# CHAPTER THREE

# METHODOLOGY

This chapter will introduce the method employed on this research starting from designing of the PTC, fabricating a prototype of the designed PTC and evaluating its thermal performance. The important consideration on designing this research is on the low-cost materials without compromising its thermal performance.

## 3.1 Design and Construction

There are 2 important parts in designing concentrated solar thermal (CST) using parabolic trough collector (PTC) design. The first part is the collector itself, and the second part is the thermal receiver. Both will be elaborated in detail below.

### 3.1.1 Parabolic Collector

The fabrication of parabolic trough collector reported here was carried out based on three designed steps; the first model of an aperture area of 0.06 m$^2$ followed by the second model of an aperture area of 0.24 m$^2$ and then a prototype used during the experimental evaluation that has an aperture area of 0.96 m$^2$.

Reason behind undergoing three steps in the design and fabrication of the PTC is to obtain the accurate fabricating reflector as well as the exact focal point, because the performance of the PTC depends on the accuracy of the parabolic mold structure and the exact focal point.

The basic identification of parameter used in the prototype collector design is shown in Figure 6. The design of the collector was developed using AUTOCAD software. The dimensions required in designing the collector are summarized in Table 2. The focal length ($f$) and the radius ($R$) of the parabola PTC developed can be calculated using equation 3.1 and 3.2 respectively,

$$y = \frac{x^2}{2R} \tag{3.1}$$

$$f = \frac{R}{2} \tag{3.2}$$

Where $\theta$ is fixed at $90^0$ for this case, $x$ and $y$ are the Cartesian coordinates respectively (refer Figure 6).

*Figure 6: Sketch of the Parabolic Thermal Collector Parameter.*

Taken aperture width of the collector as 80 cm, therefore $x$ = 40 cm and $y$ = 20 cm. Using the parabolic equations of 3.1 and 3.2, we can calculate radius, $R$ and focal length, $f$ of the collector.

$$x^2 = 2 \times R \times y$$

$$(40)^2 = 2 \times R \times 20$$

$$1600 = 40R$$

$$\therefore R = \frac{1600}{40} = 40 \text{ cm}$$

Using eq 3.2,
$$f = \frac{R}{2}$$

$$\therefore f = \frac{40\ cm}{2} = 20\ cm$$

PTC parameter used in the design of this experimental work is listed in Table 2 below.

*Table 2: PTC Design Parameters*

| **Parameter** | **Symbol** | **Value** |
|---|---|---|
| Collector Width | $W_c$ | 0.8 m |
| Collector Area | $A_c$ | 0.96 $m^2$ |
| Receiver Length | $L_r$ | 1.2 m |
| Receiver Inner Diameter | $D_{ir}$ | 0.02 m |
| Receiver Outer Diameter | $D_{or}$ | 0.025 m |
| Rim Angle | $\theta$ | $90^0$ |
| Collector Radius | $R_c$ | 0.4 m |
| Concentration Ratio | $C_r$ | 10.2 |
| Focal Length | f | 0.2 m |
| Receiver Area | $A_r$ | 0.094 $m^2$ |

Figures 7 and 8 show 2D and 3D illustration of the collector design respectively. The mold structure was designed and fabricated into two equal parts for easy assemblies and transportation. Mild steel (M.S) was chosen as the collector support mold. The reason behind choosing the M.S sheet is due to its light weight, availability at low-cost and its suitability for the mold reflecting film. Fabrication of the PTC mold was carried out with a higher precision, since the accuracy of parabolic trough collector depends on the accuracy of the parabolic mold structure. Aluminum foil was selected as an inexpensive reflecting material and attached to the constructed M.S mold.

*Figure 7: 2D-Schematic Diagram of the Collector Dimensions Design.*

*Figure 8: 3D-Schematic Diagram of the Collector Dimensions Design.*

The front and back view of the fabricated M.S reflecting surface structures are given in Figure 9 (a) and (b) respectively. The materials and dimensions of the PTC reflecting surface structure are made of mold steel sheet of size 120 cm × 80 cm and 0.5 mm thickness. The support rim metal made of mold steel with 20 mm thickness. All the steel were painted with brown paint.

(a)

(b)

*Figure 9: (a) Front Side and (b) Back Side of the Fabricated Mold Surface.*

### 3.1.2 Thermal Receiver.

The thermal receiver consists of 2 components, which are the tube receiver and receiver cover-box. The tube was inserted in a custom designed box fabricated from M.S sheet with one surface made of glass placed at the top of the box as shown in Figure 10.

The receiver tube located inside the receivers cover box was aligned at the focal length of the collector where the water flowing was carried out during the thermal experiments. Copper tube was chosen as a tube receiver in this research project due its high thermal conductivity. During the fabrication, copper tube receiver and cover-box receiver were painted black with high temperature resistant paint while the inner part of the box was insulated to prevent the heat loses and thereby increases the thermal conductivity of the receiver.

