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Design Development of Parabolic Trough Solar Concentrator for Water Heating

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Abstract— In this paper a survey of parabolic trough solar concentrator and its application for heating water is provided. Initially, an overview of environmental related problems to the use of conventional sources of energy is presented and benefits offered by renewable energy systems are outlined. An introduction of flat-plate collector and its characteristics are compared with parabolic trough solar collector, and the corresponding results are obtained for PTC. This is followed by an optical, thermal and thermodynamic analysis of the collectors and description of the methods used to evaluate their performance. A tracking system is used to track the sun rays so as to get the maximum intensity which would be used for a wide range of application and provide significant benefits, therefore, they should be used wherever possible.

Index Terms— Solar Energy, Parabolic Collector, Solar Collector.

1 INTRODUCTION

THere are various renewable energy sources available like wind energy, solar, tidal, etc. Each of the energy source has its advantages and limitations. The use of wing energy using vertical axis and horizontal wind turbine for mechanical or electrical energy generation has been reported by many researchers [1-3]. The use of a solar thermal system for heating application is becoming popular day by day. The rising prices of fuel, as well as the effects of its usage on the environment, are the main concerns nowadays.

Parabolic trough collectors (PTCs) are currently the most feasible solar thermal technology for fluid heating since high temperature can be obtained without any decrease of the collector efficiency. The parabolic trough concentrator (PTC) converts solar energy into thermal energy in its linear receiver [4].

Flat-plate collector, Evacuated tube collector, Linear Fresnel reflector, cylindrical trough collector, parabolic trough collector have temperature application range of 30 – 80^0 C, 50 – 200^0 C, 60 – 250^0 C, 60 – 300^0 C, 60 – 400^0 C respectively [5].

PTC is contributing the 90% of the solar concentrators because this technology is the most usable among the concentrating collectors; it leads to lightweight structure systems and high-temperature range [6].

Htun et al. [7] designed a parabolic trough collector system for electricity generation through steam turbines. It is designed for 1 MVA capacity. Design calculation of absorbed flux, useful heat gain, and exit temperature are described. Sintali et al. [8], development of energy equations for computation of the efficiency of Parabolic-Trough Collector (PTC) using solar coordinates. The thermal efficiency of the PTC considered both the direct and reflected solar energy incident on the glass-cover as well as the thermal properties of the collector and the total energy losses in the system. The developed energy equations can be used to predict the performance of any PTC using the meteorological and irradiative data of any particular location.

Figure 1 shows the different configurations of the solar collectors.

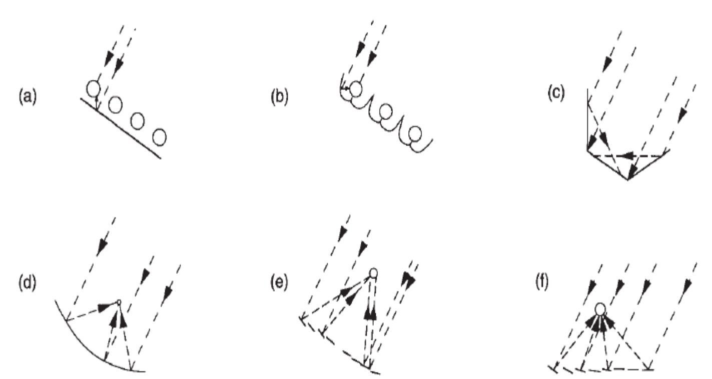

Figure 1 - Possible concentrating collector configurations: (a) tubular absorbers with diffuse back reflector; (b) tubular absorbers with specular cusp reflectors; (c) plane receiver with plane reflectors; (d) parabolic concentrator; (e) Fresnel reflector; (f) array of heliostats with central receiver [3].

Yaseen [9], performed an experimental and theoretical study has been conducted to determine the thermal efficiency of a parabolic trough solar collector. It has been found the experimental thermal efficiency of the collector is less than the theoretical one.

2 Terminologies in Parabolic Trough Collector

2.1 Concentration Ratio

It is the ratio of surface area of the collector to the surface area of the receiver tube.

2.2 Rim Angle

The angle between the optical axis and the line between the focal point and the mirror rim

2.3 Focal Length

The distance between the focal point and the vertex of a parabola is a parameter that determines the parabola completely.

3 Design and Specifications of Collector

This topic includes the selection of local and operating parameters, geometrical parameters, selection of rim angle, and construction of parabola and fabrication of parabolic trough collector. Table 1 shows the factors considered for parabolic trough collector design.

