CHAPTER 1

INTRODUCTION

1.1 Background of Study

Man has needed and used energy at an increasing rate for his sustenance and well-being ever since he came on the earth a few million years ago. Primitive man required energy primarily in the form of food. He derived this by eating plants and animals which he haunted. Subsequently he discovered fire and his energy needs increased as he started to make use of wood and other biomass to supply the energy needs for cooking as well as for keeping himself warm. With the passage of time, man started to cultivate land for agriculture. He added a new dimension to use of energy by domesticating and training animals to work for him. With further demand for energy, man began to use the wind for sailing ships and driving windmills, and the force of falling water to turn water wheels. Till this time, it would not be wrong to say that the sun was supplying al the energy needs of man either directly or indirectly and that man was using only renewable sources of energy.

The solar energy option has been identified as one of the promising alternative energy sources for the future. The nature of this source, its magnitude and characteristics can be described into various methods – direct and indirect. Solar energy plays a crucial role in the group of environment-friendly energy for domestic, agricultural, transportation, aerospace and especially for industrial. According to Garg and Prakash (2000), solar energy will be even more relevant for developing countries whose energy requirements are increasing rapidly as a result of large scale industrialization and growing population.

Solar water heating (APPENDIX A-1 Figure 1: Schematic diagram for Water Heating System) is a very simple and efficient way to grab energy from the sun and use it as an alternative energy apart from electricity. A flat plate collector is commonly used for water heating system. The flat-plate collector is the most important type of solar collector because it is simple in design, has no moving parts and required little maintenance. It can be used for a variety of applications in which temperatures ranging from 40^{o}C to about 100^{o}C are required. It consists of an absorber plate on which the solar radiation falls after coming through one or more transparent covers (usually made of glass). The absorbed radiation is partly transferred to a liquid flowing through tubes which are fixed to the absorber plate or are integral with it.

When temperatures higher than 100^{o}C are required, it becomes necessary to concentrate the radiation. This is achieved using focusing or concentrating collectors. A schematic diagram of a typical concentrating collector is shown in Figure 2 below.

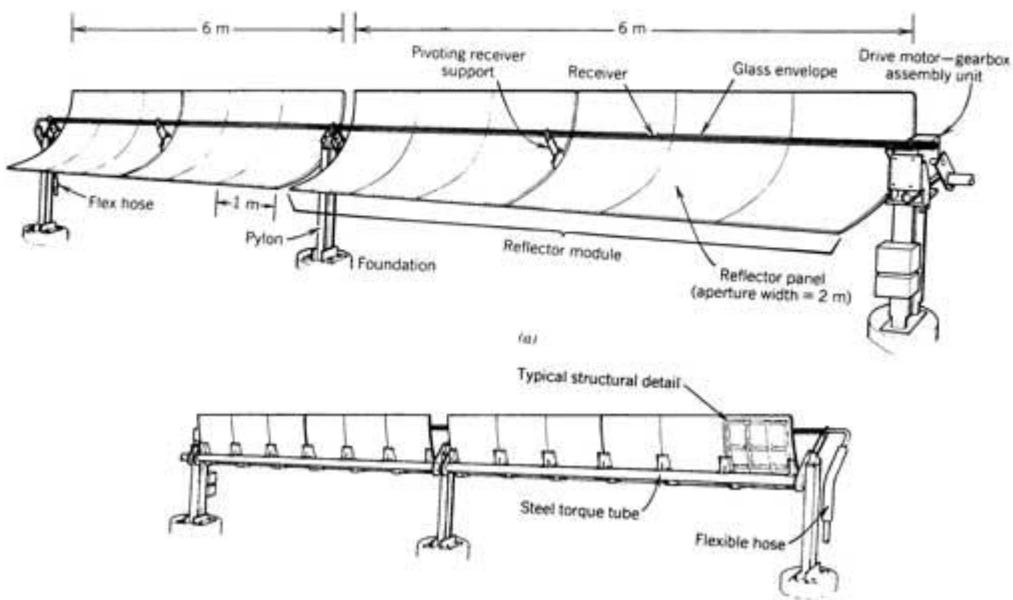

Figure 1.1: Example of Parabolic Concentrating Collector

(Source: Solar Energy, Principles of Thermal Collection and Storage,2nd Edition, S P Sukhatme, Tata Mc Graw Hill.)

The collector consists of a concentrator and a receiver. The concentrator shown is a mirror reflector having a shape of cylindrical parabola. It focuses the sunlight onto its axis, where it is absorbed on the surface of the absorber tube and transferred to the fluid flowing through it. A concentric glass cover around the absorber tube helps in reducing the convective and radiative losses to the surroundings. In order that the sun's rays should always be focused onto the absorber tube, the concentrator has to be rotated. This movement is called tracking. In the case of cylindrical parabolic concentrators, rotation about a single axis is generally required. Fluid temperatures up to $400^{o}C$ can be achieved in cylindrical parabolic focusing collector system.

Since Malaysia is located close to the equator and is also a developing country with growing energy demand, therefore, the solar energy becomes a potential energy option. Solar energy is the most abundant, free and non-polluting energy resources that have been identified as the one of the major resources of renewable energy (RE) in the "Five fuel strategy Malaysia" under the Eight Malaysia Plan. The solar concentrator is to increase the amount of incident energy on the absorber surface as compared to that on the concentrator aperture. This increase is achieved by the use of reflecting or refracting surfaces which concentrate the incident radiation onto a suitable absorber/receiver. Due to the apparent motion of the sun, the concentrating surface is unable to redirect the sun rays on the absorber throughout the day if both the concentrator surface and absorber surface are stationary. The solar concentrator generally consists mainly of a focusing device, an absorber/receiver provided with or without a transparent cover and a tracking device for continuously following the sun.

1.2 Problem Statement

1.2.1 Problem Identification

As referred to the title, this project attempts to design and develop the parabolic solar water heating system that consists of the parabolic solar concentrator as the main source of heat energy collection. The main objective is to produce a specific temperature of a steam since this system is connected to absorption refrigeration system that needs steam to separate ammonia and water in the generator. The research on parameter of parabolic concentrator must be done to achieve the optimum condition with low economic cost. The method of heat exchanger can be used for heat transfer application with good insulation material for thermal storage tanks to sustain the temperature and to prevent heat losses as well as the waste of energy. Technical drawing of the testing model will be developed that apply to the designed Solar Parabolic Through Concentrator Water Heating System for Steam Production

1.2.2 Significance of Project

The significance of this project is to contribute in the utilization of the solar energy in water heating purpose to provide steam for absorption refrigeration system. This project will be conducted by investigating the effectiveness and feasibility of the solar parabolic through concentrator. Successful design of the Solar Parabolic Through Concentrator Water Heating System would significantly improve the energy consumption and reduce the overall heat losses to surroundings. In terms of economic analysis, the savings can be done and the payback period for capital investment is shorter. It would give benefit to society in terms of energy and economic savings. The usage of solar as a clean and renewable energy can reduce harmful to environment since this system do not produce dangerous gases and unsafe material that threat lives in the world. The project also contributes to the development of absorption refrigeration system.

1.3 Objective and Scope of Study

1.3.1 Objectives

The objectives of the project are as follow:

- To study the effect of various design parameters of a Solar Parabolic Through Concentrator on its performance.
- To design and develop technical drawings of testing model that will apply the designed Solar Parabolic Through Concentrator Water Heater System.

1.3.2 Scope of Project

The scope of this project is to design a system (water heating system) using Solar Parabolic Through Concentrator for absorption refrigeration system and then develop the details technical drawings according to space constraints. The research must be conducted by manipulating the parameter of Solar Parabolic Through Concentrator to produce high efficiency of the energy. Other aspects that need to be considered are thermal insulator material which can maintain temperature of the hot water. The requirements of physical properties of absorption refrigeration system also need to be investigated.

1.3.3 Project Feasibility

This project has been carried out over two academic semesters. The main activities have been forecasted with a margin of planning error, which has also been included into the schedule. After analyze and study the schedule planning, the project is found to be feasible. Throughout the span of time, project progress would be measured against the Gantt chart to track the project.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 The basic concept of solar energy

The Sun, which is the largest member of the solar system with other members revolving around it, is a sphere of intensely hot gaseous matter with diameter of $1.39 x 10^9$ m and, on average, at a distance of $1.5x10^{11}$ m from the earth. With an effective blackbody temperature T_s of 5777K, the sun is effectively, a continuous fusion reactor.

The energy produced in the interior of the solar sphere at temperature of many millions degree and it can be transferred out to the surface and then be radiated into space ($E = \varepsilon\sigma T_s^{\ 4}$; ε and σ are respectively the emissivity of surface and Stefan-Boltzman constant).

It is estimated that 90% of the sun's energy is generated in the region 0 to 0.23 R (R being the radius of the sun); the average density ρ and temperature T in this region are 10^5 kg/m^3 and about 8-40 x 10^6 K respectively. At a distance of about 0.7R from the centre, the temperature drops to about 1.3 x 10^5 K and the density to 70 kg/m^3. Hence for r > 0.7R convection begins to be important and the region 0.7R < r < R is known as the convective zone. (APPENDIX A-1 Figure 2: The structure of the sun)

Radiation is the only one that can be propagated without a transfer medium. Unlike conduction or convection, the transfer of energy by radiation can occur through empty space. Virtually all the energy available on the Earth originates from the sun. However, radiation is emitted by all matter.

Although the Sun is large, it subtends an angle of only 32 minutes at the earth's surface. This is because it is also at a very large distance. Thus, the beam radiation received from the sun on the earth is almost parallel. The brightness of the sun varies from its centre to its edge. However, for engineering calculations, it is customary to assume that the brightness all over the solar disc is uniform.

Measurements indicate that the energy flux received from the sun outside the earth's atmosphere is essentially constant. The solar constant I_{sc} is the rate at which energy is received from the sun on a unit area perpendicular to the rays of the sun, at the mean distance of the earth from the sun.

2.1.1 Characteristics of radiation

In the case of radiation, quantity is associated with the height of the wave, or its amplitude. Everything else being equal, the amount of energy carried is directly proportional to wave amplitude. The quality or type of radiation is related to another property of the wave, the distance between wave crests or wavelength, which is the distance between any two corresponding points along the wave.

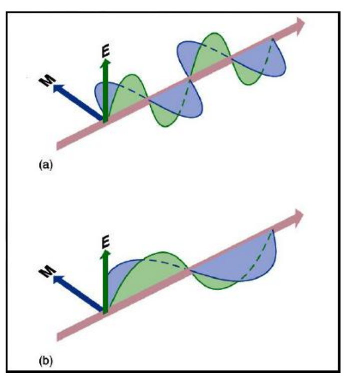

Figure 2.1: Characteristic of radiation

Electromagnetic radiation consists of:

a) electric vave (E)

b) magnetic wave (M)

The waves in (a) and (b) have the same amplitude, so the radiation intensity is the same. However, (a) has shorter wavelength, so it is qualitatively different than (b). Depending on the exact wavelength involved, the radiation in (a) might pass through the atmosphere, whereas that in (b) might be absorbed. (APPENDIX A-1 Figure 3-types of wavelength in micrometers)

The single factor that determines how much energy a blackbody radiates is its temperature. Hotter bodies emit more energy than do cooler ones. The intensity of energy radiated by a blackbody increases according to the fourth power of its absolute temperature.

