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Research Article

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Design and Testing Parabolic Trough Solar Collector

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Abstract In this paper, an experimental study of a simple parabolic trough solar collector is tested under local weather condition. It shows the collector performance using forced water as working fluid. A simple scale model of a parabolic trough collector was designed and installed. The reflector and receiver were fabricated from glass black steel pipe respectively. It was tested at Aswan University (24^{o} N latitude) and was E-W oriented. In conclusion, the model is fairly acceptable for the thermal processes in Aswan.

Keywords Solar Energy; Parabolic Trough; Solar Collector; Collector Performance.

1. Introduction

In facts, Energy shortage has become one of the major problems in Egypt. Accordingly, solar thermal systems became one of the most attractive and appropriate solution for this problem. Concentrating solar power technologies are usually categorized in three different concepts: parabolic troughs, power towers and parabolic dishes. Parabolic trough collector is currently the most proven solar thermal electric technology [1]. Parabolic trough solar collector is widely used to produce steam for electric power generation [2-3]. High temperature can be achieved without any lack of the collector efficiency.

2. Collector Design

The collector is designed with simple parabolic equation. Equation (1) is a geometrical relation of the parabolic section. The cross section of the parabolic trough collector is shown in figure 1 in which various important factors are shown. The incident radiation on the reflector at the rim of the collector (where the mirror radius is maximum) make an angle ψ with the center line of the collector, which is called the rim angel .the glass was curved to form a parabolic trough module of 2m length and 1.2 m aperture width with effective aperture area of 2.4m^2. The simple parabolic equation in Cartesian coordinates is

$$X^2 = 4FY \qquad (1)$$

From the equation (1), the height of the parabola is function of the focal length and aperture diameter is

$$X = \frac{a}{2} \;\; \& \;\; Y = h \quad Then, \quad h = \frac{a^2}{16F} \qquad (2)$$

So, the rim angle ψ is given by:

$$tan\frac{\psi}{2} = \frac{a}{4F} \qquad (3)$$

The Geometrical concentration ratio CR is defined as the area of the collector aperture A_a to the surface area of the receiver A_r

From the selected values of the concentration ratio and the ratio between the concentrator lengths to its aperture width, the values in table 1 can be calculated. In this model, the focal point is selected at the aperture line with rim angle of 90^{o} and the same of focal length and collector height.

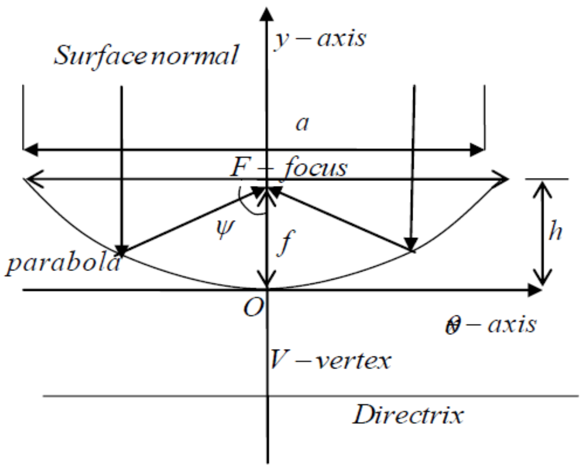

Figure 1: Schematic Diagram of the Collector

Table 1: Data of Parabolic Trough Collector Model

Item	Sample	Value
Length	L	2m
Aperture	a	1.2m
Rim angel	ψ	90o
Focal length	f	0.3m
Receiver diameter	d	0.0254m
Concentration ratio	CR	15.04
Collector height	h	0.3m

The accuracy and stability for the parabolic trough collector is very important item. It was designed as a rigid support structure. The structure frame is supported to be fixed of the parabolic trough collector reflecting surface. The receiver pipe was made from black steel pipe. Although the black steel pipe has low thermal conductivity, it has relative high absorptive. The pipe has 2.14 cm inside diameter and 2.54cm outside diameter. It is acceptable according to the aperture width to give a concentration ratio of 15.04. According to the specification and limitation of the collector, some parameter was consideration such as mass flow rate, heat losses. The collector is fixed east- west direction so this direction make direct solar beam reflected to the absorber during the day without tracking. The collector reflecting surface is curved to given parabolic shape with aperture area 2.4m² as in figure 2.

