Design and Development of Solar Parabolic Concentrator with Sensor Based Tracking System

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Abstract—*Solar energy is the promising renewable energy resource for major energy requirements. Solar thermal collectors are the most important equipment to achieve higher efficiencies for harvesting the solar energy. Among those collectors, solar parabolic concentrators (SPC) are most commonly using for medium and high temperature applications. This paper explains the design and development of a new parabolic concentrator with dual axis sensor based tracking system. Incorporated tracking system enhanced the efficiency of the overall system. Aperture area, depth and focal length of the parabolic concentrator were 2.25* m^2*, 0.3 m, and 0.46 m, respectively. Theoretical design calculations for the concentrator developed were also described. The developed tracking system and the program logic are explained for the concentrator system. Detailed performance evaluation was undertaken in different testing modes to analyze the performance of the system and to determine the maximum temperature achieved. The testing of the developed system is progressing well and the results obtained so far are satisfactory.*

Keywords: *Solar thermal collectors, solar parabolic concentrator, tracking system.*

1. INTRODUCTION

Sun's energy has been widely harnessed to perform a number of jobs such as heating and cooling buildings, to heat water for domestic and industrial use, to power refrigerators, to desalinate water for drinking purpose and many more. In solar thermal systems, solar radiation is converted into thermal energy. In this process, to improve the collection and conversion efficiencies of the system, solar thermal collectors play an important role. Concentrating and non concentrating collectors [1] are the two different categories in solar thermal collectors. In concentrating collectors, solar parabolic concentrator (SPC) is the most widely used for medium and high temperature applications.

The solar tracker is a device that keeps the solar energy collectors in an optimum position perpendicular to the solar radiation during sunshine hours, increases the collected energy. Solar trackers [2] are basically two types based on the components used such as active trackers and passive trackers. Based on the axis of rotation, trackers are classified as Single axis and dual axis trackers.

Solar parabolic concentrators were developed and analyzed by many researchers for different applications. Ozturk [3-4] developed a SPC which is used for cooking application. Parameters in terms of thermodynamic laws were analyzed. Exergy and energy efficiencies were experimentally evaluated. Petela [5] analyzed a parabolic concentrator of cylindrical trough shape from exergy point of view. Equations of heat transfer between different surfaces of the concentrator were derived and the exergy efficiency was evaluated.

A few design methodology of solar tracking system has been proposed in recent days. Khalifa et al. [6] developed a two axis sun tracking system for compound parabolic concentrator. The developed design consists of photo transistors separated by a partition. The radiation difference on the two sensors creates a voltage difference; accordingly the program logic was designed to activate DC motor. Abdallah et al. [7-8] designed and constructed two axes, open loop, PLC controlled tracking system. The principle of the system is based on the slope of the surface and azimuth angle. Depending upon the speed of the sun and motor, the logic is developed and programmed into PLC.

With the help of these literatures, this paper explains a new design for the parabolic concentrator along with the sensor based tracking system. This tracking system is developed accordingly to track the sun's position continuously throughout the day.

2. DESIGN OF SOLAR PARABOLIC CONCENTRATOR

Several parameters [9] are used to describe solar concentrating collectors. Given below are brief descriptions of some of these parameters:

The aperture area (A_a) is the area of the collector that intercepts solar radiation.

The Acceptance angle (ϕ) is defined as the angle through which a source of light can be moved and still converge at the receiver. The Absorber area (A_{abs}) is the total area of the absorber surface that receives the concentrated solar radiation.

The Concentration ratio (C) is defined as the ratio of the aperture area to the absorber area. i.e. $C = A_a/A_{abs}$

The Optical efficiency (η_o) is defined as the ratio of the energy absorbed by the absorber to the energy incident on the concentrator aperture.

The Thermal efficiency (η_{th}) is defined as the ratio of the useful energy delivered to the energy incident at the concentrator aperture.

