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Construction, and Testing of a Parabolic Trough Collector for water heating purposes in Libya

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Abstract

Libya is one of the biggest countries in Africa with an area about 1,760,000 km2, lies between latitudes 19° and 34°N, and longitudes 9° and 26°E. The total daily average ranges between 5 and 7 kWh/m^2.day, thus, it owns a great potential of solar energy. The energy for water heating represents the biggest portion of energy consumption which is proportional to the availability of solar radiation during the day. Introducing renewable energies on the housing and industrial sectors should lead to energy savings. In this paper, construction and testing of a Parabolic Trough Collector have been investigated under local climate conditions of Sabratha City in Libya (latitude 32.8° N, longitude 12.5°E). The testing is taken from December 30, 2015 to April 5, 2016. The testing results showed that the maximum instantaneous outlet water temperature of 88.4 °C for a direct solar radiation of 930 W/m2 at a flow rate of 14.4kg/hr at 12:45 PM on March 30, 2016. Moreover, the maximum instantaneous thermal efficiency reached 52.7% for a direct solar radiation of 243 W/m^2 at a flow rate of 14.4kg/hr at 10:00 AM on January 4, 2016.

Keywords: Parabolic Trough Collector, useful heat gained, solar radiation, Collector efficiency.

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1. Introduction

World energy consumption shows that the Non-renewable energy sources supply approximately 84.7% of the world energy and only 9.9% by renewable. The rising fossil fuel prices and the emission of greenhouse gases have encouraged the world to overcome the dependency on conventional fuels [1]. Over the past decades in Libya fossil fuels have provided most of its energy because these are more convenient and much cheaper than energy from alternative energy sources. However, these Non-renewable energy sources such as natural gas and oil cannot resupply in the future. As the energy supply of Non-renewable energy sources shrinks, because the combustion of fossil fuels has caused serious air pollution problems and it also has resulted in global warming, there is a need for clean, renewable energy sources to meet growing energy demands [2]. Libya is an oil- rich country with about 90% of the area is located in the Sahara desert which make it a promising country in alternative energy sources, because of its location in solar belt region with an ideal direct solar radiation level [3].This solar energy resource can be converted into different kinds of energy for example to heat and electricity. One of the most important applications of solar thermal energy, which has recently become a promising technology, is its use in industries which use heat in their processes, in the range of 250°C [4]. The parabolic trough collector (PTC) is currently one of the thermal technology fields which proved for large-scale of solar energy, and they are capable of supplying thermal energy over a wide range of temperatures. It is divided into two main groups[5]: the first group is the industrial processes that need temperature ranging from 100°C to 250°C in their processes like space heating, cooling, drying, and refrigeration. The second group is the parabolic trough solar power generation that requires temperatures ranging from 300°C to 400°C

which is the main application of the concentrated solar power technology for generating electrical energy. Ahmed M. Ahmed et al. [6]run an experimental evaluation of a PTC under Libyan climate in the winter season. They used water as heat transfer fluid. Their experimental results showed that the maximum instantaneous thermal efficiency reached 43.9% for a direct solar radiation of 474 W/m^{2}at a flow rate of 14.4 kg/hr, and the maximum outlet temperature reached 79.5 °C for a direct solar radiation of 650 W/m^2 at a flow rate of 14.4kg/hr. They stated that Libya holds a real potential for the PTC technology to meet the increasing demand for water heating systems. Venegas-Reyes et al.[7] designed a light PTC structured from aluminum made only using hand tools has a rim angle of 45° and the receiver without a glass cover for low-enthalpy steam generation and hot water. Jaramillo O. A et al.[8] presented three PTCs have a rim angle of 90° and the other two have a rim angle of 45° for the purpose of water heating. Both types considered receivers without glass cover to reduce manufacturing and transportation costs. In the construction and assembly of both types of PTCs, only hand tools are used. The authors carried out thermal and optical analyses for each type of PTCs, and the results showed the maximum efficiency of the PTCs with a rim angle of 45° and 90° are 35% and 67% respectively. The aim of this paper is construction and testing of a PTC under local climate conditions of Sabratha City to produce hot water for residential and industrial processes.