Solar energy is most intense in the visible portion of the spectrum. Most of the radiation has wavelength less than 4 micrometers which we generically refer to as shortwave radiation (0.15 µm to 3 µm). Radiation emanating from Earth’s surface and atmosphere consists mainly of that having wavelengths longer than 4 µm. This type of electromagnetic energy is called long wave radiation (3 µm to 100 µm). (APPENDIX A1-Figure 4: Sun emission compared to earth emission)

2.2 The Absorption refrigeration System

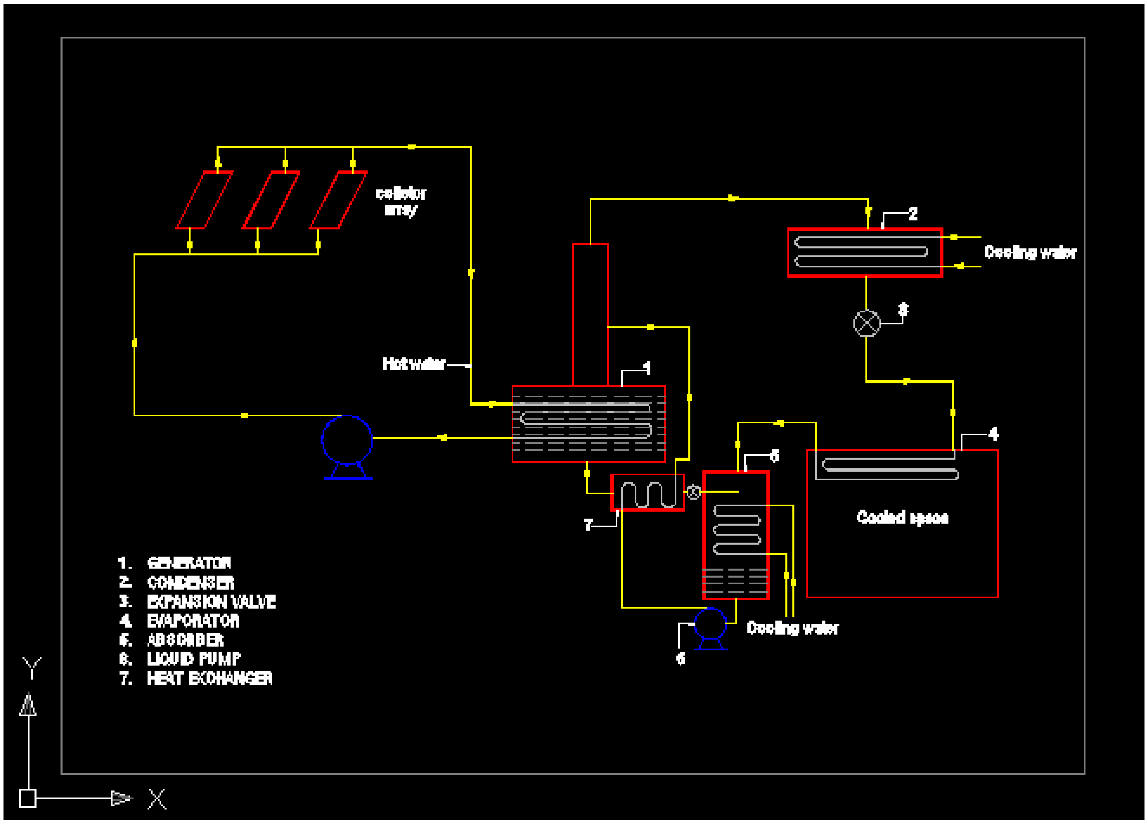

Figure 2.2: Solar Absorption Refrigeration System

One of the most interesting thermal applications of solar energy is for the purpose of cooling. Space cooling may be done with the objective of providing comfortable living conditions or of keeping a food product cold. Since the energy of the sun is being received as heat, the obvious choice is a system working on the absorption refrigeration cycle which requires most of its energy input as heat. The most growing refrigeration technology that utilizes the solar energy is the absorption refrigeration technology in which the solar energy is used as the driving force that powers the refrigeration cycle. A few household units called absorption refrigerators operate on the absorption principle utilizing the solar energy in these refrigerators there is a strong solution of ammonia in water is heated by solar energy in a container called a generator.

2.2.1 Principle of operation of Absorption Refrigeration System

State 1

The diagram of a simple solar operated absorption refrigeration system is shown above (Figure 6). Water heated in a parabolic concentrator is passed through a heat exchanger called the generator, where it transfers heat to a solution mixture of the absorbent and refrigerant, which is rich in the refrigerant. Refrigerant vapour is boiled off at high pressure and goes to the condenser.

State 2-3

At condenser, refrigerant is condensed into a high pressure liquid. The high pressure liquid is throttled to a low pressure and temperature in an expansion valve and passes through the evaporator coil.

State 4

Here, the refrigerant vapour absorbs heat and cooling is therefore obtained in the space surrounding this coil.

State 5-6

The refrigerant vapour is now absorbed into a solution mixture withdrawn from a generator, which is weak in refrigerant concentration. This yields a rich solution which is pumped back to the generator, thereby completing the cycle.

State 7

The rich solution flowing from the absorber to the generator is usually heated in a heat exchanger by the weak solution withdrawn from the generator. This helps to improve the performance of the cycle.

Some of the common refrigerant-absorbent combinations used are ammonia-water, and water lithium bromide. Typical values for COP range between 0.5-0.8. Unfortunately the installation cost of solar thermal refrigeration system is high. Thus although many experimental studies have been conducted, no commercialization has taken place.

2.3 Design of Parabolic Solar Concentrator

The concentration is achieved by the use of suitable reflecting or refracting elements, which results in an increased flux density on the absorber surface as compared to that existing on the concentrator aperture. The key concept in **concentrated solar water heating** is the use of mirrors or other reflective surfaces to concentrate the suns rays hitting a large area onto a tube or container full of a fluid which is heated. A solar concentrator consists of focusing device, a receiver system and tracking arrangement. Temperature as high as 3000^{o}C can be achieved using solar concentrators, and hence they have potential applications in both thermal and photovoltaic utilization of solar energy at high delivery temperature.

Because of the optical system, certain losses are introduced. These include reflection or absorption losses in the mirror or lenses and due to geometrical imperfections in the optical system. The combined effect of all such losses is indicated through the introduction of a term called *optical efficiency.* The introduction of more optical losses is compensated for by the fact that the flux incident on the absorber surface is concentrated on a smaller area. As a result, the thermal loss terms do not dominate to the same extent as in plat-plate collector and the collection efficiency is usually higher.

It has been noted earlier that some of the attractive features of a flat-plate collector are simplicity of design and ease of maintenance. The same cannot be said for concentrating collector. Because of the presence of optical system, a concentrating collector usually has to follow or track the sun so that the beam radiation is directed onto the absorber surface.

In order to be consistent, the phrase “concentrating collector” will be used to denote the whole system. The term “concentrator” will be used only for the optical subsystem which directs the solar radiation onto the absorber, while the term "receiver" will normally be used to denote the subsystem consisting of absorber, its cover and other accessories. The *aperture (W)* is the plane opening of the concentrator through which the solar radiation passes. The *concentration ratio (CR)* is the ratio of the effective area of the aperture to the surface area of the absorber. The *acceptance angle* ($2\theta_r$) is the angle over which beam radiation may deviate from the normal to the aperture plane and yet reach the absorber.

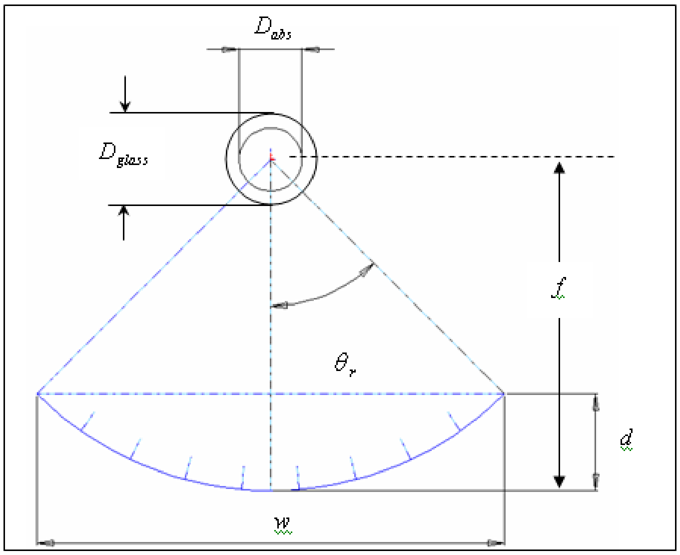

Figure 2.3: The section view of PTC

The advantages of using parabolic concentrator are:

- It increases the intensity by concentrating the energy available over a large surface onto a smaller surface (absorber).
- Due to the concentration on a smaller area, the heat loss area is reduced. Further, the thermal mass is much smaller than that of a flat plate collector and hence transient effects are small.
- The delivery temperatures being high, a thermodynamics match between the temperature level and the task occurs.
- It helps in reducing the cost by replacing an expensive large receiver by a less expensive reflecting or refracting area.

Now the performance analysis of a cylindrical parabolic concentrating collector is considered whose concentrator has an aperture W, length L, and rim angle $\theta_{r.}$ The absorber tube has an inner diameter $D_{abs.in}$ and an outer diameter $D_{abs.out}$ and it has a concentric glass cover of inner diameter $D_{glass.in}$ and outer diameter $D_{glass.out.}$ The fluid being heated in the collector has a mass flow rate, a specific heat C_p, an inlet temperature T_{fi} and outlet temperature $T_{fo.}$

Balbir & Fauziah (2003) has noted that the level of concentration is restricted by the design parameters and is given as an equation Eq.(2.1) and Eq.(2.2) that relates the concentration ratio, (CR) to the acceptance half-angle and the best value is based on the sun's subtend angle of 0.54^o with the highest CR at 212. Although the values look promising, the whole design process cannot be based only on these values.

$$CR = \frac{(w - d_{abs})L}{\pi \cdot d_{abs} L} \tag{2.1}$$

$$CR = \frac{(w - d_{abs})}{\pi \cdot d_{abs}} \tag{2.2}$$

Balbir & Fauziah (2003) defined the important relationships between the width, depth and focus length shown at Eq.(2.3) and Eq.(2.4)below,

$$y = \frac{d}{(0.5w)^2} \cdot x^2 \tag{2.3}$$

$$f = \frac{w^2}{16d} \tag{2.4}$$

Eq.(2.5) is used to calculate the rim angle, based on the focus length, width and depth;

$$\cos\theta_R = \frac{2f}{\sqrt{(0.5w)^2 + (d - f)^2}} - 1 \tag{2.5}$$

The rim angle of 90 ^{o} is preferred as it gives an optimum intercept factor and allows the depth to be the focus point. The focus point, where the rim angle is set at 90 ^{o} can be calculated b using the width value alone, as shown in Eq.(2.6).

$$f = \frac{w}{4} \tag{2.6}$$

The reflecting surface on the parabolic surface should have a very good specular reflectance, ρ where electroplated silver records a value of 0.96. Thermal analyses on the overall heat loss coefficient, convective heat transfer coefficient, collector efficiency factor and heat removal factor are performed. Finally, by the aid of meteorological data, the efficiency of the collector is determined.

2.3.1 Performance Analysis of Parabolic Trough Concentrator

An energy balance on an elementary slice *dx* of the absorber tube, at a distance *x* from the inlet, yields the following equation for a steady state:

$$dq_u = \left[I_b r_b (W - D_{abs.out}) \rho\gamma(\tau\alpha)_b + I_b r_b D_{abs.out} (\tau\alpha_b) - U_l \pi D_{abs.out} (T_p - T_a) \right] dx \tag{2.7}$$

Where:

dq_u = useful heat gain rate for a length dx

ρ = specular reflectivity of the concentrator surface

γ = intercept factor, the fraction of the specularly-reflected radiation intercepted by the absorber tube

$(\tau\alpha)_b$ = average value of transmissivity-absorptivity product for beam radiation

U_l = overall loss coefficient

T_p = local temperature of absorber tube

T_a = ambient temperature

The first term on the right hand side represents the incident beam radiation absorbed in the absorber tube after reflection, the second term represent the absorbed incident beam radiation which falls directly on the absorber tube. The third term represents the loss by convection and reradiation.