The materials and dimensions used for thermal receiver fabrication are given below:

Mild steel sheet: 0.8 mm thickness for the cover-box receiver

Copper receiver tube: 130 cm long and 25 mm thickness

Black resistance paint.

Screws

Glass

Glue, silicon sealant

Insulator

Water flow tubes

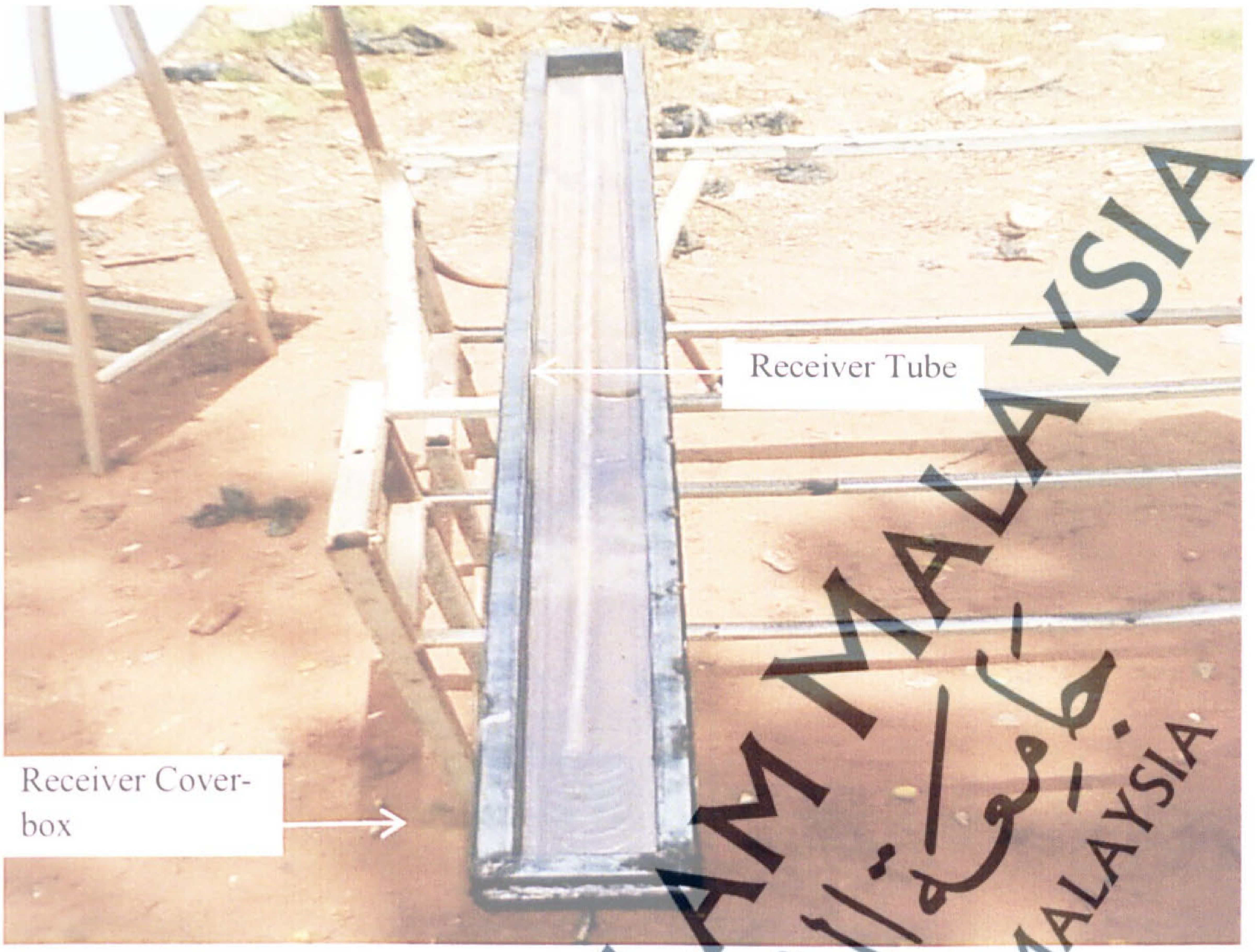

*Figure 10: Thermal Receiver System.*

### 3.1.3 Structures

The schematic diagram of the PTC stand structure and tube receiver is given in Figure 11. The stand structure was constructed with the M.S square material. It consisted of two triangular shapes welded in opposite direction, along the length of the supporting frame structures. The two PTC supporting structures were mounted with a ball bearing that connected the receiver at central position to allow the collector to rotate freely along its axis of rotation as seen in the Figure 12. The materials and dimensions used for the stand structures are given below:

1. Bottom width of the supporting stand: 136 cm
2. Top width of the supporting stand: 37 cm
3. Mild steel square meter: for supporting stand 20 mm thickness

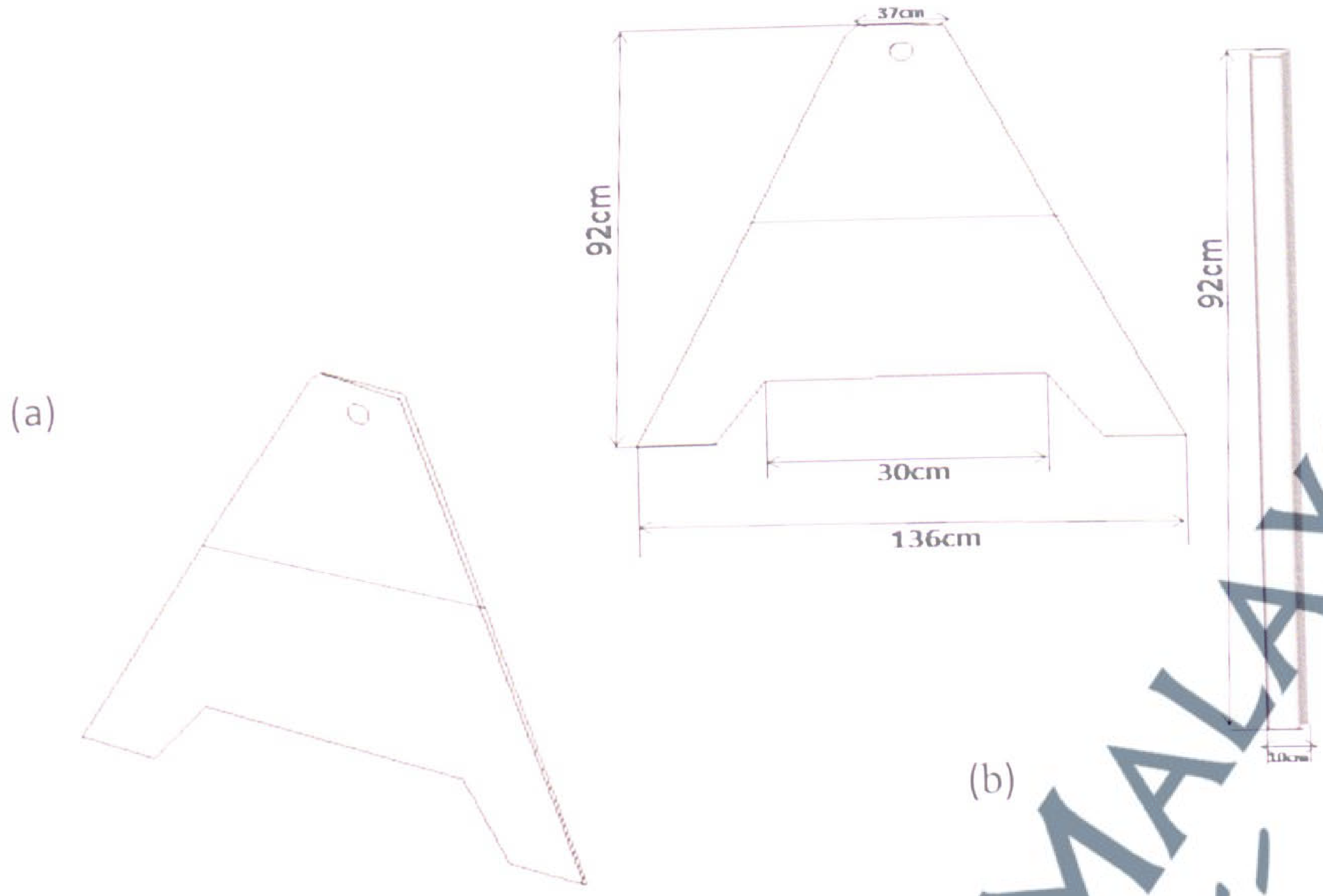

*Figure 11: (a) Designed and Dimension of PTC Stand Structure and, (b) Dimension of Tube Receiver.*

*Figure 12: PTC Supporting Stand Structure*

Mild Steel (M.S) sheet square steel used were cut into three pieces according to the above measurement and then welded together to form a triangular parabolic supporting stand. Then two already fabricated parabolic supporting stand were joined together in opposite side with the parabolic mold in between them along the 130 cm length of the supporting frame structure which form a complete PTC structure.

