American Journal of Engineering Research (AJER)
E-ISSN: 2320-0847 p-ISSN: 2320-0936
Volume-8, Issue-2, pp-24-30
www.ajer.org
Research Paper Open Access

# Experimental investigation of the thermal performance on an evacuated parabolic trough collector

[1]Fatima A. Abdulkareem, [2] Sami R. Aslan, [3]Ehsan F. Abbas
*Kirkuk Technical College / Northern Technical University, Kirkuk- Iraq*
*Corresponding Author: Fatima A. Abdulkareem,*

***ABSTRACT:*** *This paper presents theoretical and experimental study to investigate the thermal performance of parabolic trough collector (PTC) manufactured in Iraq, Kirkuk by local facilities. The construction of (PTC) was made of 1.5 m length and 1 m width with 70° rim angle. An aluminum plate used as a reflector and it's covered with solar film in order to increase the reflectivity of the receiver. A copper tube used as an absorber and covered with an evacuated glass tube. Therminol VP-1 used as heat transfer fluid (HTF) because of its ability to transfer heat at high temperature. The solar collector also contains thermal storage works as a heat exchanger which is used to cool the oil with the water. The oil passes through the shell and the water passes through 25 mm copper tube coil. The operation condition was carried out under the oil flow rate of (0.014 – 0.028) kg/s and water flow rate of (0.01 – 0.044) kg/s. The practical result of (PTC) shows that the highest heat gain by the water was about 84% when the ratio between oil and water was 0.34 with water flow rate 0.044 kg/s. While the highest heat gain by the oil was (1698.76)W.h when the oil flow rate was about 0.015 kg/s. The maximum thermal efficiency was about 69.33%, although the direct solar radiation rate was about 350.41 W/m$^2$. On the other hand, the collector thermal efficiency was determined according to ASHRAE Standard 93 (1986) and compared it with another researcher's result.*

***KEYWORDS:*** *Solar energy, PTC collector, Sun tracking system, Thermal storage, Thermal efficiency.*

---

Date of Submission: 24-01-2019 Date of acceptance: 08-02-2019

---

## I. INTRODUCTION

In the energy field, the world is facing a critical challenge with the increasing of the depletion of coal, oil and natural gas. Currently, the increase in population will increase the average energy consumption, population growth from (1.3 – 2)% per year and this range expected to be doubled over 60 years. For these reasons, researchers have now focused on alternative and renewable sources as opposed to conventional fossil fuels [1]. Renewable energy technologies are the base stone of humanneeds and have attracted much attention over the last 15 years. This has led many researchers to find ways to exploit renewable energy resources such as solar energy, wind, waves, tides, etc. ), As they are less polluting for the environment and contribute to reducing the consumption of other energy sources [2].Solar energy is the most important source of renewable energy because it is available in vast quantities that exceeded the needs of the universe. The energy provided by the sun to the Earth is enormous. The amount of solar radiation reaching us is about 10,000 times the global energy consumption per year. Solar energy has been given priority over other energy sources because it is sustainable energy, less polluting to the environment and most characterized by its ability to meet the needs of humanity [3]. Parabolic trough collector (PTC) is a type of concentration collectors which prepared the most proven solar energy technologies at this time. These collectors are characterized by its ability to track the sun where the reflector focuses the beam solar radiation to the focal line of the collecting tube to heat the fluid passing through it, whether water or oil and the heat transfer fluid (HTF) may reach 400°C [4]. Coccia et al [5], presents a prototype of a PTC with small concentration ratioand 90°C rim angle. the test was performed depending on the ASHRAE Standard 93 (2010). Which results shows the equation of the collector's thermal efficiency which the intercept of it equals 0.658 either the slope was equals –o.683 and the maximum HTF was reached 85°C. ValanArasu and Sornakumar [6], studied the design and manufacturing of 90° rim angle PTC for generating hot water. The performance of the collector found according to ASHRAE Standard 93 (1986) which indicated a high accuracy of PTC.The objective of the current work is to study the theoretical and experimental thermal performance of the Parabolic trough collector (PTC) by designing and manufacturing a 1.5m$^2$ solar collector which contains an evacuated receiver. Tests are conducted within four months at the (PTC), from March to June 2018 and the results are compared with reference to ASHRAE 93 (1983), to check the results of the tests.

## II. DESIGN AND CONSTRUCTION

According to the target plan, PTC was manufactured from locally available materials after the completion of the design process which is based on the following relations where PTC is designed by the equivalent equation according to coordinates (x, y), is given by [7] :

$$y^2 = 4fx \quad (1)$$

Where

$y^2 = (W/2)^2$ and $x = h_p$ (2)

Substituting (2) into (1) and rearranging

$$h_p = \frac{W^2}{16f} \quad (3)$$

The main dimension of the collector shown in Fig (1) can be calculated using a set of equations as [7]:

$$f = \frac{W}{4\tan\left(\frac{\theta_r}{2}\right)} \quad (4)$$

Another important dimension is the arc length of the parabola curve can be found from Eq. (5) [8]:

$$S_p = \left[\frac{W}{2}\sqrt{\left(\frac{4h_p}{W}\right)^2 + 1}\right] + 2f\ln\left[\frac{4h_p}{W} + \sqrt{\left(\frac{4h_p}{W}\right)^2 + 1}\right] \quad (5)$$