We define absorbed flux *S* as follows:

$$S = I_b r_b \rho\gamma(\tau\alpha)_b + I_b r_b (\tau\alpha)_b \left(\frac{D_{abs.out}}{W - D_{abs.out}} \right) \tag{2.8}$$

Equation (2.7) thus becomes,

$$dq_u = \left[S - \frac{U_l}{CR}(T_p - T_a \right](W - D_{abs.out})dx \tag{2.9}$$

The useful heat gain rate dq_u can also be written as:

$$dq_u = h_f \pi D_{abs.in}(T_p - T_f)dx \tag{2.10}$$

$$= \dot{m} C_p dT_f \tag{2.11}$$

where:

h_f = heat transfer coefficient on the inside surface of the tube

T_f = local fluid temperature

Equation (2.8) and (2.9) are combined to eliminate the absorber tube temperature T_p, and obtain:

$$dq_u = F' \left[S - \frac{U_l}{CR}(T_f - T_a) \right](W - D_{abs.out})dx \tag{2.12}$$

Where F' is the *collector efficiency factor* defined by:

$$F^{'} = \frac{1}{U_l\left[\frac{1}{U_l} + \frac{D_{abs.out}}{D_{abs.in}h_f}\right]} \qquad (2.13)$$

Again, combining eq (2.11) and (2.12), we obtained the differential equation:

$$\frac{dT_f}{dx} = \frac{F^{'}\pi D_{abs.out}U_l}{\dot{m}C_p}\left[\frac{CR(S)}{U_l} - (T_f - T_a)\right] \qquad (2.14)$$

Integrating and using the inlet condition at x = 0, $T_f = T_{fi}$ we have the temperature distribution:

$$\frac{\left[\frac{CR(S)}{U_l} + T_a\right] - T_f}{\left[\frac{CR(S)}{U_l} + T_a\right] - T_{fi}} = \exp\left(-\frac{F^{'}\pi D_{abs.out}U_l x}{\dot{m}C_p}\right) \qquad (2.15)$$

The fluid outlet temperature is obtained by putting $T_f = T_{fo}$ and x = L in Equation (2.15). Then, we have:

$$\frac{(T_{fo} - T_{fi})}{\frac{CR(S)}{U_l} + T_a - T_{fi}} = 1 - \exp\left(-\frac{F^{'}\pi D_{abs.out}U_l L}{\dot{m}C_p}\right) \qquad (2.16)$$

Thus, the useful heat gain rate:

$$q_u = \dot{m}C_p(T_{fo} - T_{fi})$$

$$= \dot{m} C_p \left[\frac{CR(S)}{U_l} + T_a - T_{fi} \right] \left[1 - \exp\left(- \frac{F^{'} \pi D_{abs.out} U_l L}{\dot{m} C_p} \right) \right]$$

$$= F_R (W - D_{abs.out}) L \left[S - \frac{U_l}{CR} (T_{fi} - T_a) \right] \tag{2.17}$$

Where F_R is the *heat removal factor* defined by:

$$F_R = \frac{\dot{m} C_p}{\pi D_{abs.out} L U_l} \left[1 - \exp\left(- \frac{F^{'} \pi D_{abs.out} U_l L}{\dot{m} C_p} \right) \right] \tag{2.18}$$

The instantaneous collection efficiency η_i is given by:

$$\eta_i = \frac{q_u}{(I_b r_b + I_d r_d) WL} \tag{2.19}$$

if ground-reflected radiation is neglected. The instantaneous efficiency can also be calculated on the basis of beam radiation alone, in which case:

$$\eta_i = \frac{q_u}{I_b r_b WL} \tag{2.20}$$

2.4 Analysis of a Simplified Model of Collector/Absorber Performance by Heat Transfer Analysis.

2.4.1 Overall Loss Coefficient and Heat Transfer Correlation

$$\frac{q_l}{L} = h_{p-c}(T_{pm} - T_c)\pi D_{abs.out} + \frac{\sigma\pi D_{abs.out}(T_{pm}^4 - T_c^4)}{\left\{\frac{1}{\varepsilon_p} + \frac{D_{abs.out}}{D_{glass.in}}\left(\frac{1}{\varepsilon_c} - 1\right)\right\}} \qquad (2.21)$$

$$= h_w(T_c - T_a)\pi D_{glass.out} + \sigma\pi D_{glass.out}\varepsilon_c(T_c^4 - T_{sky}^4) \qquad (2.22)$$

Where:

$\frac{q_l}{L}$ = heat loss rate per unit length

h_{p-c} = convective heat transfer coefficient between the absorber tube and the glass cover.

T_{pm} = average temperature of the absorber tube

T_c = temperature attained by the cover.

2.4.2 Heat Transfer Coefficient between the Absorber Tube and the Cover

The natural convection heat transfer coefficient h_{p-c} for the enclosed annular space between a horizontal absorber tube and a concentric cover is calculated by using a correlation due to Raithby and Hollands.

$$\frac{k_{eff}}{k} = 0.317(Ra^*)^{1/4} \qquad (2.23)$$

Where:

k_{eff} = effective thermal conductivity defined as the thermal conductivity that the motionless air in the gap must have to transmit the same amount of heat as the moving air.

Ra^{*} = modified Rayleigh number related to the usual Rayleigh number by the following equation:

$$(Ra^{*})^{1/4} = \frac{In(D_{glass.in} / D_{abs.out})}{b^{3/4}\left(\frac{1}{D_{abs.out}^{3/5}} + \frac{1}{D_{glass.in}^{3/5}}\right)^{5/4}} Ra^{1/4} \tag{2.24}$$

The characteristic dimension used for the calculation of the Rayleigh number is the radial gap $b = (D_{abs.in} - D_{glass.out})/2$. Properties are evaluated at the mean temperature $(T_{pm} + T_{c})/2$.

Thus,

$$h_{p-c} = \frac{2k_{eff}}{D_{abs.out} In(D_{glass.in} / D_{abs.out})} \tag{2.25}$$

2.4.3 Heat Transfer Coefficient on the outside Surface of the Cover

$$Nu = C_{1}\,\mathrm{Re}^{n}$$

Where C_1 and n are constants having the following values:

For	40	< Re < 4000	C_1 = 0.615, n = 0.466
For	4000	< Re < 40000	C_1 = 0.174, n = 0.618
For	40000	< Re < 400000	C_1 = 0.0239, n = 0.805

2.4.4 Heat Transfer Coefficient on the Inside Surface of Absorber Tube

For a Reynolds number less than 2000, the flow is laminar and the heat transfer coefficient may be calculated from the equation

$$\mathrm{Nu} = 3.66$$

For a Reynolds number greater than 2000, the flow is turbulent and the equation is:

$$Nu = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4}$$

Harrigan & Stine (1985) noted that the development of a widely used yet simple model for prediction of the thermal energy output (i.e., performance) of various solar collectors. The model is applicable to all (including the central receiver with some extension) collector concepts and hence is discussed separately from any one collector concept to avoid the misunderstanding that the model is useful only for that one concept.

The quantity of thermal energy produced by any solar collector can be described by the energy balance equation

$$\dot{Q}_{out} = \dot{Q}_{opt} - \dot{Q}_{loss} \qquad \text{(W)} \qquad (2.26)$$

Where

$\dot{Q}_{out}$ = rate of thermal energy output

$\dot{Q}_{opt}$ = rate of optical energy absorbed by receiver

$\dot{Q}_{loss}$ = rate of thermal energy lost from receiver

This equation (2.15) can be expanded to yield a more useful form by examining the $\dot{Q}_{opt}$ and $\dot{Q}_{loss}$ terms separately. The optical energy absorbed by the receiver can be expressed as:

$$\dot{Q}_{opt} = A_a \rho_{s.m} \tau_g \alpha_r RSI_a \qquad \text{(W)} \qquad (2.27)$$

Where

$\rho_{s.m}$ = specular reflectance of concentrating mirror, if any (1.0 for non concentrating flat-plate collector)

τ_g = Transmittance of any glass envelop covering the receiver (e.g., glass cover plate in the flat-plate collector)

I_a = isolation (irradiance) incident on collector aperture (W/m^2); for a non focusing collector (e.g., a flat plate), this is the total insolation $I_{t,a}$; for a focusing concentrator, this is the beam insolation $I_{b,a}$.

A_a = Aperture area of the collector

α_r = absorbance of the receiver

Since the *S*, *R*, α_r, $\rho_{s.m}$, and τ_g are constants dependently only on the materials used and the structure accuracy of the collector, they can be lumped into a single constant term, η_{opt}, the optical efficiency of the collector. For a flat plate collector utilizing no reflectors, *S*, *R*, and $\rho_{s.m}$ are not physically meaningful and are set equal to 1.0.

Likewise, $\dot{Q}_{loss}$ can be expanded to a function that employs an overall heat loss coefficient, $U_L\,(W/m^2\ {}^0C)$ and the difference in temperature between the hot receiver and the surrounding environment:

$$\dot{Q}_{loss} = A_r U_l (T_r - T_a) \qquad \text{(W)} \qquad (2.28)$$

Where

T_r = temperature of receiver $({}^oC)$

T_a = ambient temperature $({}^oC)$

A_r = surface area of receiver (m^2)

Since the receiver ion a collector is not at a uniform temperature, an average receiver temperature is used in equation (2.17). Thus

$$T_r = \frac{T_{out} + T_{in}}{2} \tag{2.29}$$

Where

T_{out} = temperature (^oC) of the fluid leaving collector

T_{in} = temperature (^oC) of fluid entering the collector

The heat loss coefficient U_L in equation (2.17) is not a simple constant but instead may vary as heat-loss mechanisms change with temperature. For example, as the temperature increases, radiant heat loss from the receiver increases. Radiant heat transfer varies as $(T_r^4 - T_a^4)$. If equation (2.17) were plotted for a real collector, therefore, U_L would be found to be not a true constant. However, as is seen in the following paragraphs, expression of $\dot{Q}_{loss}$ as a function of $(T_r - T_a)$ is valuable in that it leads to a rather simple collector performance model that yields reasonably accurate performance predictions for collectors.

The collector efficiency,

$$\eta_{col} = \frac{\dot{Q}_{out}}{A_a I_a} \tag{2.30}$$

CHAPTER 3

PROJECT METHODOLOGY

3.1 Procedure identification

In order to complete this project successfully, a systematic and structural methodology is crucial. Thus, a thorough discussion been held with the supervisor to address this issue. As the project title been assigned, a brief study on the project title been held. This is to get a general/rough idea on the study area of this title. Upon completion on this study, a thorough literature survey through all the available sources such as internet, online or printed journals, reference books and discussion with the supervisor. This definitely gives a deeper and more profound understanding on the topic. As the project progresses, more literature reviews and discussion will be held to address all the arising problems. The project methodology can be generally divided into two main parts which for the first semester and the second semester. The literature review, gathering information, research and deciding the parameter of PTC are the main target for first semester and the details calculation and technical drawings, implementation, data collection and data analysis are set for the second semester.

3.1.1 The literature review

The literature review involves the fundamental about solar energy and radiation that is significance as the project is utilizes solar energy as the main source. The simple formula regarding the characteristic of radiation is stated in the literature review.