## 3.2 Experimental Setup

The experimental setup used during the experimental test of the CST with PTC system is shown schematically in Figure 13 and Figure 14. It was started by system arrangement where the water tank A that was filled with water was placed 1 m above the solar collector so as to ensure a perpetual flow of water to the water tank B that was placed on the ground. The PTC was oriented along North-South direction and the water flow rate was adjusted to the required value. All measuring instruments were properly checked before the water at ambient temperature from the tank was allowed to flow into the receiver tube of the parabolic trough collector. Solar insolation beam reflected by the PTC onto the receiver will heat water enters into the receiver tube. Heated water will flow into the water tank B through a plastic tube (open system).

In order to record the data from the experiment a weather station connected to a laptop was used along with thermocouples. The two thermocouples were calibrated inside a small hole drilled in the two sides of the receiver for temperature measurement. Another thermocouple for ambient temperature reading was also used. The signal from thermocouples would be sent to micro-controller board and MCP3424 to digital converters (ADC) with programmable gain amplifier and then into the computer where the high accuracy data were monitored. The data of the ambient temperature, inlet temperature, outlet temperature, solar insolation, humidity and wind speed was continuously recorded every half an hour during the experiment. The experimental evaluation was conducted for both automatic and manual tracking systems in this manner with tracking provided to the PTC in the E-W direction.