The effective surface area of the absorber was calculated as 0.071 m^2. The concentration ratio for the developed collector was worked out to be 31.5. The system has an acceptance angle of 10.26^o. The calculated focal length of the parabolic collector was 46 cm. More design details are depicted in Table. 1

2.1 Fabrication details

Table 1: Materials used for construction

Description	Dimensions
Base dish Material	1.5mx1.5m
Reflecting Material	2 sq m
Cylindrical support	0.9 m height
Receiver pot support	0.9 m length
Vertical support	1.8 m length
Receiver base	Diameter – 25cm
Receiver pot	Diameter–12.5cm
Other support structures	As per the stability of the structure

Fig. 1: Photograph of the concentrator

3. DEVELOPMENT OF TRACKING SYSTEM

The concentrator is moved accordingly with the sun's position with the help of sensor based tracking system.

The major components those are used in the tracking mechanisms are given below:-
- Photo resistor
- Arduino interfacing board
- Microcontroller
- Motor

Table 2: List of components used for tracking system development

Components	Specifications
Photo resistor	CdS, Vmax-250V, Pmax 250mW
Microcontroller	ATMega 328
Interfacing board	Arduino Uno
DC motor	24V,2A,50W

Other electric components like resistors and capacitors are used as per the circuit requirements for the development of the tracking system as shown in Fig. 2.

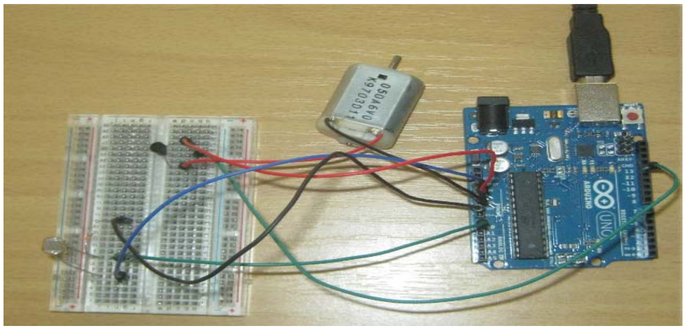

Fig. 2: Lab scale tracking system

3.2. Program logic for tracking

To enhance the efficiency of the solar thermal collector, tracking the sun's position is necessary. For the purpose of tracking the sun throughout the day a programming logic is developed. This logic explains the working of sensors and the motor control based on the intensity of the solar radiation.

Main logic for tracking:

```
intvalueOne = analogRead(inputOne);
intvalueTwo=analogRead(inputTwo);
int diff=valueOne-valueTwo;
if(valueOne<950 || valueTwo<950)
  {
if(diff>=100)
   {
currPos=currPos+2;
```

```
mydcmotor.write(currPos);
delay(30);
   }
else if(diff<=-100)
{
currPos=currPos-2;
mydcmotor.write(currPos);
delay(30);
```

Depending upon the solar radiation on the sensors the total system will move from East to West with continuous tracking.

Fig. 3: Working of tracking set up for the concentrator

4. RESULTS AND DISCUSSION

Experimental performance analysis on the fabricated solar parabolic concentrator with two axes sun tracking system was carried out for different days with and without reflecting film. Each experiment was conducted from 10:50 A.M. to 4:00 P.M. The global solar radiation on a horizontal surface was measured using pyranometer. Calibrated thermocouples, coupled to digital thermometer were used to measure the pot temperature, ambient temperature and reflector temperature.

Fig. 4 shows the ambient temperature measured during the test hours for the two days in which the experimental was conducted. Higher temperatures were observed during the day time with peaks occurring between 1:50 h and 2:30 h. The initial, maximum and final ambient temperatures recorded on the first day are 30.8°C, 33.2°C and 29.5°C respectively. On the Second day initial, maximum and final were observed as 35.8°C, 37°C and 33.9°C respectively.

Variation of the global solar radiation, measured during the test period throughout the day is shown in Fig. 5. Higher values of global solar radiation were achieved between 11:00 h and 1:10 h with a peak occurring at about 12:30 h. The maximum solar radiation observed on the first day was 781.3W/m^2. The second day the maximum solar radiation was 815.2W/m^2.