The principle of operation of absorption refrigeration is analyzed to be familiar with the requirement and characteristic since PTC system is connected to the absorption refrigeration system. The requirement temperature needs to be achieved for optimum efficiency of absorption refrigeration system.

This literature review also includes the study of the basic theories that related to the design of the parabolic solar reflector. The relationship of the design parameters (width, depth, rim angle and focus length) are identified in this step with the designed excel template. A mathematical model was generated to determine the expected temperature outlet and the required length of the PTC to meet the main objective of the project.

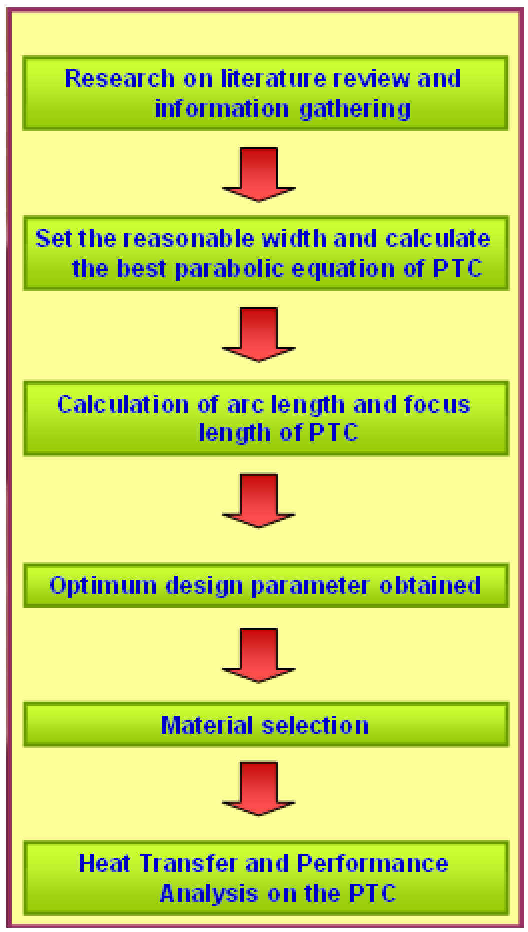

Figure 3.1: Flow chart showing steps involved in the project for first semester

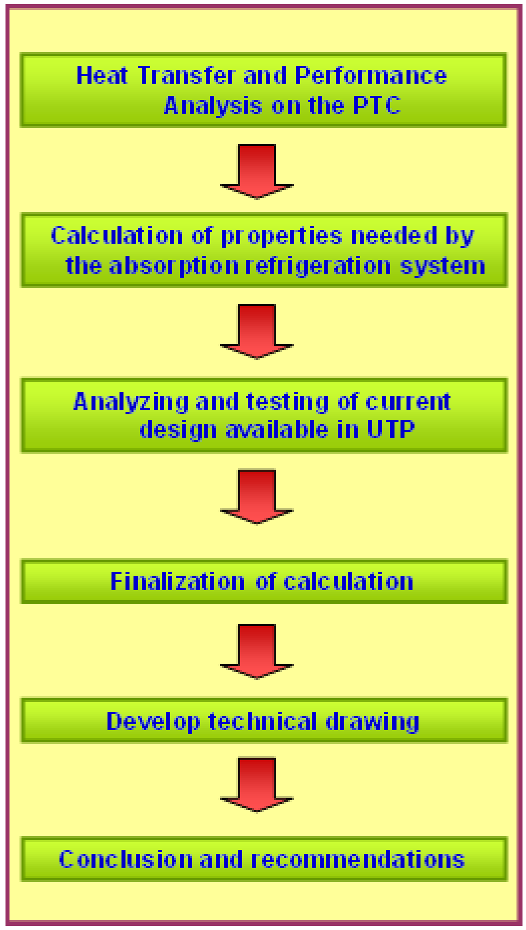

Figure 3.2: Flow chart showing steps involved in the project for second semester

3.2 Design

Table 3.1: Prototype Design Specifications

Parameters	Design Specifications
Width / Aperture	1.5 m
Focus Length	0.375 m
Rim angle	90^o
Tracking mode degree	-45^o to $+45^o$
Material for absorber	Copper
Material for reflector	Mirror
Flow rate control device	Gate valve

3.2.1 Detail Design of the Parabolic Concentrator

Figure 3.3: The drawing shows the design of the prototype configuration.
(Source: Design and Development of A Cylindrical Parabolic Solar Concentrator, Tsen Wee Yew, Final Year Project, June 2006)

The details of the drawing are shown in APPENDIX A-1: Figure5, 6 and 7.

3.2.2 Schematic diagram for the entire system

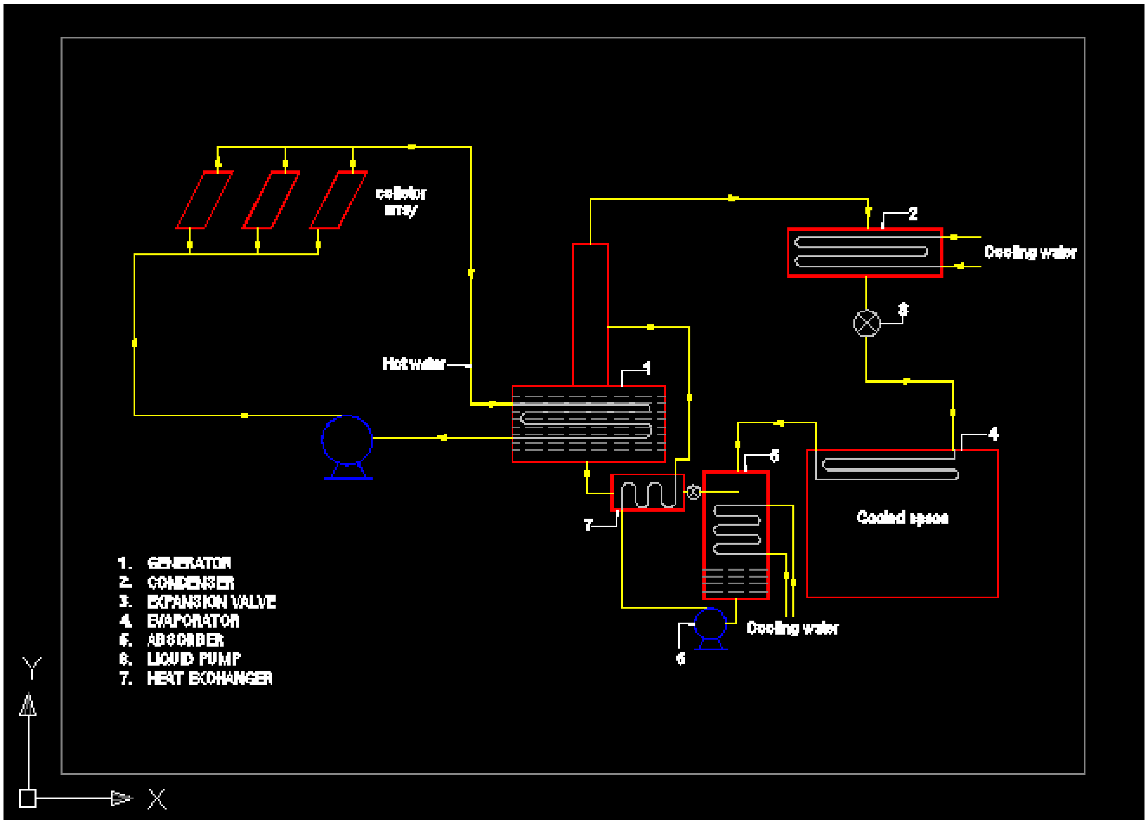

Figure 3.4: Proposed Design of Steam Production System

3.3 Tools and Equipment

The software required for my project is Microsoft Excel to generate graph based on the governing equations and operating variables and parameters of Parabolic Through Concentrator. Formulae based on this paper will be constructed in Microsoft Excel and certain values will be key in to obtain several graphs.

Drafting software, AutoCAD is used to produce design layout for the absorption system. The design wills only showing two-dimensional drawing of the steam production system for absorption refrigeration system.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Parabolic Trough Concentrator design parameters calculation

According to Balbir & Fauziah (2003), the 4 main design parameters of the PTC consists of depth (*d*), width (*w*), focus length (*f*) and rim angle (θ_r). The value of focus length (*f*), rim angle (θ_r) are calculated based on the equation (2.4), (2.5) and Simpson's rules with the constant value of depth (*d*) and variable value of width (*w*). Due to the constraint of space and budget available, the width of the PTC is set to constant value at 1.5*m.*

Sample calculation

Table 4.1: Known PTC design parameters data

KNOWN	VALUE
Width , *w*	1.5*m*
Variation of Depth, *d*	0.1m, 0.2m, 0.3m, 0.4m, 0.5m, 0.6m

To plot the graph of the arc, we will use equation 2.3. According to the equation:

$$y = \frac{d}{(0.5w)^2} \cdot x^2$$

We can simply determine the equation of the arc by substituting the value of depth and width. The x value will be incremented 0.01 starting from 0 to 1.5 m. See figure below for an example:

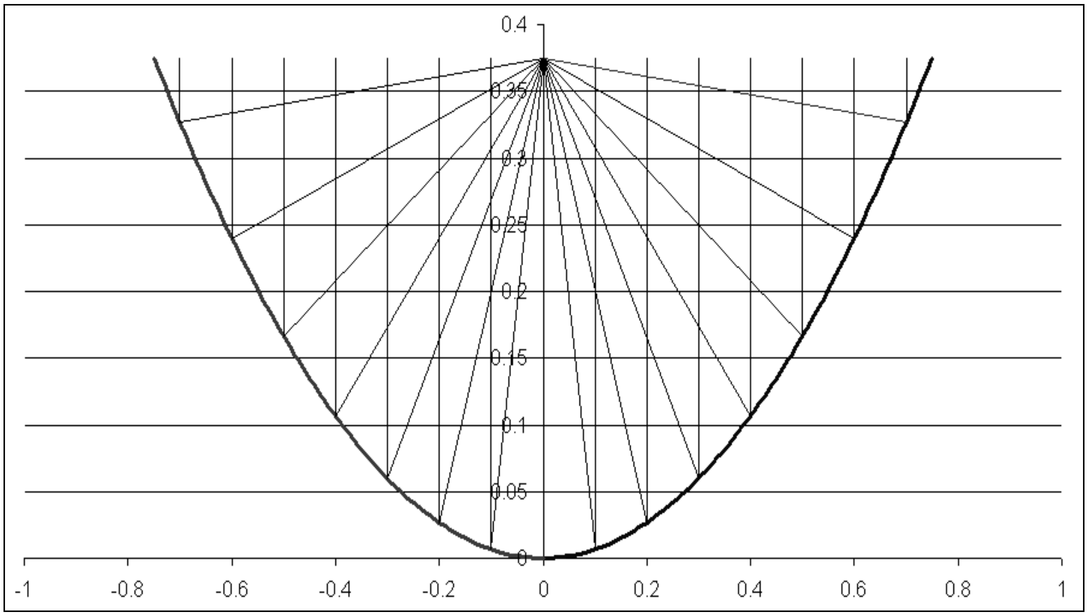

Figure 4.1: The graph shows the cross section of the designed PTC, depth and the focus point ($d = f$) - half portion of the absorber receives the solar heat flux

From the graph above, the blue line arc is constructed by using equation 2.3. This is the optimum design specification based on the calculation that has been made on it.