2. The Collector Design and Construction

Design and construction of the PTC are done at the workshop of the mechanical engineering department at Sabratha engineering college, Sabratha University. There are two pieces of PTCs made with the same geometrical properties. A mild steel tube was selected from the available local tubes as a receiver with an internal diameter of Di = 0.017m and an external diameter of Do = 0.021m . The PTC was designed with simple parabolic equations. A cross-section of a parabolic trough collector with various important factors is shown in Figure (2.1). The body of the first PTC was made of 10 pieces of plywood traded in parabolic shapes as shown in figure (2.2). They are fixed in equal spaces by four solid steel rods and wooden plates 3 m length at both sides. The reflecting surface was made of Formica sheet with length and width of which gives an effective aperture area of . A bright aluminum foil is used to coat it with a reflectivity of $\rho = 0.85$. The second PTC was made from thin steel sheet 2.0 mm thickness, with the length of and width of which gives an effective aperture area of . It is also coated with a bright aluminum foil with the same properties as first PTC.

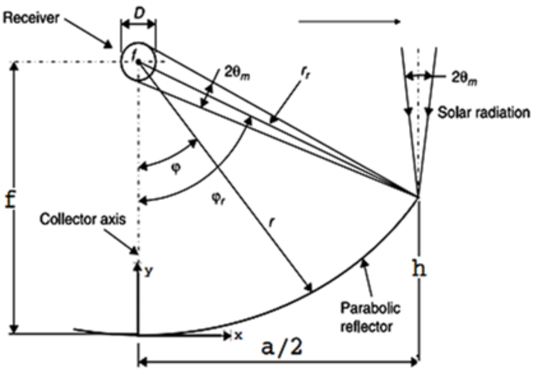

Figure 2.1: Cross-section of the PTC with circular receiver

Figure 2.3: Construction of the first PTC from wood

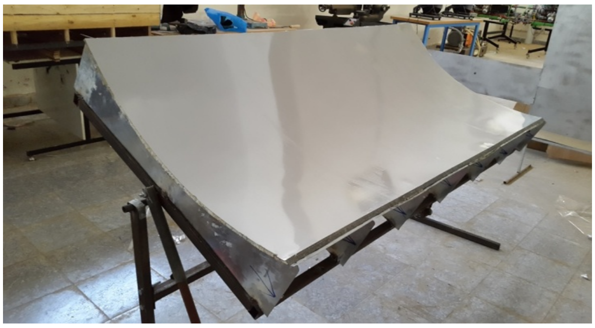

Figure 2.2: Construction of the second PTC form steel

Figure 2.4: Final setup of the experimental work

Table 2.1: Geometrical data of the PTC model

Parameter	Unit	Symbol	Value
Aperture width	m	a	1
Aperture area	m^2	Aa	4.992
Collector height	m	h	0.125
Collector Length	m	L	4.8
Focal length	m	f	0.5
Parabola curve length	m	S	1.04
Receiver inner diameter	m	D_i	0.017
Receiver outer diameter	m	D_o	0.021
Rim angle	^{o}	φ_r	53.13

The two assemblies have the same optical characteristics. Therefore, they are arranged in series as shown in figure (2.3), and their receivers are connected by flexible tube to give a total length of L= 4.8m

3. Testing procedures

The experimental work was done in an open flow method from December 30, 2015 to April 5, 2016. The whole work is done in an open space in the sun and the readings were taken from 10:00 AM to 2:00 PM each 15 minutes daily. The system consists of the constructed PTCs, storage tank and measuring instruments. The storage tank was used for storing the supply water fixed at 3m above the PTC level so that the water flow due to the gravity. A flexible pipe made of plastic was used for carrying the supply water from the storage tank to the receiver through a control valve and the flowmeter. The flowmeter was connected before the inlet of the receiver tube to measure the water flow rate. During the experiment, the readings taken are the inlet water temperature , outlet water temperature , ambient temperature and tube surface temperature . They are recorded using digital thermometers. Air velocity is measured using a digital anemometer. The water flow rate was measured using flowmeter. Moreover, the solar radiation intensity was measured using digital pyrheliometer. The photos of the different measuring devices used during the experiment are shown in figures (3.1a-d).

4. Results and discussion

Figure (4.1) shows variations of the solar radiation measured for the test period on 26th of January and 29th of March 2016. The measured radiation is taken from 10:00 AM to 4:00 PM. At 10:00 AM, the solar intensity is low, and the time passes, the intensity starts to raise until reaching its peak around 1:30 P.M. After then, the intensity decreases till the end of the day. It can be noticed that the value of the radiation increases as the time was closer to spring, this is due to the increased elevation angle of the sun, and the earth is closer to the sun at this angle.

Figure (4.2) shows the variation of the outlet water temperature with experimental days at 10:00 AM, 11:00 AM, 12:00 PM, 1:00 PM, and 2:00 PM. It can be noticed that the outlet water temperature starts to increase each day from the beginning of the experiment at 10:00 AM to reach its maximum value at 1:00 PM then, it starts to decrease. This variation is same to the solar radiation behavior because the outlet water temperature depends mainly on the solar radiation intensity.