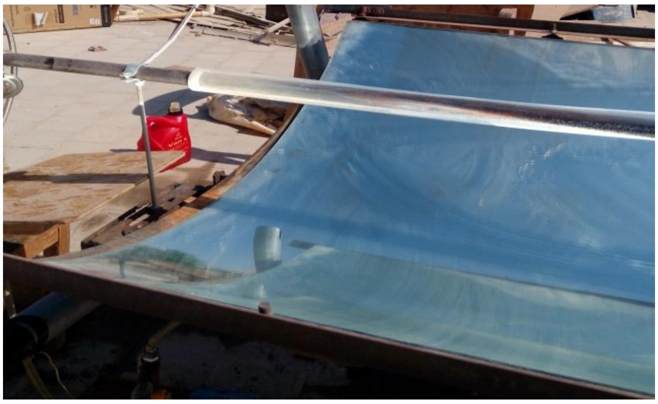

Figure 2: Photographic View of the Reflecting Surface

3. Experimental Setup

The experimental procedure was started by flushing the system. Then, the system was filled with water and the flow rate was adjusted to the required value. The solar collector was allowed to run for over 25 min to achieve

steady state conditions. Before starting the experiment all measuring instrument was checked, including the temperature indicator, anemometer. Cold water from the storage tank enters the black steel pipe receiver of the parabolic trough collector by using pump (187.5w) power. As water in the receiver tube, this is located at the focal axis of the trough. The solar radiation heat the water flow in receiver and the pump force the hot water pass through the receiver to the tank. The experiment has been performed for 7h over the day from 09:00 hour to 15:00 hour. During the experimentation, the parabolic trough collector has been oriented with it focal axis point in the east-west (E-W) orientation to avoid the tracking process, and makes minimum of incidence with aperture plane at all times of a day. The test was carried outdoor during May and July 2016.
The performance of the parabolic trough collector is determined by obtaining values of the instantaneous thermal efficiency and the system efficiency for different values of incident radiation, ambient temperature and inlet water temperature, the useful energy, Q_u, is calculated from the measurement of the inlet and outlet water temperature and the mass flow rate m as follows [4].

$$Q_U = m\,Cp\,(T_i - T_o) \quad (4)$$

The instantaneous thermal efficiency (ηth) is calculated as follows [5].

$$\acute{\eta}_{th} = \frac{m\,Cp\,(T_i - T_o)}{I\,A_a} \quad (5)$$

The rate of energy gained (Qs) by the water in storage tank for a time interval of one hour is given by [6].

$$Q_s = m_w\,Cp\,(T_i - T_f) \quad (6)$$

4. Results and Discussions

A period of 5 clear days (5, 10, 15, 20, and 25 May) has been selected for measuring all necessary data to analysis the performance of the parabolic trough collector. Figure (3) shows the temperature distribution in storage tank. it can be seen that the temperature difference between the outlet and inlet of the receiver increase progressively with time due to the increase in solar radiation which varies from 680 to 918 w/m² .the heat transfer fluid (HTF) is re-circulated through a storage tank of capacity 40 liters with flow rate 0.0166 kg/s. the temperature of the water in storage tank increase steadily from an initial temperature of 35°C at 9:00 h and reach a maximum value of 61°C at 14:00 h without any draw-off water.
It's clear that no difference between the temperature in inlet and outlet in the afternoon. Figure (4) show the relation between outlet temperature and beam radiation .its noted that the outlet increase with beam radiation increase
Figure (5) show the relation between the useful heat gain, Q_u, and the beam solar radiation I, from morning to afternoon.