Focus length, f

$$f = \frac{w^2}{16d}$$

$$f = \frac{1.5^2}{16(0.375)}$$

$$f = 0.375$$

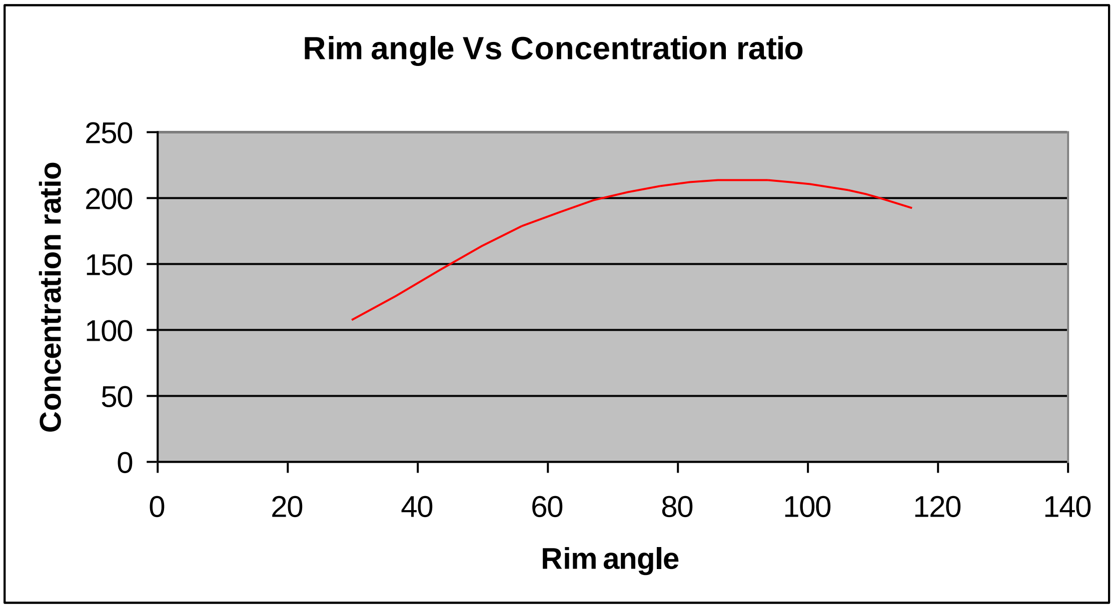

Figure 4.2: The graph showing the maximum concentration ratio obtained at a rim angle of 90°

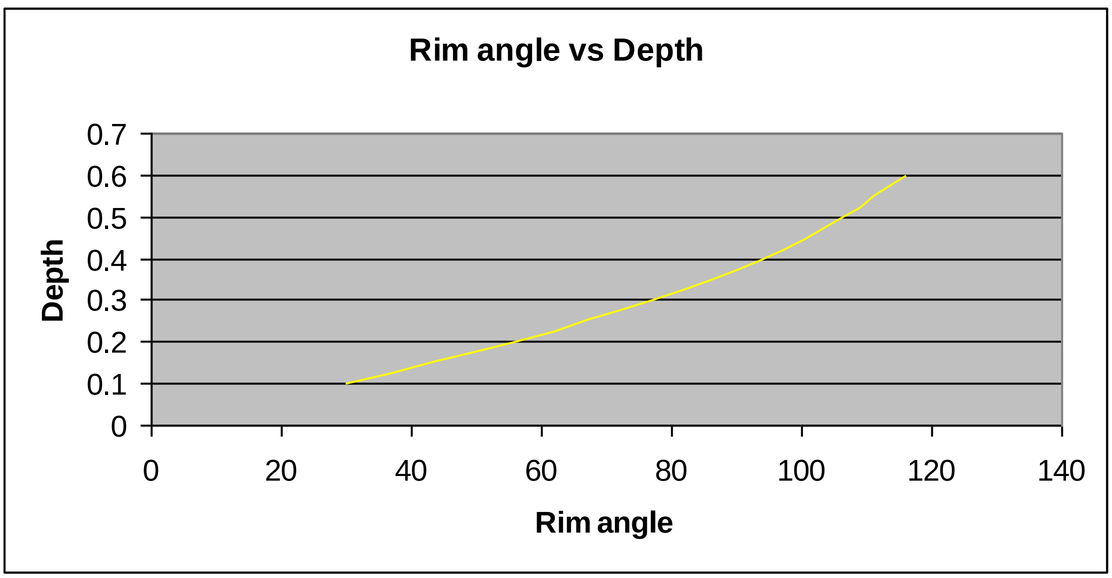

Figure 4.3: The graph showing the proportional relationship between Rim angle and Depth of PTC

The rim angle of 90 ° is preferred as it gives an optimum intercept factor and allows the depth to be the focus point (See Figure 12). The maximum value of concentration ratio is achieved when the rim angle is 90 °. According to the Figure 13, the depth is 0.375 m when the rim angle is 90 ^{o}. That is why the value of 0.375 m was taken as the depth of the concentrator.

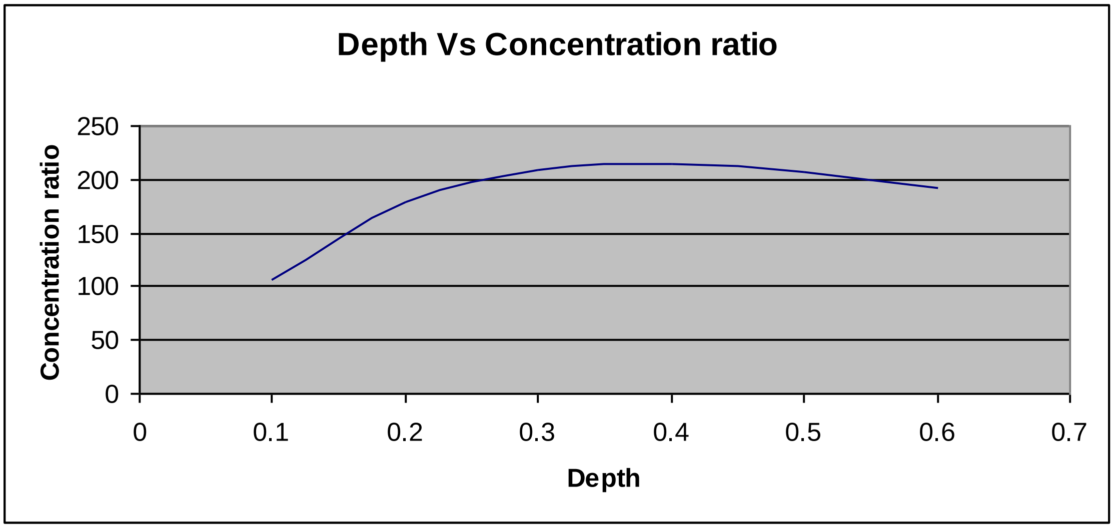

Figure 4.4: The graph showing the depth of PTC when the concentration ratio achieves the maximum value

Graph above shows Depth vs Concentration ratio which the maximum value of concentration ratio is 214.832 when it intercepts at 0.375 m value of the depth.

Rim angle, θ_r

$$\cos\theta_R = \frac{2f}{\sqrt{(0.5w)^2 + (d-f)^2}} - 1$$

$$\cos\theta_R = \frac{2(0.375)}{\sqrt{((0.5)(1.5))^2 + (0.375-0.375)^2}} - 1$$

$$\theta_R = 90^o$$

Concentration ratio, *CR*

$$CR = \frac{\sin\theta_r}{\pi \sin \text{Øc}}$$

$$CR = 214.832$$

Table 4.2: The table shows the variation of other design parameters when depth varied

Depth (m)	Width (m)	Rim angle	Focus length (m)	Concentration ratio
0.1	1.5	29.86283	1.40625	106.9828157
0.2	1.5	56.14497	0.70313	178.4224718
0.3	1.5	77.31962	0.46875	209.6005347
0.375	1.5	90	0.375	214.832
0.4	1.5	93.69522	0.46875	214.3825165
0.5	1.5	106.26020	0.28125	206.2243387
0.6	1.5	115.98923	0.23438	193.0827825

4.2 Heat Transfer Analysis

4.2.1 Absorption refrigeration system

$$COP = \frac{Q_{gen}}{Q_{eva}}$$

The normal COP for absorption refrigeration system for terrace house is around 0.7 to 0.8. So we take average around 0.75. The power of the evaporator is 18 kW to produce output temperature around 15°C to 18°C for the hall of terrace house (10m x 15m x 5m)

$$Q_{gen} = (COP)(Q_{eva})$$

$$\begin{aligned} &= (0.75)(18 \text{ kW}) \\ &= (0.75)(18 \text{ kJ/kg}) \\ &= 13.5 \text{ kJ/kg} \end{aligned}$$

With assumption of no heat losses at the generator, $Q_{in} = Q_{gen} = 13.5$ kJ/kg.

$$Q_{gen} = \dot{m} C_p (T_{gen.in} - T_{gen.out})$$

Q_{gen} = 13.5 kJ/kg

$\dot{m}$ = 0.05 kg/s

C_p = 4.186 kJ/kg.K

$T_{gen.out}$ = is assumed to be the same on the entire system = 40°C (313 K).

$$T_{gen.in} = \frac{Q_{gen}}{\dot{m} C_p} + T_{gen.out}$$

$$= \frac{13.5kJ/kg}{(0.05kg/s)(4.186kJ/kg.K)} + 313K$$

$$= 104.5\ ^{o}C$$

4.2.2 PTC and Heat Transfer Analysis

The following is the calculation which refers to the Garg and Prakash (2000) for the length required for the PTC solar concentrator to heat up the water from room temperature to 136 ^{o}C with the flow rate of 0.05 kg/s.

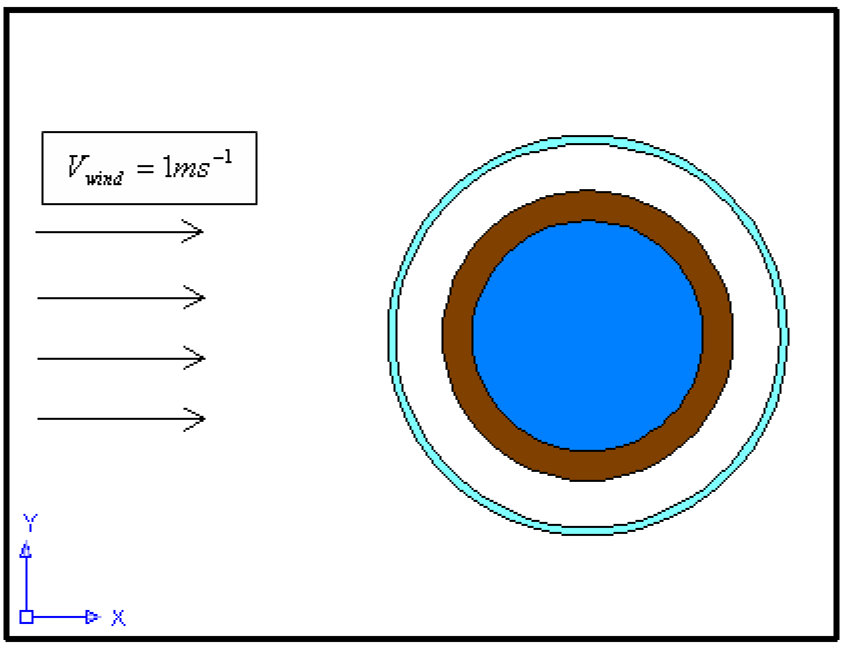

Figure 4.5: Cross sectional view of water tube

Glass temperature, T_{glass} = 331.4 K

Absorber temperature, T_{abs} = 324.6 K

Water temperature, T_{water} = 313 K

Surrounding temperature, T_{surr} = 304.9 K

Parameters given:

Width / Aperture = 1.5 m

Length = 20 m

Absorber tube :

$$D_{abs.in} = 3.81cm(0.0381m)$$
$$D_{abs.out} = 4.135cm(0.04135m)$$

Glass cover:

$$D_{glass.in} = 5.60cm(0.056m)$$
$$D_{glass.out} = 6.30cm(0.063m)$$

Reflectivity of concentrator, ρ = 0.85

Glass cover transmissivity, τ = 0.84

Glass cover emmisivity/absorptivity, α = 0.88

Absorber tube emmisivity/absorptivity, α = 0.90

Intercept factor, γ = 0.95

Data was taken in April 15, 2009

Time : 1230h

I_b : 705 W/m^2

I_g : 949 W/m^2

Ambient temperature : 304.9 K

Wind speed : 1 m/s

Inlet temperature : 40^{o}C

1. Slope of the Aperture Plane and Angle of Incidence

On April 15, 2009, n = 105

$$\delta = 23.45 \sin\left[\frac{360}{365}(284 + 105)\right]$$

$$= 9.415^o$$

Therefore, substituting δ = 9.415^o, ω = -7.5^o, Φ = 4.6^o

$$\cos\theta = (1-\cos^2 9.415^o \sin^2(-7.5))^{1/2}$$

$$\cos\theta \;= 0.9917$$

$$\theta \;= 7.398^o$$

2. Absorbed Flux, S

$$r_b = \frac{0.9917}{\sin 4.6(\sin 9.415) + \cos 4.6(\cos 9.415)(\cos -7.5)}$$

$$= 0.988$$

$$S = 705x0.988\left[0.85x0.95x0.84x0.90 + \frac{0.84x0.90x0.04135}{1.5-0.04135}\right]$$

$$= 440.14 \text{ W/m}^2$$

3. Convective Heat Transfer Coefficient, h_f

Reynolds number with the assumption of wind speed at 1 ms^{-1},

$$\mathrm{Re} = \frac{VD}{\nu}$$

$$\mathrm{Re} = \frac{(1)(0.063)}{1.822\times10^{-5}}$$

$$\mathrm{Re} = 3457.74$$

The air properties are based on the film temperature, T_f at 52.8 ^oC, from the Reynolds number that obtained, it shows that the flow on the glass tube outer surface is turbulent flow, with refer to Dewitt & Incropera (2001), the Nusselt number become

$$Nu = C \cdot \mathrm{Re}^m \cdot \mathrm{Pr}^n \cdot \left(\frac{\mathrm{Pr}}{\mathrm{Pr}_s}\right)^{1/4}$$

$$Nu = 0.26(3457.74)^{0.6}(0.7107)^{0.37}\left(\frac{0.7107}{0.7093}\right)^{0.25}$$

$$Nu = 30.45$$

The convection heat transfer coefficient between glass cover and ambient air which due to wind,

$$h_w = \frac{N_u K_a}{D_g}$$

$$h_w = \frac{(30.45)(0.028)}{0.063}$$

$$h_w = 13.53 W/m^2 K$$

The radiation heat transfer coefficient between glass cover and the ambient,

$$h_{r,c-a} = \varepsilon_g\ \sigma(T_g + T_a)(T_g{}^2 + T_a{}^2)$$

$$h_{r,c-a} = (0.88)(5.67\times10^{-8})(331.4+304.9)(331.4^2+304.9^2)$$

$$h_{r,c-a} = 6.438 W/m^2 \cdot K$$

The radiation heat transfer coefficient between absorber tube and cover tube,

$$h_{r,r-c} = \frac{\sigma(T_{abs} + T_g)(T_{abs}{}^2 + T_g{}^2)}{\frac{1}{\varepsilon_{abs}} + \frac{A_r}{A_c}\left(\frac{1}{\varepsilon_{abs}} - 1\right)}$$

$$h_{r,r-c} = 6.786 W/m^2 \cdot K$$

The overall heat loss coefficient,

$$U_L = \left[\frac{A_r}{A_c\,(h_{c,c-a} + h_{r,c-a})} + \frac{1}{h_{r,r-c}} \right]^{-1}$$

$$U_L = \left[\frac{0.0015}{(0.00246)(6.348 + 13.53)} + \frac{1}{6.786} \right]^{-1}$$

$$U_L = 5.617\,W/m^2 \cdot K$$

The Reynolds number of the flow inside the absorber,

$$\mathrm{Re} = \frac{4\dot{m}}{\pi D_i\,\mu}$$

$$\mathrm{Re} = \frac{(4)(0.05)}{(3.142)(0.0381)(5.716x10^{-4})}$$

$$\mathrm{Re} = 2923$$

From the Reynolds number that obtained, it shows that the flow in the absorber tube is turbulent flow; with refer to Dewitt & Incropera (2001), the Nusselt number become

$$Nu = 0.023\,\mathrm{Re}_D^{\;0.8} \cdot \mathrm{Pr}^{1/3}$$

$$Nu = 0.23(2923)^{0.8}\,(4.002)^{0.333}$$

$$Nu = 21.63$$

The convective heat transfer coefficient between the absorber and the fluid,

$$h_{c,i} = \frac{N_u K}{D_i}$$

$$h_{c,i} = \frac{(21.63)(0.6331)}{0.0381}$$

$$h_{c,i} = 359.42\,W/m^2 \cdot K$$

4. Collector Heat Removal Factor and Overall Loss Coefficient

$$F^{'} = \frac{1}{U_l\left[\frac{1}{U_l} + \frac{D_{abs.out}}{D_{abs.in} h_f}\right]}$$

$$F^{'} = \frac{1}{5.617\left[\frac{1}{5.617} + \frac{0.04135}{0.0381(359.42)}\right]}$$

$$F^{'} = 0.9833$$

$$\frac{\dot{m} C_p}{\pi D_{abs.out} U_l L} = \frac{0.05(4186)}{\pi(0.04135)(5.617)(20)}$$

$$= 14.34$$

$$F_R = 14.34\left[1 - \exp\left(-\frac{0.9833}{14.34}\right)\right]$$

$$F_R = 0.9503$$

$$CR = \frac{1.5 - 0.04135}{\pi(0.04135)}$$

$$CR = 11.29$$

$$q_u = F_R (W - D_{abs.out}) L\left[S - \frac{U_l}{CR}(T_{fi} - T_a)\right]$$

$$q_u = 0.9503(1.5 - 0.04135)20\left[440.14 - \frac{5.617}{11.29}(50 - 31.9)\right]$$

$$q_u = 11952.4W$$

5. Exit Temperature

$$0.05(4.186)(T_{fo} - 50) = 11.9524$$

$T_{fo} = 107^{0}C > 104.5^{o}C \rightarrow$ Valid

6. Instantaneous Efficiency

$$\eta_i = \frac{q_u}{(I_b r_b)WL}$$

$$= \frac{11952.4W}{(705x0.988)x(1.5)(20)}$$

$$= 0.572$$

4.3 Selection of Material For Concentrator

4.3.1 Selective coating for absorber

The fact that blackbodies are good absorbers lead to the coating of absorber to increase its absorptance and reduce its emittance. The considerations of factor that need to be taken into account are:

a) high solar absorptance (α)

b) low Infrared emittance

c) low cost

d) ease to manufacture

e) durability/life-cycle

The most suitable material for selective coating is copper oxide on copper. The characteristic of this material are high solar absorptance about 0.90 and low IR emittance (0.12). Even though there are other materials that have high solar absorptance and low IR emittance such as black nickel on copper and black chrome on copper, the cost for construction is higher than expected cost. This project encourages low cost consumption and easy to manufacture. So copper oxide on copper is the most suitable material and it has long life cycle. (APPENDIX A-2 Table 1: Solar absorptance, infrared emittance for various selective coatings)

4.3.2 Material for absorber plate

The absorber plate should have higher thermal conductivity, adequate tensile and compressive strength and good corrosion resistance. Copper is generally preferred due to its high thermal conductivity (386 W/m ^{o}C) and resistance to corrosion. Other suitable materials for absorber plate are aluminium, steel and various thermoplastics. (APPENDIX A-2 Table 2: Properties of metals used for absorber)

4.3.3 Material for insulation

Several thermal insulating materials which can be used to reduce heat losses from absorbing plate are commonly available. The desired characteristics of an insulating material are:

a) Low thermal conductivity
b) Suitability at high temperature up to 200 ^{o}C
c) No degassing up to 200 ^{o}C
d) Self supporting feature without tendency to settle
e) Ease of application
f) No contribution to corrosion

Glass wool is the most suitable material for insulation because it has low thermal conductivity (0.044 W/m ^{o}C) and it is cheap compare to other material. (APPENDIX A-2 Table 3: Properties of thermal insulating material for solar collector)

4.3.4 Material for Cover Tube

The functions of cover tube are:

a) To transmit maximum solar energy to absorber plate

b) To minimize upward heat loss from the absorber

c) To shield the absorber from direct exposure to weathering

The most critical factors for the cover plate material are:

a) Strength

b) Durability

c) Non-degradability

d) Solar energy transmittance

Tempered glass is the common material for collectors because of its proven durability and stability when exposed to UV radiation. If properly installed, it is highly resistance to breakage both from thermal cycling and natural events. Glass cover also reduces radiation loss from absorber because it is opaque to the longer wavelength IR radiation emitted by the absorber.

Transmittance of glass depends upon its iron contents. A normal sheet of window glass looks green when viewed through the edge because the presence of iron oxide. Water white crystal glass has the lowest iron content and therefore, the highest transmittance of solar radiation.

Polycarbonate plastic, plastic films of Tedlar and Mylar, commercial plastics as Lexan may also be used for cover plate. Plastics materials have limited life because of the effect of UV radiation in reducing their transmissivity. These are also partially transparent to long wave radiation and are therefore, less effective in reducing radiated heat losses from the absorber plate. (APPENDIX A-2 Table 4: Thermal and optical properties of cover tube materials)

4.3.5 Reflecting and Refracting Surfaces

The reflectors should have high reflectivity and good specular reflectance. For low CR, the reflector need not be highly specular. Glass silvered on the rear or second surface is usually used as mirror materials. Front surface mirrors can also be used. Aluminium can also be used for the purpose. It is protected by a coating of aluminium oxide, magnesium fluoride or cerium oxide. Aluminium with a total reflectivity of about 80-90 percent and silver around 95 percent are very good reflecting surfaces for solar energy application. However, silver is not adequate for front-surface mirror since its film is tarnished.

The reflectors should be light weight so that they can be oriented easily. They should be able to withstand wind and other weather extremes, as dust, sand and other contamination strongly affect the performance.

4.4 Working Fluids

Working fluid takes away the heat from receiver for further use. Therefore, for effective heat transfer, the fluid should be stable at high temperatures, non-corrosive and safe; besides, it also needs to be cost effective. Air is attractive for heating and cooling application, but the heat transfer is very poor. The commonly used materials are pressurized water, liquid metals, thermirol 55 and Mobile therm 603.

4.5 Discussion

With the constant width, *w* of the PTC 1.5*m* varies the depth value 0.1*m*, 0.2*m*, 0.3*m*, 0.4*m*, 0.5*m*, 0.6*m*. The calculation results (please refer to Figure 12, Figure 13 and Figure 14) show the following relationships when (aperture diameter) width, w constant:

i. The graph showing the maximum concentration ratio obtained at a rim angle of 90^o Depth, d inversely proportional to Focus length, *f*.

ii. The graph showing the proportional relationship between Rim angle and Depth of PTC

iii. The graph showing the depth of PTC when the concentration ratio achieves the maximum value.

