above on the properties of the material of steel and copper, copper has more advantages as compared to its disadvantages. However, it is decided to experiment steel as the storage material for the Design of Molten Salt Thermal Storage Tank.

3 METHODOLOGY

3.1 RESEARCH METHODOLOGY

For this study, there are three parts of research: Design of Thermal Storage Tank, Chemical for Storage and Driving Mechanism of Solar Energy. For this study, research will be done accordingly using the internet and other written references i.e. books, articles, journals and etc. The steps in designing the storage tank are presented in the flowchart below:

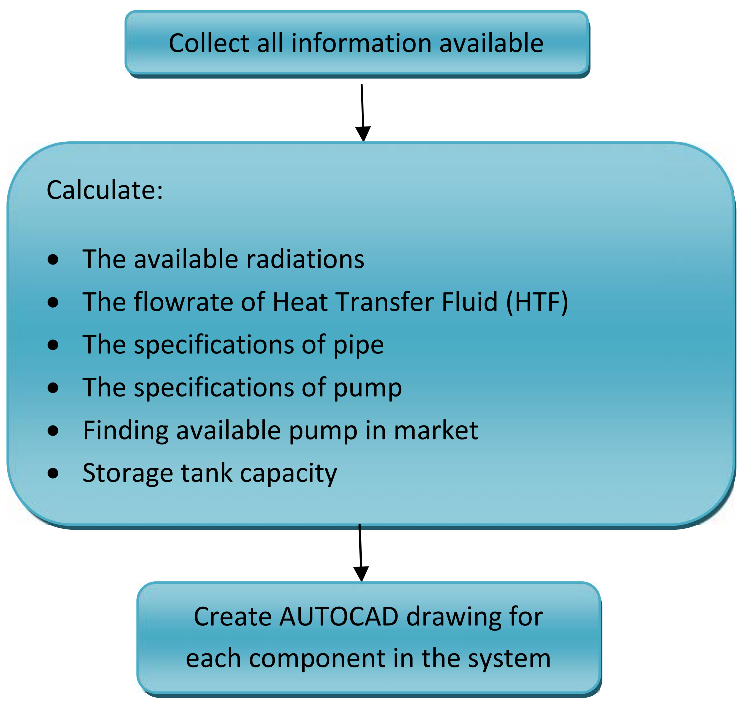

Figure 4: Research Methodology

3.2 PROJECT ACTIVITIES

The activities for the project include:

- Designing the storage tank
- Chemical storage selection
- Driving mechanism path for solar energy storage design

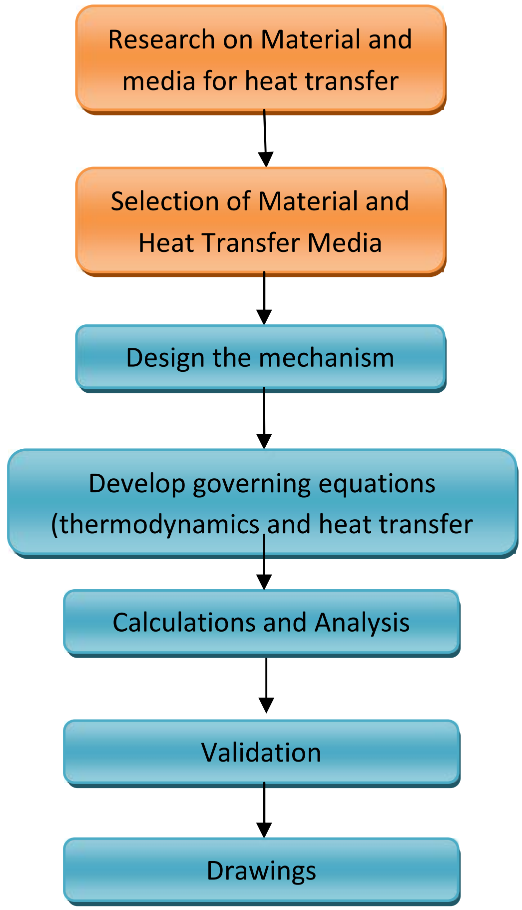

Figure 5: Flowchart of Project Methodology

3.3 KEY MILESTONE

3.3.1 Materials

Currently, researches have been done and the selected media is Potassium Nitrate (KNO_3) and the storage material to be used is Steel.