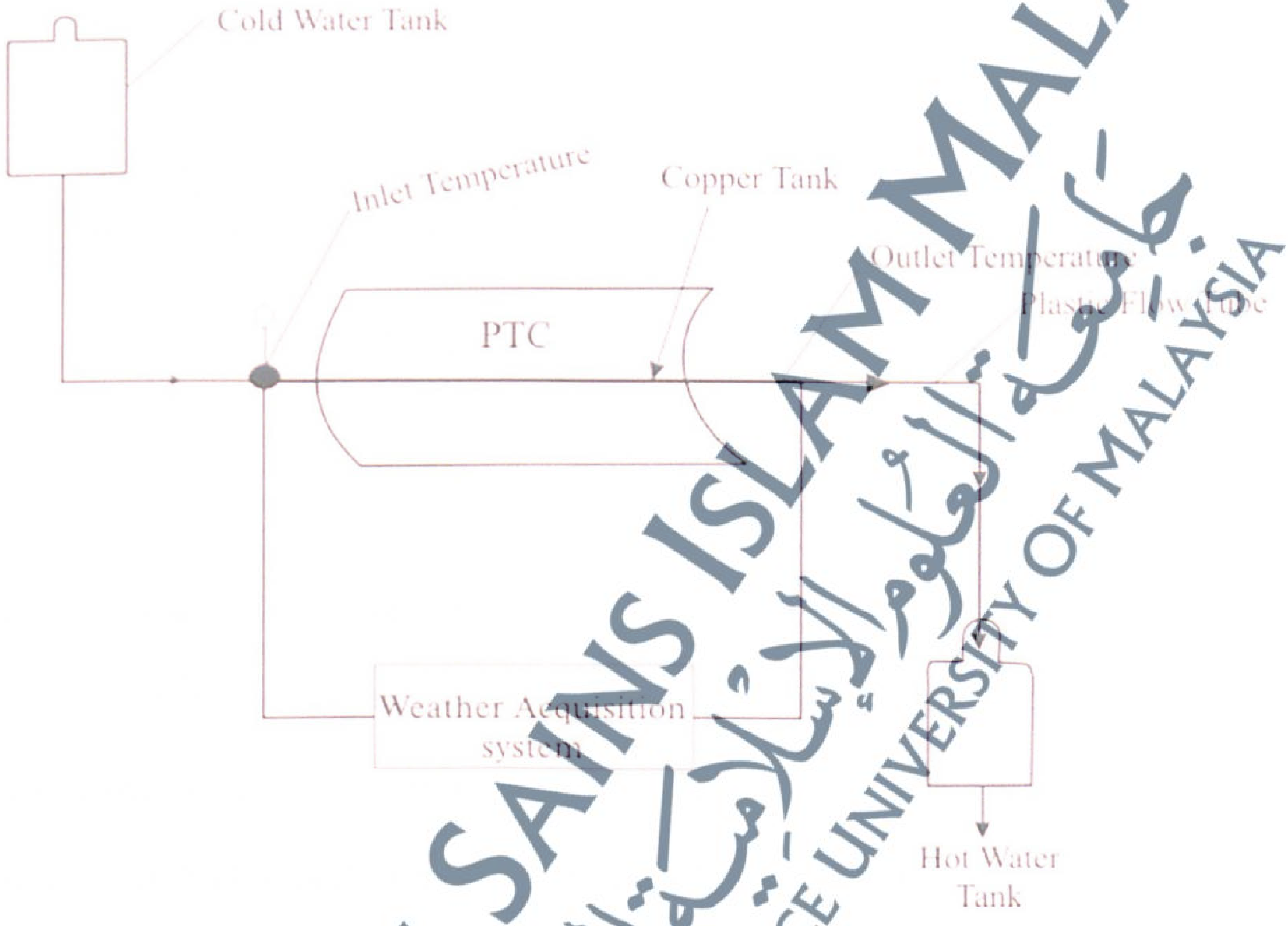

*Figure 13: Schematic Diagram of Experimental Setup for Open System.*

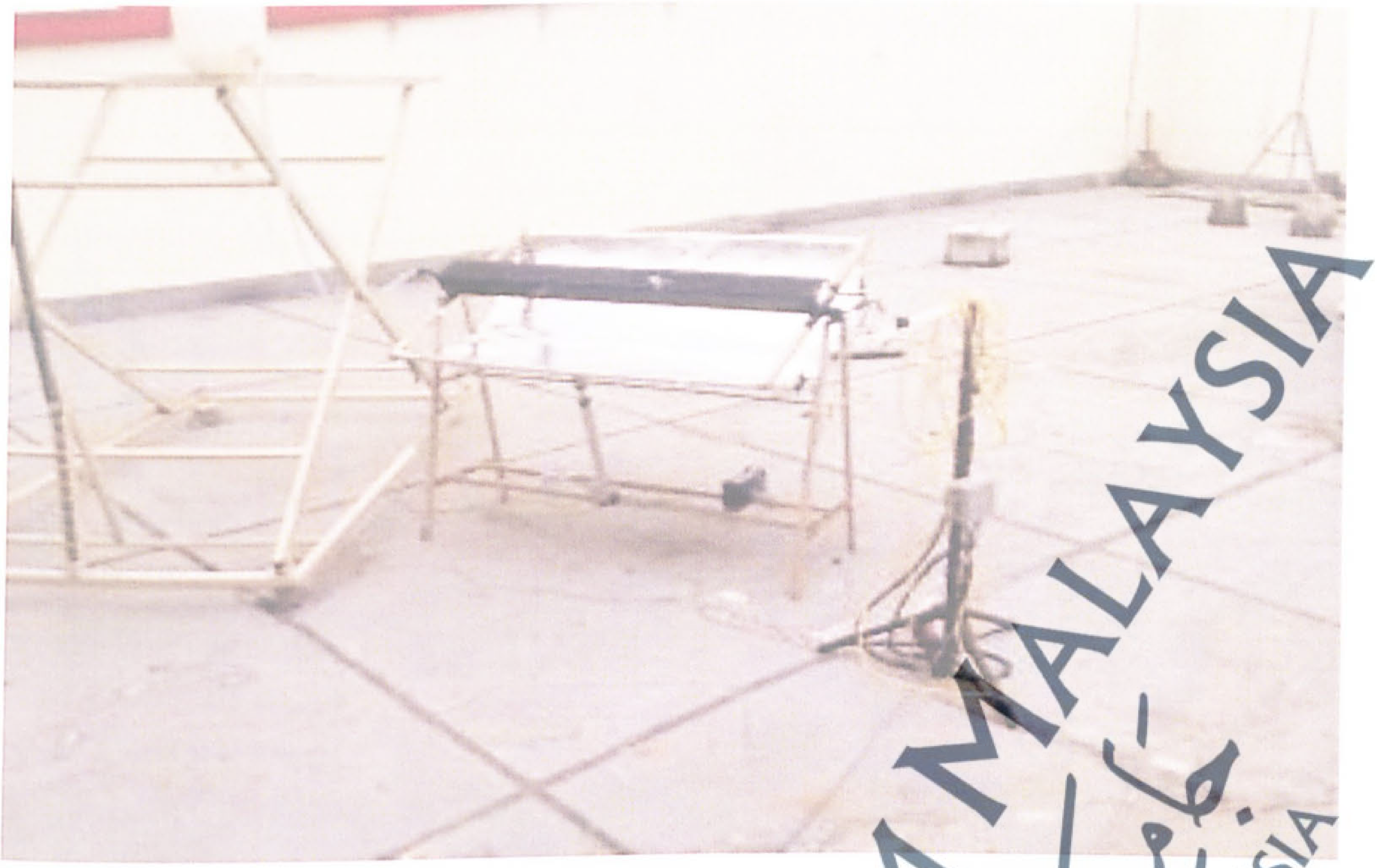

*Figure 14: Experimental Setup of the CST Using PTC System for Water Heating Application.*

### 3.3 Tracking System Assembling

Automatic tracking system was used in this experiment. The tracking system was designed to be single axis tracking and was assembled based on the materials given in Table 3.This method is based on the following; availability at low-cost, easy to assemble, and capability of maximizing the solar energy collection with the simple PTC.