Table 4.3: The selected design parameters of the PTC

Depth (m)	Width (m)	Rim angle	Focus length (m)	Concentration ratio
0.1	1.5	29.86283	1.40625	106.9828157
0.2	1.5	56.14497	0.70313	178.4224718
0.3	1.5	77.31962	0.46875	209.6005347
0.375	1.5	90	0.375	214.832
0.4	1.5	93.69522	0.46875	214.3825165
0.5	1.5	106.26020	0.28125	206.2243387
0.6	1.5	115.98923	0.23438	193.0827825

Balbir & Fauziah (2003) reported that the rim angle of 90 degree is preferred as given an optimum intercept factor and allows the depth to be the focus point. This will contribute to the highest concentration ratio and a proper support structure can be easily designed.

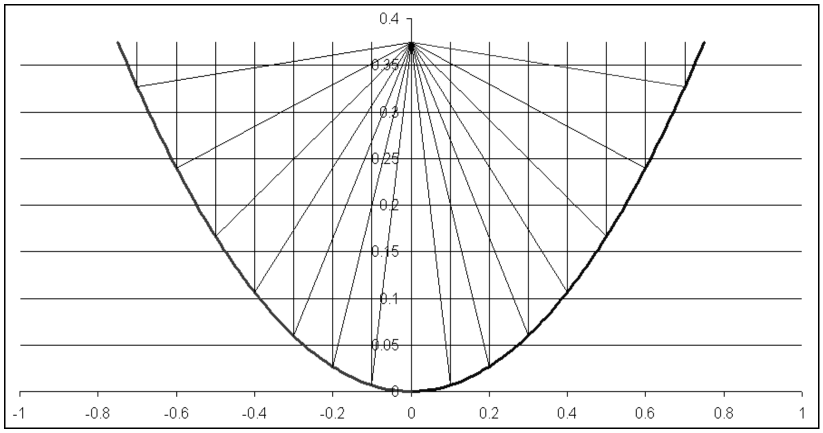

Figure 4.6: The graph show the selected PTC for the testing model

Improvement in efficiency of solar water collector can be done by evaluating the parameter in the construction of PTC. Factors that affected the efficiency of the collector are:

a) design factor, F

b) effective incident radiation, G

c) transmittance, τ

d) absorptance, α

e) heat loss coefficient, U

f) temperature dirrefence (T_c-T_a)

g) collector fluid temperature, T_c

Desired parameter change	Method of change	Effect on the collector
$F\uparrow$	improved geometry of collector	better heat transfer from radiation to collector
$G\uparrow$	concentration of incident radiation — south facing and tracking	higher thermal input
$\tau\uparrow$	selective windows	reduced radiation losses
$\alpha\uparrow$	selective absorber on collector	increased absorbance and reduced emittance
$U\downarrow$	e.g. double glazing, better insulation	reduced conduction and convection losses
$(T_c - T_a)\downarrow$ $T_c\downarrow$	reduced working fluid temp	reduced conduction and radiation losses

Figure 4.7: Improving the efficiency of collector

Effect of Inlet Temperature

As the fluid inlet temperature increases, the temperature of the absorber tube surface also increases. As a result, losses due to reradiation and convection to the surrounding increase, resulting in a decrease in efficiency.

Effect of Mass Flow Rate

An increase in mass flow rate of the fluid increases the value of the inside heat transfer coefficient. Due to this, the collector efficiency factor and collector heat removal factor increase and the efficiency increases.

CHAPTER 5

CONCLUSION

As a conclusion, the methodology and up to date progress which is used in this project can support the objectives in the project which are to design the Solar Parabolic Through Concentrator and to produce steam with specific temperature for absorption refrigeration system. With the constant width, *w* of the PTC 1.5*m* varies the depth value 0.1*m*, 0.2*m*, 0.3*m*, 0.4*m*, 0.5*m*, 0.6*m*, the data as listed below. The calculation results (please refer to Figure 12, Figure 13 and Figure 14) show the following relationships when (aperture diameter) width, w constant:

i The graph showing the maximum concentration ratio obtained at a rim angle of 90^{o} Depth, d inversely proportional to Focus length, *f*.

ii The graph showing the proportional relationship between Rim angle and Depth of PTC

iii The graph showing the depth of PTC when the concentration ratio achieves the maximum value.

Balbir & Fauziah (2003) reported that the rim angle of 90 degree is preferred as given an optimum intercept factor and allows the depth to be the focus point. This will contribute to the highest concentration ratio and a proper support structure can be easily designed.

The design parameters that are required in this project had been classified to produce the maximum efficiency of the outlet temperature of the water. This water heating system is connected to absorption refrigeration system that operates at specific temperature only. It will ensure that the absorption refrigeration system can operate with high efficiency by the steam provided in water heating system.