Table1

Factors considered for PTC design

Sr. No.	Parameters	Values
1	Average beam insolation for a day	744W/m^2
2	Wind velocity	3 m/s
3	Flow rate of water	0.0013 kg/s
4	Average ambient temperature	30 ^{0}C
5	Area of the collector	0.5 m^2
6	Outlet water temperature required	65 ^{0}C
7	Orientation	N-S horizontal

Table 2 gives information about parameters selected for the construction of PTC. It includes a selection of the length of the trough, the width of a trough, rim angle, and receiver diameter. Parabolic trough collector with frame support

Table 2

Specifications of PTC

Sr.No.	Parameters	Value
1	Width of Aperture	600 mm
2	Length of Aperture	1 m
3	Focal Length	154 mm
4	Rim angle	90^0
5	Outer Receiver Diameter	12.5 mm
6	Concentration Ratio	13.33
7	The material used for trough	M.S. sheet of 2mm thick coated with Aluminum foil.
8	Receiver	Copper tube
9	Rotameter	0 – 10 LPH

Figure 2 shows the geometrical construction of the parabola.

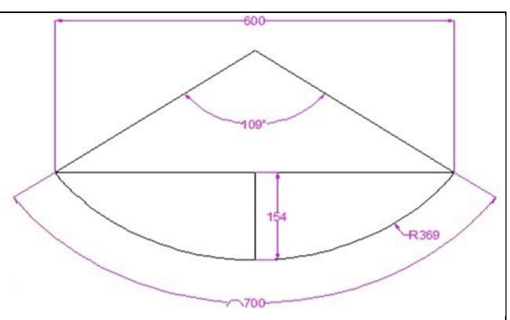

Figure 2 - Construction of Parabola.

The analytical relation between the focal length of the parabola and the width of the parabola is given by the below equation.

$$F / W = (1+\cos\emptyset)/(4\sin\emptyset)$$

Where F is the focal length of the parabola and width of the parabola. The geometrical concentration ratio is given by the following relation,

$$CR = (\sin\emptyset)/\pi\sin\sigma$$

$\emptyset$ is the rim angle of the parabola. Figure 3 shows the variation of concentration ratio with the rim angle of the parabola.

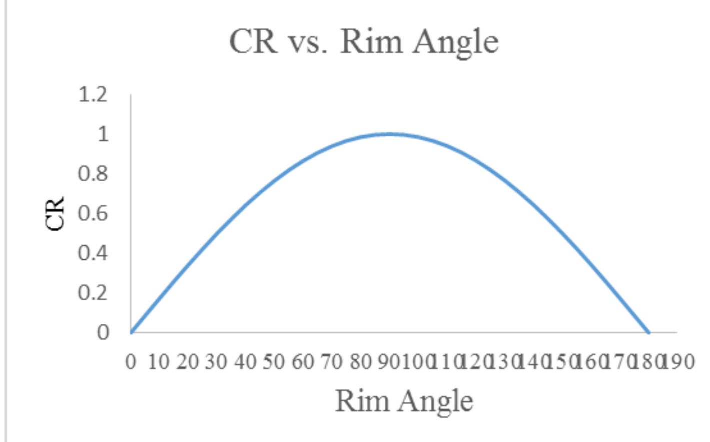

Figure 3 – Concentration Ratio vs. Rim Angle

It is desired to have higher concentration ration for the collector. From figure 3 it can be observed that the rim angle of 90^o has maximum concentration ratio. Therefore rim angle of 90^o is selected for a parabola

4. Experimental Analysis

Figure 4 shows the schematic model of the parabolic trough with a uniform diameter for better performance. It consists of absorber pipe with uniform diameter & parabolic trough. The absorber is a copper pipe with a uniform diameter.

Figure 4 – Experimental Setup

5. Result and Discussion

This section discusses the results of parabolic trough solar collector with a uniform tube copper receiver and its characteristics. Readings were taken between 12.00 pm to 2.00 pm.

5.1 Effect of Mass Flow Rate on outlet Temperature

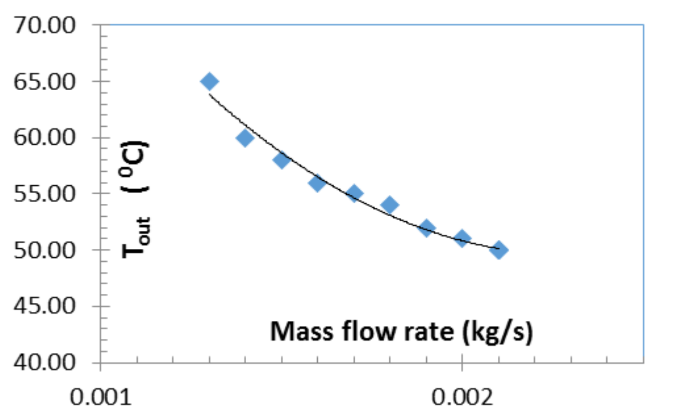

Figure 5 – Mass Flow Rate vs. Temperature

From figure 5 it can be observed that the mass flow rate of water is increased, the outlet temperature of the water is decreased. The maximum temperature of the water is found to be 65^{O}C when the mass flow rate of water was 0.0013 kg/s.