*Table 3: Materials for the Tracking System Assembling*

| Name | Model | Quantity |
|---|---|---|
| Integrated circuit (IC) | LM339N | 1 |
| Integrated circuit (IC) | L293D | 1 |
| Diode | 1N4148 | 2 |
| Light dependent resistors (LDR) | LDR | 2 |
| Resistance | 10K | 2 |
| Resistance | 12K | 1 |
| Resistance | 22K | 1 |
| Resistance | 47K | 1 |
| Variable Resistance | 47K & 100K | 1 & 1 |
| Shaft & Motor | 12V 4 | 1 |
| Supply | 12V | 1 |
| Circuit Board | | 1 |

Figure 15 shows the circuit diagram of single axis solar tracking system. The tracking system comprises the following: H-bridge motor driver IC L293D (IC2), comparator IC LM339, Light-dependent resistors LDR1, LDR2 and a few discrete components. The light-dependent resistors LDR1, LDR2 are used in the solar collector as sensors to detect the collector's position relative to the sun direction. These two LDR are fixed at the edges of the solar collector and then connected to comparators A1 and A2, which serve to send a signal to motor IC2 and then turn the solar collector along the sun's direction. This method was employed from the previous work of Tanvir Islam & AnikSarker, 2014.

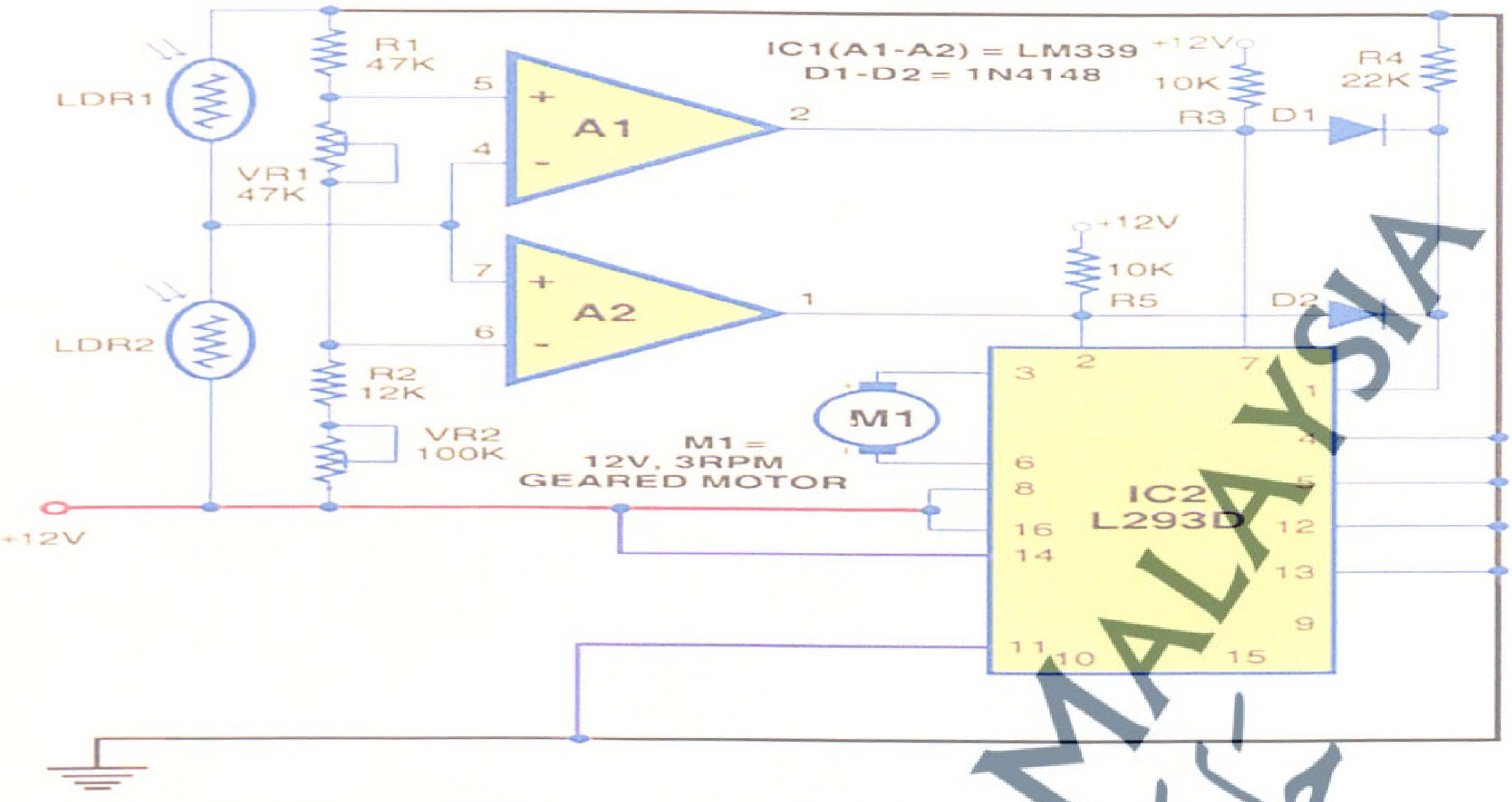

*Figure 15: Circuit Diagram of Single Axis Solar Tracker*

## 3.4 Measuring Instruments and Devices

Data required in order to be able to determine the thermal performance of the fabricated PTC includes the temperature of the working fluid, direct solar insolation, mass flow rate and weather (humidity and wind). More details on how the measurement was carried out is described in the following sections.

### 3.4.1 Temperature

In order to determine the thermal performance of the system, temperature measurement is very essential. To measure the temperature of the water flowing through the receiver, two pairs of thermocouples type-K were fixed along the inlet and outlet of the receiver tube. The thermocouples were directly connected to the analog input channels (V10 and V11). The analog input device has many channels in positive and negative terminals. For example, V1x+ represent positive terminal for the analog input channel + while V1- represent the ground channel – and the analog input channels is connected to the PC via USB cable where the data will be displayed and recorded as shown in Figure 16.

(a) (b)

**Figure 16: (a) Analog Input Channels and (b) Recorded Data Instantaneously.**

### 3.4.2 Solar Insolation

Solar insolation is the amount of solar energy that strikes a square meter of the earth's surface in a single day. This is another important parameter that needs to be measured during the experimental evaluation of the solar thermal system. The direct solar insolation was measured from the pyranometer. The pyranometer from weather system was used, which was located nearby to the designed collector system during the experimental evaluation. Pyranometer was connected to the PC via USB cable for data monitoring.

### 3.4.3 Mass Flow Rate

The mass flow rate was determined prior to the experiment. A simple gravity-based system was designed and implemented for the water flow system. In this respect, water at ambient source was positioned in a plastic container 1 m above the solar collector with the second container positioned on the ground. At the outlet of the receiving tube, an empty 10-litre tank was placed. The ambient water was allowed to flow in slowly through the plastic tube from the first container and passed through the receiver tube inlet and then recollected through the outlet of the receiver tube down to the second container automatically for the period of one hour. To measure the mass flow, every hour, the amount of water collected at the second container was measured. It is observed that 9 liters of water is flowing through the system for every one hour. This indicate that mass flow rate of water is equivalent to 0.0025 kg/s. This flow rate was kept constant throughout the experiment.

### 3.4.4 Wind and Humidity

Weather around experimental area was determined during the experiment by the readily available designed weather station in UniversitiKebangsaan Malaysia (UKM). The compact weather system consists of humidity sensor and wind speed sensor that help to determine the percentage (%) of humidity on each day of the experiment as well as the wind speed. The compact weather system was design based on micro controller board and MCP3424 with a programmable gain based amplifier, which allow the micro controller board to measure a high accuracy analog input. Those parameters were recorded directly from the PC, which connected to the system from weather station via USB cable as shown in Figure 17.

*Figure 17: Experimental Setup of the CST Using PTC System for Water Heating Application*

## 3.5 Experimental Procedure

The experimental procedure for designing, fabrication and testing the PTC is described in the flow chart below: The fabrication of parabolic trough collector reported here was carried out based on three designed steps and four system analyses.