Table 6: Materials for the Design

Storage Material	Steel
Storage Media	Potassium Nitrate
Receiver Material	Copper
Pipe Material	Steel

3.3.2 Governing Equations

For the calculations, the below equations are used to determine the parameters required for the design of the molten salt storage tank.

3.3.2.1 Available Solar Radiations Daily

$$Q_A = I \times Hr_{sunshine} \quad \text{...(1)}$$

Where:	Q_A	Total Energy (Whr/m^2)
	I	Radiation Available (W/m^2)
	$Hr_{sunshine}$	Sunshine hours available daily (hr)

3.3.2.2 Energy Reflected

$$Q_{ref} = Q_A \times \eta \quad \text{.................................(2)}$$

Where:	Q_{ref}	Total energy reflected by heliostats (Whr/m2)
	Q_A	Total energy available (Whr/m2)
	η	Efficiency

3.3.2.3 Radiation Heat Loss

$$Q_{rad} = \varepsilon \times \sigma \times A_s \times (T_s^{\,4} - T_{ã}^{\,4}) \quad \text{.................................(3)}$$

Where:	Q_{rad}	Radiation reflected by heliostats (Whr)
	ε	Emissivity of surface
	σ	Stefan-Boltzmann Constant (5.67 x 10^{-8} W/m^2.K^4)
	A_s	Total area of surface (m^2)
	T_s	Surface temperature (K)
	$T_{ã}$	Sky temperature ($0.0552T_{ambient}^{1.5}$ K)

3.3.2.4 Convection Heat Loss

$$Q_{conv} = h \times A_s \times (T_s - T_f) \quad \text{.................................(4)}$$

Where:	Q_{conv}	Convection heat loss (Whr)
	h	Heat transfer coefficient (W/m^2°C)
	T_s	Surface temperature (°C)
	T_f	Fluid Temperature (°C)

3.3.2.5 Energy Absorbed

$$Q_{abs} = n \times C_p \times \Delta T \quad \text{.................................(5)}$$

Where:	Q_{abs}	Energy absorbed (W)
	m	Mass of fluid (kg)
	C_p	Specific heat capacity (kJ/kg)
	ΔT	Temperature difference (K)

3.3.2.6 Area of image created at the receiver

$$A_{surr-rec} = \eta_{spill} \times A_{image} \quad \text{...(6)}$$

Where:	$A_{surr\text{-}rec}$	Area of image created at the receiver (m^2)
	A_{image}	Image area of the sun reflected (m^2)
	η_{spill}	Spillage losses (%)

$$A_{image} = [И_{\ heliostat} + 0.00925 D_{air}] \times [L_{heliostat} + 0.00925 D_{air}] \quad \text{........(7)}$$

Where:	A_{image}	Image area of the sun reflected (m)
	$W_{heliostat}$	Width of a heliostat (m)
	$L_{heliostat}$	Length of a heliostat (m)
	D_{air}	Air distance between the heliostat location and the receiver (m)

$$D_{air} = \frac{H_{tower}}{\cos\theta_{rec}} \quad \text{....................................(8)}$$

Where:	D_{air}	Air distance between the heliostat location and the receiver (m)
	H_{tower}	Height of the tower (m)
	$-_{rec}$	Rim angle (deg)

$$\cos(\theta_{rec}) = \tan^{-1}\frac{D_{ground}}{H_{tower}} \quad \text{.........................(9)}$$

Where:	D_{ground}	Ground distance between the heliostat and the receiver (m)
	H_{tower}	Height of the tower (m)
	$-_{rec}$	Rim angle (deg)

3.4 PROGRESS PLAN

For this study, the activities are planned for a total of 8 months. This is enough time for all three (3) project activities. The activities are completed in time according to the planned schedule in the Gantt chart below:

Table 7: Gantt chart for Project Progress

No	Project Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Final Year Semester I															
1	Title Selection and Proposal	■	■	■											
2	Literature Review, Extended Proposal			■	■	■	■								
3	Submission of Extended Proposal						■								
4	Solar Energy Research	■	■	■	■										
5	Chemical Thermal Storage Research and Selection	■	■	■	■	■	■	■							
6	Material for Tank Research	■	■	■	■	■	■	■	■	■	■				
7	VIVA: Proposal Defense								■	■					
8	Final Report										■	■	■	■	■
Final Year Semester II															
1	Further research on materials	■	■	■	■										
2	Tank Design	■	■	■	■										
4	Progress Report Due					■	■	■	■						
6	Preparation for Pre-SEDEX								■	■	■	■			
7	Pre-SEDEX											■	■		
8	Final Report													■	■
9	Technical Report Submission													■	■
10	Viva													■	■

3.5 TOOLS

Engineering software, Automated Computer-Aided Design (AutoCAD) is used for designs of the storage tank.

4 RESULTS AND DISCUSSION

4.1 DATA GATHERING AND ANALYSIS

Using the equations mentioned in the previous chapter, the results obtained are as follow:

Table 8: Available Radiation daily

Available Radiations		
Ambient Temperature	**30**	°C
Radiation available	**500**	W/m2
Daily sunshine hours	**6**	hr
Daily Available Radiation	**3000**	Whr

The ambient temperature and the radiation available refer to the daily average value in Ipoh, Perak, Malaysia. The sunshine hours refers to the duration of sunshine that is received in the particular area. The daily available radiation is calculated using equation (1) in the previous chapter, where both available radiations and sunshine hours are constants.

Table 9: Heliostat parameters

Heliostat Data		
Number of heliostat	**3**	nos
$W_{heliostat}$	**1.65**	**1.9**
$L_{heliostat}$	**1.9**	**3.3**
Area of heliostat	**12.54**	m^2
Total Area reflected	**12.56**	m^2

The table above shows the calculations for the total reflected area where it is the sum of the area of each heliostat. There are 3 heliostat considered in this study where, the dimensions are 3.3 x 1.9 and two 1.9 x 1.65. The total area reflected by the heliostat is 12.56 m^2.

Table 10: Heat available at the receiver

Receiver Data		
D_{ground}	**5**	m
H_{tower}	**6**	m
Spillage	**0.96**	-

cos(rim)	**39.81**	-
D_{air}	**0.15**	m
A_{image}	**12.56**	m2
$A_{surr-rec}$	**12.05**	m2
Q_{rad}	**34718**	W
ε	**0.07**	-
σ	**5.67E-08**	$W/m^2.K^4$
T_{rec}	**377**	°C

Table 7 above shows the results obtained using equations (2), (6-9). The equations calculate the amount of energy received by the reflected solar radiations. In this calculation, Stefan Boltz-man constant is used which is 5.67 x 10^{-8}. The heat radiation energy increases when the distance on the ground between the heliostat and tower (D_{ground}) decreases. This occur the opposite for the height of the tower (H_{tower}). This means that when the height of the tower increases, the energy received at the receiver also increases. When both the values of D_{ground} and H_{tower} increase, apparent change in the total area of the heliostat (A_{image}) occurs, however, for the area of the image on the receiver ($A_{surr-rec}$), it only changes slightly and not as high as A_{image}. The emissivity value (ε) depends on the type of coating used for the solar plate at the receiver.

From the data obtained above, the available and reflected radiations and are as the calculated using equations (1) and (2). The following graph represents the radiations available and reflected radiations of day in Ipoh.