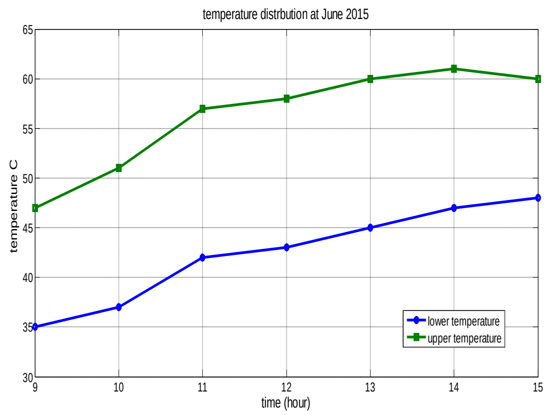

Figure 3: Lower and Upper Temperature in the Model

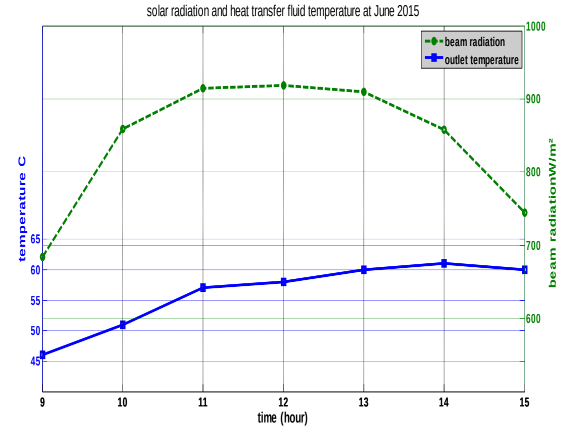

Figure 4: Effect of Radiation on the Outlet Temperature

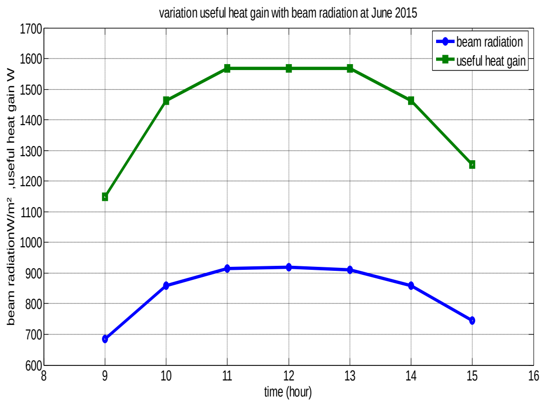

Figure 5: Effect of Radiation on the Useful Heat Gain

The thermal efficiency, η, of a parabolic trough collector can be described by ASHRAE [7].

$$\eta = F_R\,\eta_o - \frac{F_R\,U_L}{CR}\left(\frac{T_i - T_a}{I}\right) \qquad (7)$$

If the thermal efficiency from equation 5 is plotted against $\left(\frac{T_i - T_a}{I}\right)$ this is shown in figure 6. Straight line produce .the intercept is FR η_o =0.7015 and the slope (FR UL/CR) = 0.301 W/m²k. For geometric concentration ratio CR equal to 15.05. Where is FR UL =4.527 W/m²k. The optical efficiency η_o=0.719 and the heat removal factor FR = 0.9756. Its represents the ratio of actual useful energy gain of the collector to the useful gain if the whole collector were at the fluid inlet temperature and the overall heat loss coefficient UL=4.640 W/m²k. Therefore, the collector thermal efficiency equation (7) for PTSC can be found as:

$$\eta = 0.7015 - 0.301\left(\frac{T_i - T_a}{I}\right) \qquad (8)$$

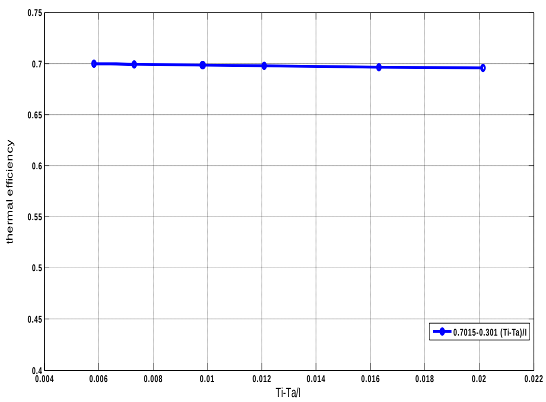

Figure 6: Thermal Efficiency Curve of the Collector

Table 2: Comparison of Collector Efficiency Equations

S. No.	Efficiency Equation	Reference
1	$\eta=0.66 - 0.233\left(\frac{T_i - T_a}{I}\right)$	Murphy and Keneth 1982 [8]
2	$\eta=0.65 - 0.382\left(\frac{T_i - T_a}{I}\right)$	Hurtado 1984 [9]
3	$\eta=0.642 - 0.441\left(\frac{T_i - T_a}{I}\right)$	Kalogirou 1994 [2]
4	$\eta=0.638 - 0.387\left(\frac{T_i - T_a}{I}\right)$	Kalogirou et .al 1996 [10]
5	$\eta=0.6905 - 0.3865\left(\frac{T_i - T_a}{I}\right)$	Valan and Samuel 2006 [6]
6	$\eta=0.6737 - 0.37\left(\frac{T_i - T_a}{I}\right)$	F. Mutlak 2011 [11]
7	$\eta=0.7015 - 0.301\left(\frac{T_i - T_a}{I}\right)$	Present work

5. Conclusions

Parabolic trough solar collector, without tracking system have been designed, manufactured and tested. The performance of the PTSC was tested experimentally with water as heat transfer fluid (HTF). The thermal efficiency of the PTSC can be obtained in the range 70% - 65% .it was noted that the receiver can achieve high water temperature during the test .this study can be used for many solar thermal application in domestic application such as water heating .the result of this study encourage investment in the PTSC system as one of a high temperature solar collector in order to reduce the heavy consumption of the oil in generation of electricity. According to the increasing demand of electric energy, due to the development, population spread, overpopulation.

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