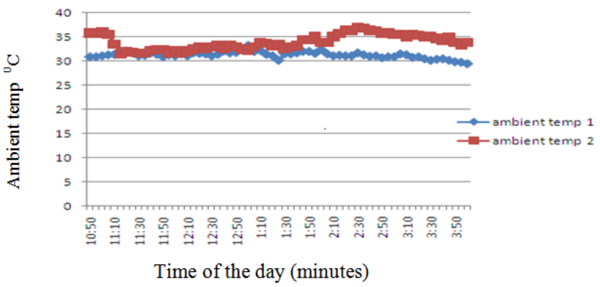

Fig. 4: Variation in Ambient Temperature with Time

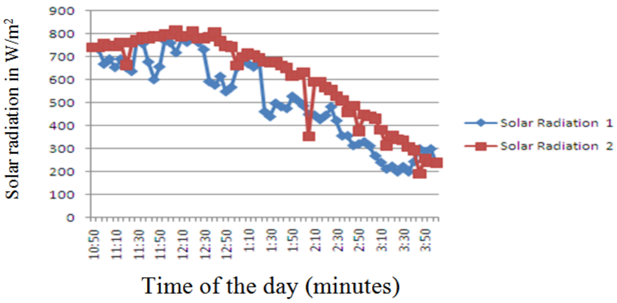

Fig. 5: Variation in Solar Radiation with Time

Fig. 6 shows the measured value of hourly variation of temperature inside the receiver pot. An increase in water's temperature was noticed during early hours of the day until it reaches its maximum value around noon hours when global solar radiation values are the highest. The maximum absorber temperatures achieved without and with reflective film were 41.1°C and 73.3°C respectively.

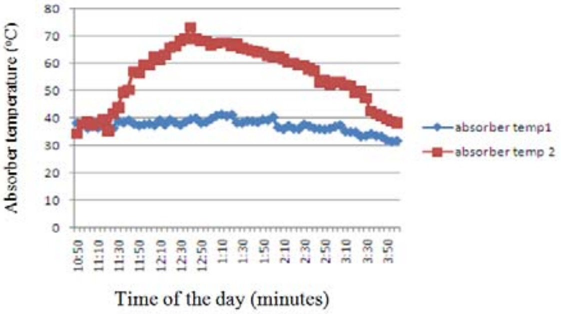

Fig. 6: Variation in Absorber Temperature with Time

Fig. 7 shows the efficiency measured after the test hours for two days in which the experimental part was conducted. Higher efficiencies were observed during the day time with peaks occurring between 11:50 h and 1:10 h. The maximum average efficiency achieved without reflective film is 44.67% and with reflective film is 51.19%.

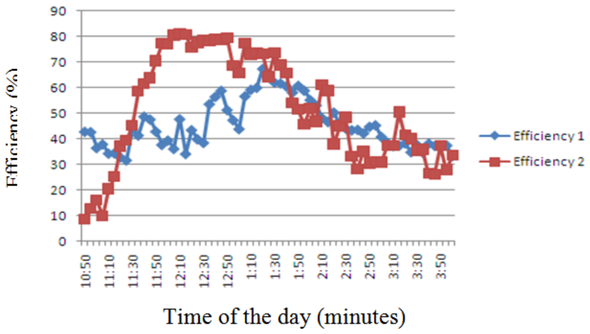

Fig. 7: Variation in Efficiency with Time

These results showed that the water temperature inside the cooking pot could still reach higher on hotter days with abundant solar radiation. At the time of operating the system for different applications such as cooking food, heating water etc., different parameters like latitude of the location, wind speed, weather conditions should be considered which will affect the thermal performance and efficiency of the system.

5. CONCLUSION

This paper describes the design and development of solar parabolic concentrator with sensor based tracking system. It mainly concentrates on the development of the working model design calculations and programming logic for the tracking system. Experimental thermal performance analysis of the cooker was calculated with and without high reflectance film. From the experimental results the efficiency of the fabricated solar parabolic concentrator was 44.66 % and 51.19 % with and without reflectance film respectively. Though the system has some limitations, it provides an opportunity to improve the design of the system in the future to obtain higher efficiencies. Further design modification is being undertaken on the developed system to augment the temperature output.

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