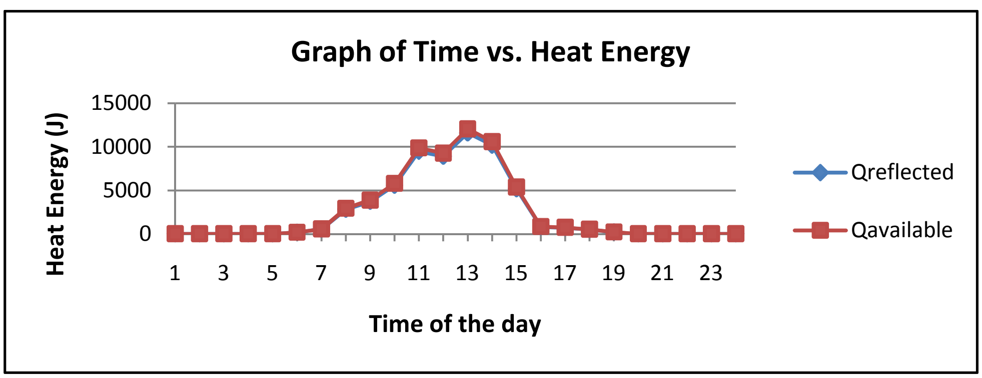

Figure 6: Graph of Heat Available Heat Energy Daily

Based on Figure 6, the reflected radiations are nearly the same amount as the available radiation. This is assumed that the heliostat has 96% efficiency. Using the equations (2) and (3) to find the absorbed and heat losses at the receiver, the results obtained are shown in the table below:

Table 11: Calculated Energy

Absorbed Heat Energy	75 MJ
Total Heat Loss	55 MJ

The heat absorbed at the receiver is temperature dependent. Higher surface temperature will increase the heat energy absorbed. The emissivity of the receiver relates to the type of material used. Higher emissivity of the material reduces the surface temperature. Therefore, the absorption of heat energy also decreases. This is proved by the graph below.

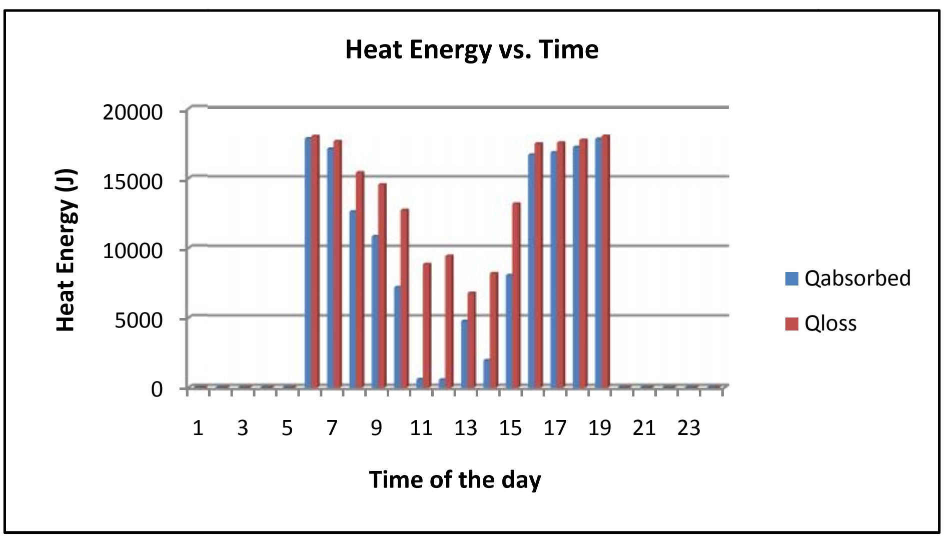

Figure 7: Graph of Heat Energy Absorbed and Lost Daily

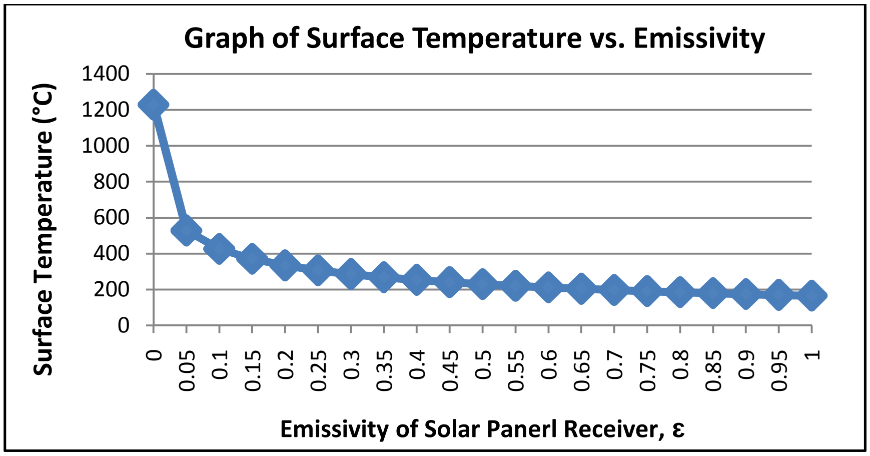

Figure 8: Surface Temperature vs. Emissivity

Based on the results obtained above, the storage tank can be designed. It is calculated using 3000Whr/m^{2}daily radiation. The results are on daily basis. The results are presented in the tables below.