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APPENDICES

Appendix A-1

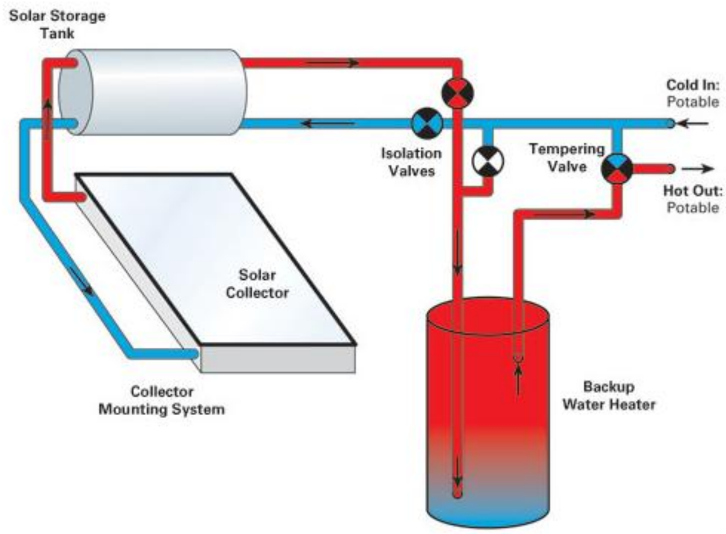

Figure 1: Schematic diagram for Water Heating System

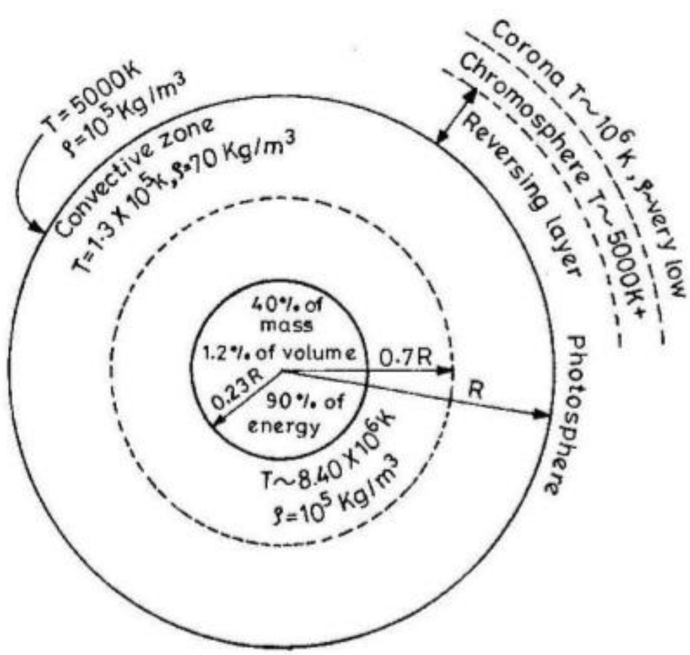

Figure 2: The structure of the sun

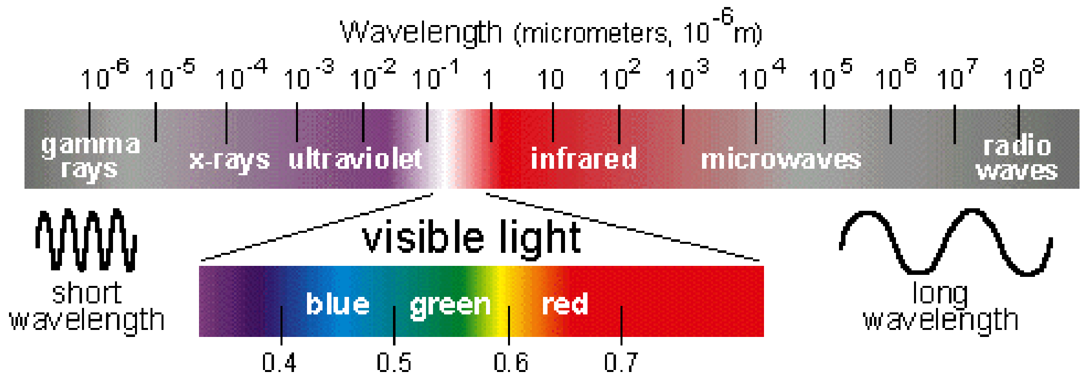

Figure 3: Types of wavelength in micrometers

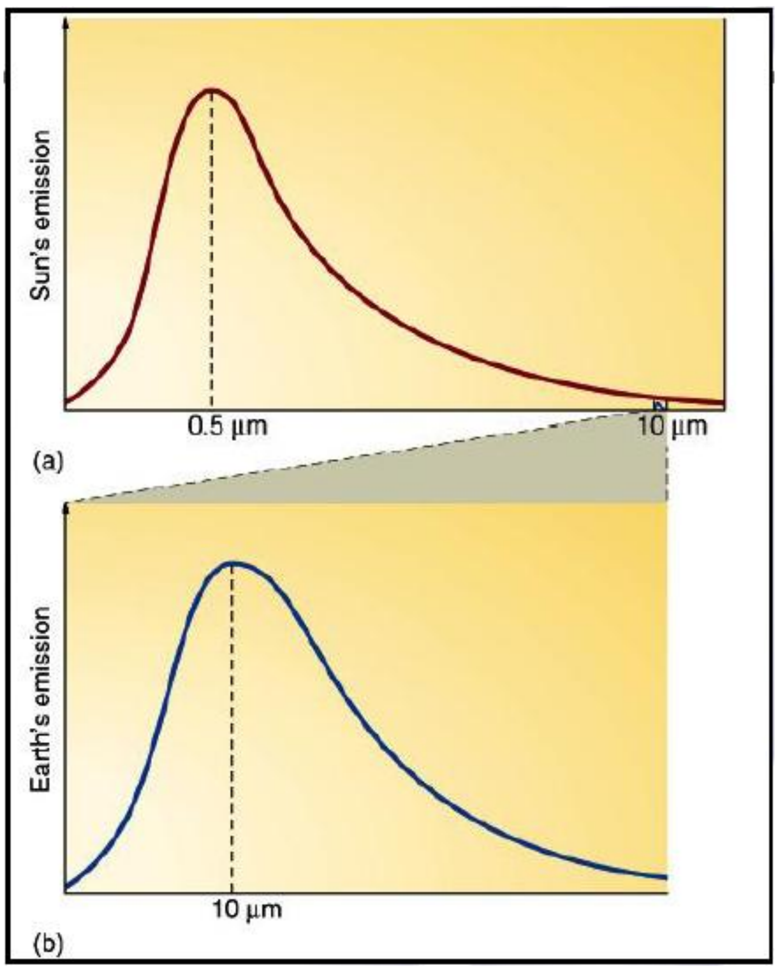

Figure 4: Sun emission compared to earth emission

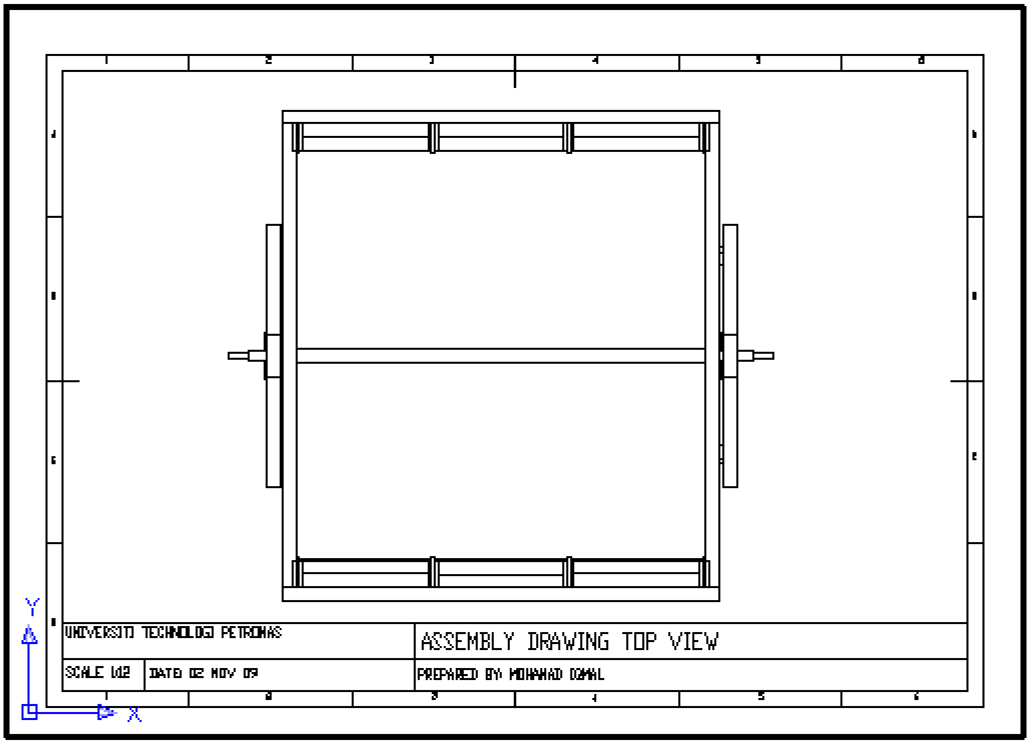

Figure 5: Top view of Cylindrical Parabolic Concentrator

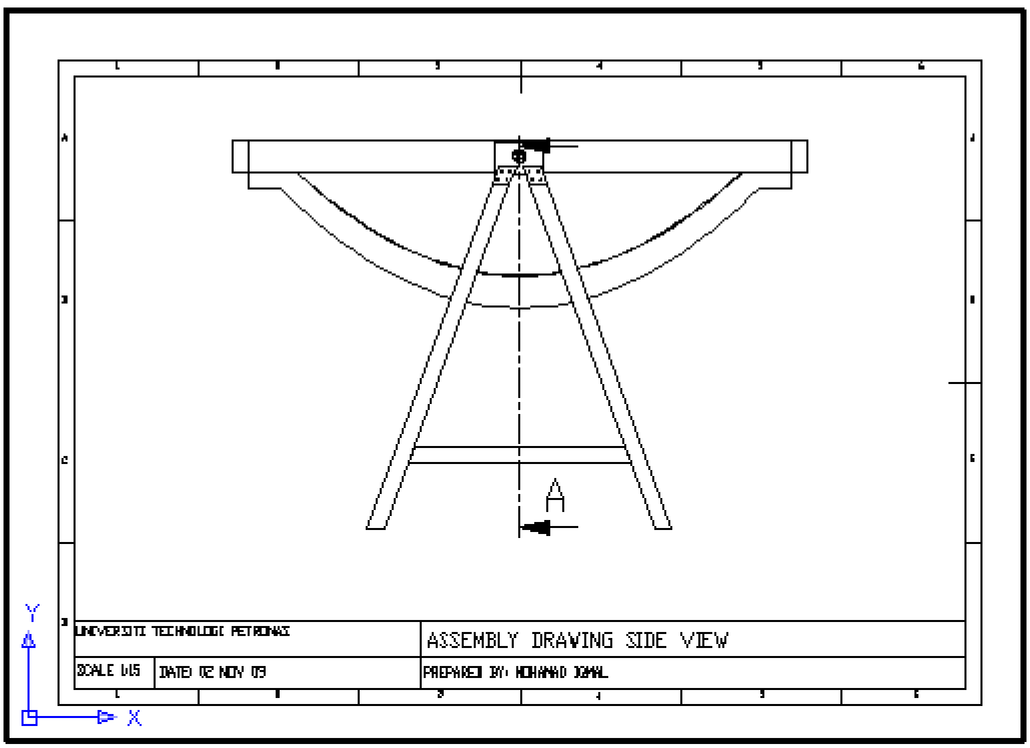

Figure 6: Side view of Cylindrical Parabolic Concentrator

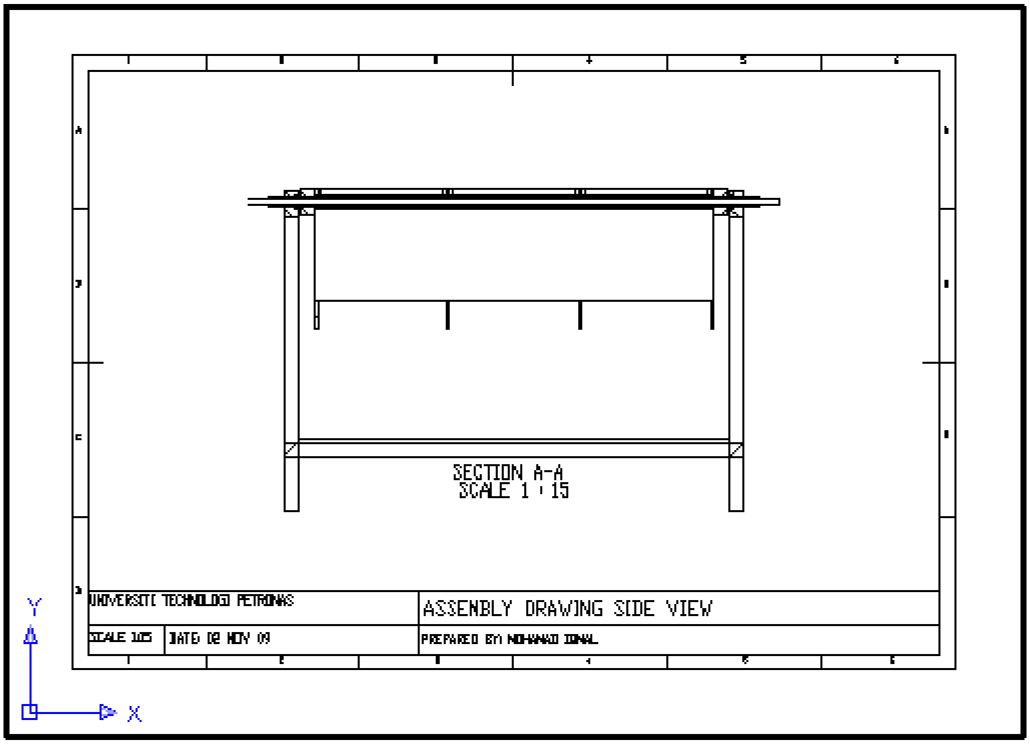

Figure 7: Front view of Cylindrical Parabolic Concentrator

Material	Solar absorptance (α)	IR emittance (ϵ_{IR})	Performance factor α/ϵ
Copper oxide on copper	0.90	0.12	7.5
Black nickel on copper	0.90	0.08 (573 K)	11
Black chrome on copper	0.95	0.12	7.92
Silicon on silver	0.76	0.06 (773 K)	12
Nonmetallic black surfaces: asphalt slate, carbon	0.92	0.94	0.98
Flat black paint	0.97	0.86	1.13
3M Velvet black paint	0.98	0.90	1.09
Grey paint	0.75	0.95	0.79
Red brick	0.55	0.92	0.6
Concrete	0.60	0.88	0.68
Galvanised steel	0.65	0.13	5
Aluminium foil	0.15	0.05	3
ZrNy on Ag	0.85	0.03 (600 K)	24

Table 1: Solar absorptance, infrared emittance for various selective coatings.

Material	*Density* (kg/m^3)	*Specific heat* ($kJ/kg°C$)	*Thermal conductivity* ($W/m\ °C$)
Aluminium	2707	0.996	204
Iron	7897	0.452	73
Steel	7833	0.465	54
Copper	8954	0.383	386
Brass (70/30)	8522	0.385	111
Silver	10524	0.234	419
Tin	7304	0.226	64
Zinc, pure	7144	0.384	112

Table 2: Properties of metals used for absorber

S.No.	Name of material	Thermal conductivity at 200°C (W/m°C)	Density (kg/m³)	Out gassing	Sazing	Colour change	Remarks
1.	Crown white wool	0.034	48	No	Yes	No	Good but expensive
2.	Crown bonded 150	0.066	48	Yes	No	Yes	Not good
3.	Spintex 300 industrial	0.975	48	No	No	No	Good, reasonable cost
4.	Glass wool	0.044	48	No	Yes	Yes	Good
5.	Calcium silicate	0.07	251.60	No	No	No	Good, but component system becomes very heavy
6.	Expanded polystyrene	0.017	32	Yes	No	Yes	Not good
7.	ISO Cyanurate	0.020	32	No	No	Yes	Under testing
8.	Phenotherm	0.029	32	Yes	No	Yes	Not good
9.	Thermocole	0.035	16	Yes	No	Yes	Not good
10.	Polyurethane foam	0.016	32	Yes	No	Yes	Not good
11.	Cellular foam	0.093	400	Yes	No	Yes	Not good
	PIPE SECTIONS						
12.	Rocklloyd	0.075	48	No	No	No	Good
13.	Isoloyd	0.021	32	No	No	No	Good
14.	Thermocole	0.035	16	No	No	No	Good
15.	Foam	0.017	32	No	No	No	Good

Table 3: Properties of thermal insulating material for solar collector

Material	Index of refraction	Normal incident short-wave transmittance (λ = 0.4-2.5 μm)	Normal incident long-wave transmittance (λ = 2.5-40 μm)	Thickness* (m)	Density (kg/m³)	Specific heat (J/°K-kg)	Thermal** capacity (W-hr/°K-m²)
Glass	1.518	0.840	0.020	3.175×10^{-3}	2.489×10^3	0.754×10^3	1.659
Fibreglass Reinforced Polyester (Sanlight)	1.540	0.870	0.076	6.350×10^{-3}	1.399×10^3	1.465×10^3	3.61
Acrylic (Plexiglass)	1.490	0.900	0.020	3.175×10^{-3}	1.189×10^3	1.465×10^3	1.534
Polycarbonate (Lexan)	1.586	0.840	0.020	3.175×10^{-3}	1.199×10^3	1.193×10^3	1.260
Polytetrafluoroethylene (Teflon)	1.343	0.960	0.256	5.080×10^{-3}	2.148×10^3	1.172×10^3	0.036
Polyvinyl Fluoride (Tedlar)	1.460	0.920	0.207	1.016×10^{-3}	1.379×10^3	1.256×10^3	0.049
Polyester (Mylar)	1.640	0.870	0.178	1.270×10^{-3}	1.394×10^3	1.046×10^3	0.051
Polyvinylidene Fluoride (Kynar)	1.413	0.930	0.230	1.016×10^{-3}	1.770×10^3	1.256×10^3	0.063
Polyethylene (Marlex)	1.500	0.920	0.810	1.016×10^{-3}	0.910×10^3	2.302×10^3	0.059

Table 4: Thermal and optical properties of cover tube materials