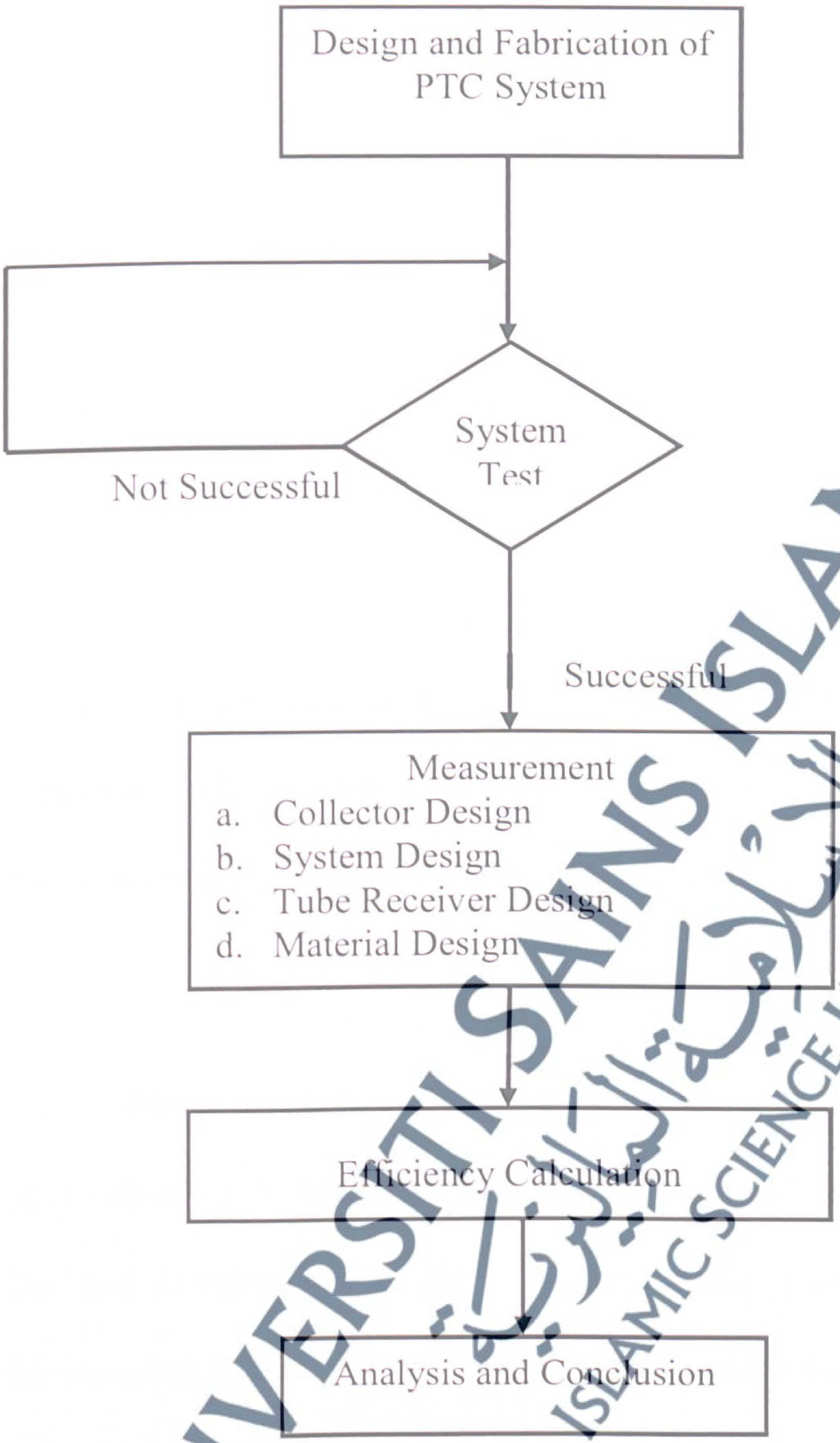

*Figure 18: Research Flow Chart*

## 3.6 Thermal Efficiency Calculation

To measure the CST design efficiency, rate of heat absorbed, $\dot{Q}$ by the water through tube receiver must be determined. Rate of heat absorbed, $\dot{Q}$ can be calculated using equation:

$$Q = \dot{m}C_p(T_o - T_i) \qquad 3.3$$

where $\dot{m}$ is the mass of water flowing through tube receiver, $C_p$ is the specific heat capacity of the water which is 4.184 J/g °C while $T_o$ and $T_i$ are the temperature of water outlet and inlet, respectively (Pradeep et al., 2013). Thermal efficiency of the system can then be calculated using:

$$\eta = \frac{\dot{Q}}{A_c \times I_b \times R} \qquad 3.4$$

where $A_c$ is the area of the collector, $I_b$ is the solar irradiance on the surface of the collector and R is the tilt angle for the solar insolation.

The concentration ratio of the PTC is given by,

$$C_r = \frac{A_a}{A_r} \qquad 3.5$$

The concentration ratio $C_r$ is the ratio of the effective aperture area $A_a$ to the area of the absorber $A_r$ where the effective aperture area is 0.96 $m^2$ and the absorber area $A_r = 2\pi r l$ and $2r$ represents the outer diameter of the absorber tube and $l$ represents length of the absorber tube. The PTC reported here in this research has a small concentration ratio since is for research purpose. The value of the concentration ratio of PTC with 2 cm copper and aluminum tube receiver is calculated to be 10.2 while that for 1 cm copper tube receiver is 16.84.

More details of the concentration ratio values calculation for different materials used here are given in section 4.5. But for commercial three-dimensional system like a parabolic dish system with a two-axis tracking system, which is focusing on one point, the maximum concentration ratio is around 45,000. However, the parabolic trough is a two-dimensional system, where a maximum concentration ratio of 200 can be reached.