Table 12: Molten Salt Details

Mass Flowrate	0.089 kg/s
Molten Salt	Sodium Nitrate ($NaNO_3$)
Storage Tank Volume	0.85 m^3
Total Energy Stored Daily	22.8 MJ

Table 13: Storage Tank Details

Type of tank	Cylindrical Pressure Tank
Dimensions	∅1472 OD x 1.5m x 0.1m wt
Pressure of Salt	11 kPa
Material	Steel
Volume	2 m^3

Note: Refer to drawing in Appendix I

This design does not include the steam generator. Therefore, the design only limits up to the cycle of the molten salt in this system. The pipes used are steel pipes of 4`` OD carrying 0.089kg/s sodium nitrate ($NaNO_3$) molten salt. The storage tank has an efficiency of 18% to store daily energy. It is assumed that there are no heat losses in the pipes and pump. The pipes and pump are selected based on the availability from manufacturers based on the designed requirements. The thermal storage tank is insulated to overcome heat loss and a heated is attached at the base to ensure that the molten salt does not solidify or crystallize. The storage tank is placed underground to decrease heat loss due to the changing weather, moving air and also other related factors.

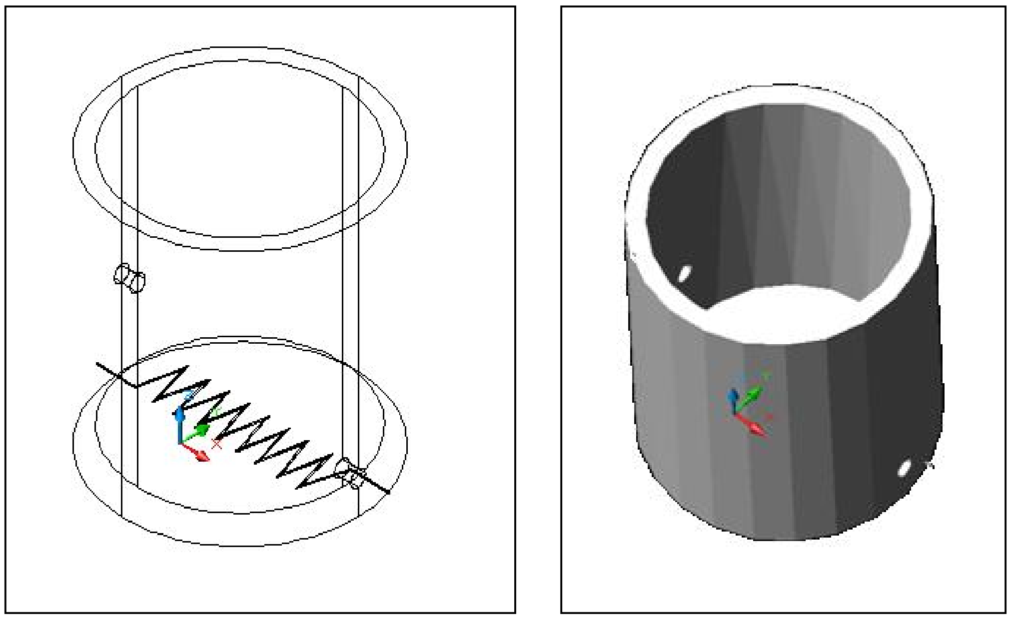

Figure 9 : Drawing of Molten Salt Thermal Storage Tank

5 CONCLUSION

The study shows that it is possible to generate high temperature at the solar tower receiver using 3 heliostats, one 3.3 x 1.9 and two 1.9 x 1.65 giving a total of 12.4 m^2 up to 300°C. Using this temperature it is possible to use the proposed molten salt to operate the turbine in order to generate electricity. The available power daily in Ipoh would be 3000Whr/m^2. This includes approximately 6 hours of sunshine daily. For this design, Sodium Nitrate ($NaNO_3$) is used as the heat transfer fluid. An insulated storage tank of volume 1.8 m^3 containing 0.85 m^3 of $NaNO_3$ is placed underground to reduce the heat loss. The amount of energy stored in the storage tank is 20 MJ daily. The pressure cylindrical thermal storage tank is placed underground to reduce heat losses. The thermal storage tank stores 18% of energy from the available radiations.