5.2 Time versus outlet Temperature

The mass flow rate of the water was kept constant while conducting this test. The flow rate of 0.0013 kg/s. has given maximum outlet temperature of the water, therefore flow rate was kept equal to 0.0013 kg/s during the entire test. The performance of the collector depends on the time slot of the day, as the radiation from the sun to earth varies from time to time. It is necessary to select such time slot so that the outlet temperature of the water is as maximum as possible.

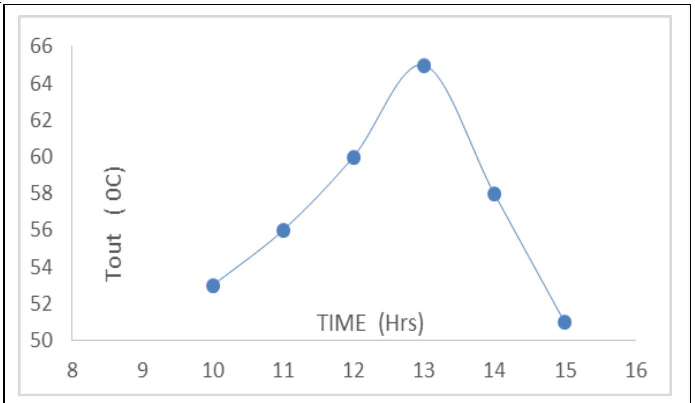

Figure 6 – Time hours vs. outlet temperature

From figure 6 it can be observed that the peak performance is achieved during the time period of 12 pm to 2 pm. It is obvious as during this period the light intensity is the highest.

5.3 Pipe Diameter vs. Outlet Temperature

Figure 7 shows the effect of the pipe diameter on the outlet temperature of the water. The pipes are available in standard size. 12 mm pipe has given the highest temperature when the flow rate was kept constant at 0.0013 kg/s.

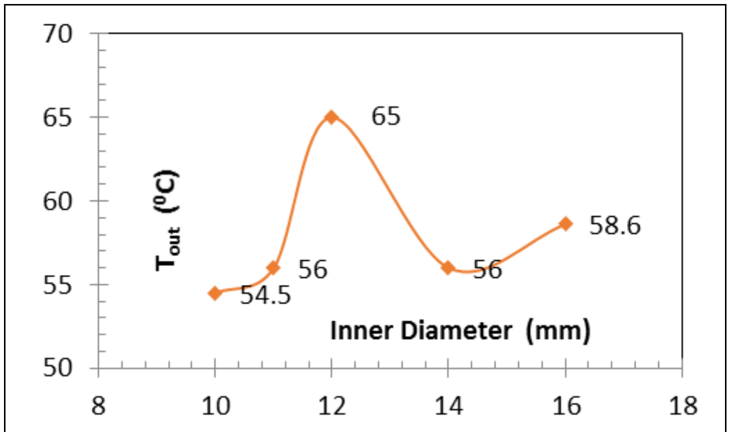

Figure 7 – Pipe diameter vs. outlet temperature

The output temperature of water first increases and then decreases. The maximum output temperature of the water is found to be 65 0C for absorber tube of inner diameter 12 mm and then correspondingly goes on reducing with an increase in diameter of the inner tube. The heat losses in the form of convection and radiation affected by the pipe size.

5.4 Temperature distribution along the length of the pipe.

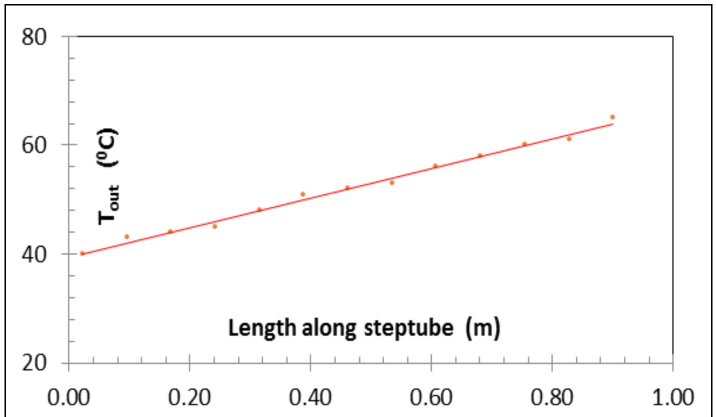

Figure 8 – Temperature of water along the length of the pipe

From figure 8, it is observed that the temperature of the water is increasing linearly along the length of the pipe.

7 Conclusion

In this study, a solar concentrator design has been installed. This equipment is based on a reflector plate and an absorber tube. The working fluid has achieved maximum temperature when the mass flow rate is kept as minimum as possible. While pipe size has a significant effect on the outlet temperature of the working fluid as the heat losses are governed by the size of the pipe. Here the environmental factors are not taken into considerations as these are non-controllable factors. In reference to the various results and conclusion made above it is clear that by increasing the parabolic area the temperature of the fluid can be increased to a certain desired level

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