The maximum outlet temperature obtained during the experimental work was 88.4 °C on 30th of March 2016 at 12:45 PM. This temperature is suitable for residential uses. This temperature is expected to reach more than 100 °C in summer when the solar radiation reaches its maximum value.

(a) Digital thermometer type Tastotherm MP1300 **(b)** Digital anemometer type GM8901-2-#7183

(c) Digital pyrheliometer type METEON CMP6 **(d)** Flowmeter type MPB

Figure 3.1: The photos of the different measuring devices used during the experiment

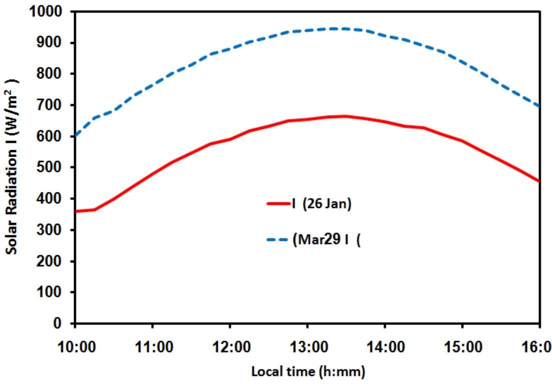

Figure 4.1: : Variation of solar radiation with local time

Figure (4.3) shows the variation of the thermal efficiency with experimental days at 10:00 AM, 11:00 AM, 12:00 PM, 1:00 PM, and 2:00 PM. It can be obviously observed that the thermal efficiency high at January and decrease till it reaches its lowest values at the end of the experimental days. It can also be seen that the thermal efficiency is higher at the beginning of the experimental day at 10:00 AM and starts to decrease gradually to reach its minimum value at the end of the experimental day. The reason is that thermal efficiency is inversely proportional to the solar radiation intensity through the equation:

$$\eta_{th} = \frac{mCp(T-T)}{I.Aa} \tag{4.1}$$

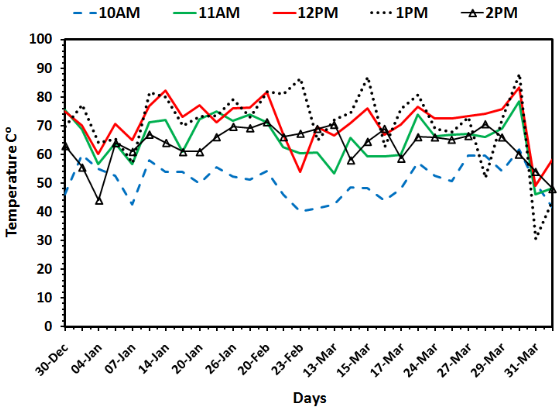

Figure 4.2: : Variation of outlet temperature at different times during the experiment days

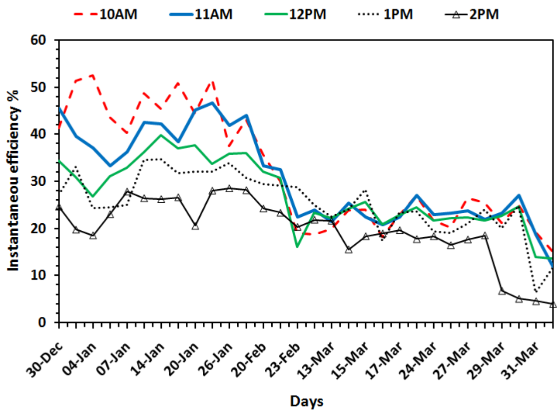

Figure 4.3: Variation of efficiency at different times during the experiment days

5. Conclusion

In this paper, a PTC was constructed specially for water heating purposes in Libya climate. The construction of the PTC was described in detail. Experimental work was conducted to evaluate the thermal performance of the PTC. The following conclusions could be drawn:

- Libya climate is suitable for application of the PTC in the area of water heating purposes in residential and industrial uses.
- The quantity of hot water which will be produced by this PTC with flow rate of 14.4 kg/hr during full day (10 hours) is calculated to be 144 Liter.
- The PTC area required to produce 1000 Liter (1 m^3) during full day with the same flow rate will be 34.7 m^2.
- The maximum value of thermal energy obtained by the PTC is 208.84 W / m^2
- The average value of thermal energy obtained by the PTC is 173.773 W / m^2
- It is recommended to use receiver with evacuated glass envelope to improve the thermal efficiency and reduce the thermal losses of the PTC.
- It is recommended to conduct a feasibility study to obtain the cost of 1m^3 of hot water for residential use.

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