RECOMMENDATIONS AND SUGGESTIONS FOR FURTHER PROGRESS

To increase the amount of heat, the amount of reflected radiations is increased. The solar tower can be placed at a higher location to achieve higher amount of radiation. By increasing the number of heliostat and its efficiency, higher amount of radiations and heat energy can be absorbed. As the area of the heliostat field is wider, the temperature of the tower receiver will be higher which indicates the large amount of heat energy collected. The material of the receiver can also be revised to find a better conducting and absorbing material that can absorb higher amount of energy. Apart from that, the heat transfer medium that can be used can either be oil or molten salt. Especially for higher temperatures and amount of heat energy for storage, molten salt is a better choice. Most molten salt operates at high temperatures and it is the best heat transfer medium at such requirement. However, most of them also have high densities making it bulky to be flow. This can be overcome by using drag reduction agents which improve fluid flow and reduce energy losses in pipelines.

REFERENCES

1. Monsoon, Malaysian Meterological Department, 2010, Retrieved from www.met.gov.my/index.php?option=com_content&task=view&id=69dintemid=160&lang=english (Date viewed: 24th May 2012)
2. Climate of Malaysia. Retrieved from www.climate.info/malaysia/ (Date viewed: 24th May 2012)
3. K.S. Ong, 1994, *Solar Water Heaters: Engineering and Applications,* Department of Publication, University of Malaya, Malaysia
4. Solar Through Technology, Enert Global 2009, Retrieved from http://www.google.com.my/imgres?start=15&num=10&um=1&hl=en&safe=strict&biw=1280&bih=675&tbm=isch&tbnid=9rD-U-QRXfqwCM:&imgrefurl=http://www.enertglobal.com/technology_e.html&docid=-xjRWoTOewvUhM&imgurl=http://www.enertglobal.com/images/chart2c.jpg&w=405&h=387&ei=jXrlT9WdFc7nrAfEvcyOCQ&zoom=1&iact=hc&vpx=331&vpy=295&dur=17&hovh=219&hovw=230&tx=112&ty=103&sig=103592830476192887049&page=2&tbnh=148&tbnw=155&ndsp=22&ved=1t:429,r:12,s:15,i:43 (Date viewed: 24th May 2012)
5. Storing the Sun: Molten Salt Provides Highly Efficient Thermal Storage (Julie Way), 26 June 2008
6. Ahmad Hazwan Ahmad Hariri, 2010, *Life Cycle Assessment of Thermal Storage System*, Universiti Teknologi Petronas
7. Hasnain SM. Review on sustainable thermal energy storage technologies, Part 1: Heat storage materials and techniques. Energy Convers Mgmnt 1998; 39:1127-38.
8. A review on phase change energy storage: materials and applications (Mohammed M. Farid, Amar M. Khudhair a, Siddique Ali K. Razack b,Said Al-Hallaj), Department of Chemical & Materials Engineering, The University of Auckland, Private Bag 92019, Auckland, New Zealand, Center for Electrochemical Science and Engineering, Illinois Institute of Technology, Chicago, IL 60616, USA, 12 September 2003
9. High-temperature thermal storage using a packed bed of rocks – Heat transfer analysis and experimental validation (Markus Hänchen, Sarah Brückner, Aldo Steinfeld), 7 October 2010
10. A Concentrated Thermal Energy System (C. Christopher Newton), Department of Mechanical Engineering, 2007
11. http://heatbath.com/2012/06/salt-bath-quenching/ , (Reviewed: 8th November 2012)
12. http://www.docstoc.com/docs/20105343/Solar-Power-Tower (Reviewed: 1st December 2012)