And the maximum radius of the parabola $r_r$ can be calculated from Eq. (6) [9]:

$$r_r = \frac{2f}{1+\cos\theta_r} \quad (6)$$

The radius of the parabola R was found using the AutoCAD software program, and it turned out to be 0.8 meters,while the rim angle $\theta_r$ was calculated by [9]:

$$\theta_r = tan^{-1}\left[\frac{8\left(\frac{f}{W}\right)}{16\left(\frac{f}{W}\right)^2 - 1}\right] = sin^{-1}\left(\frac{W}{2r_r}\right) \quad (7)$$

Another important parameter of the PTC is concentration ratio $C_R$ which can be defined as a ratio between aperture area and receiver area [10] :

$$C_R = \frac{A_a}{A_r} = \frac{(W - D_{r,out})}{\pi\, D_{r,out}} \quad (8)$$

Table I shows the geometrical dimensions of TCD according to the above relations.

**TABLE I. Some collector dimensions**

| Term | Symbol | Value |
|---|---|---|
| Length | L | 1.5 m |
| Width | W | 1 m |
| Focal length | f | 0.357 m |
| Rim angle | $\theta_r$ | 70° |
| Max.radius of parabola | $r_r$ | 0.532 m |
| Height of parabola | $h_p$ | 0.175 m |
| The radius of the arc | R | 0.8 m |
| Arc length | $S_p$ | 1.079 m |

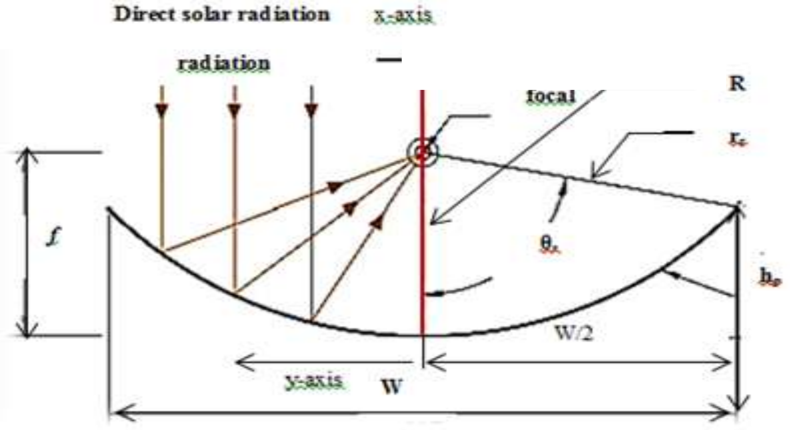


**Fig.1. Some basic PTC dimensions**

## III. SUN TRACKING SYSTEM

The solar system has a tracking system to track the sun in the two directions for PTC. The first semi-horizontal rotation of the PTC to track the sun from sunrise to sunset and the other movement of the PTC is vertical to up according to the incident angle of the sun to ensure that the radiation of the PTC is reflected along the receiving tube. And some main parts of the PTC system from Fig. 2 were described in TABLE II.


**Fig. 2. Parabolic trough collector (PTC)**

TABLE II. **Main parts of the sun collector system**

| No. | Description |
|---|---|
| 1 | Receiver tube |
| 2 | PTC |
| 3 | Sun tracking system |
| 4 | Storage tank |

## IV. THERMAL PERFORMANCE OF THE PTC

Experimental efficiency $\eta_{EXP}$ defined as the ratio between the useful energy gain by the circulating oil through the system to the total solar energy which reaches the collector and it can be expressed mathematically as [10 and 11]:

$$\eta_{Exp} = \frac{Q_{usf}}{Q_{Sol,in}} = \frac{Q_{usf}}{I_b A_a} \quad (9)$$

And energy gained can be calculated from the following equations [7]:

$$Q_{Q_{usf}} = \dot{m}_o Cp_f \left(T_{o,out} - T_{o,in}\right) \ (10)$$

$$Q_{Q_{usf}} = F_R A_a \left[S - \frac{U_L (T_{o,in} - T_{amb})}{C_R}\right] \ (11)$$

Of both Eq. (9 and 11) obtains a linear relationship with the thermal efficiency of the PTC, expressed of it [12]:

$$\eta_{th} = F_R \left[\eta_o - \frac{U_L (T_{o,in} - T_{amb})}{I_b C_R}\right] \quad (12)$$

Where $F_R$ is a thermal removal factor and is calculated from [10]:

$$F" = \frac{F_R}{F'} = \frac{\dot{m}_o Cp_f}{A_{r,o} U_L F'} \left[1 - e^{\left(-\frac{A_r U_L F'}{\dot{m}_o Cp_f}\right)}\right] \quad (13)$$

Where F" is a collector flow factor and is calculated as the following [10]:

$$F' = \frac{U_o}{U_L} = \frac{1/U_L}{\frac{1}{U_L} + \frac{D_{r,out}}{h_f D_{r,in}} + \frac{D_{r,out} \ln \frac{D_{r,out}}{D_{r,in}}}{2K}} \quad (14)$$

Where the heat gain from water and storage tank calculated as the following [13]:

$$Q_{water} = \dot{m}_w Cp_w \left(T_{w,out} - T_{w,in}\right) \quad (15)$$

$$Q_{tank} = Q_{oil} - Q_{water} \quad (16)$$

## V. RESULTS AND DISCUSSION

### A. Energy analysis and thermal efficiency of the PTC

Set of experiments were carried out on the PTC for four months starting from March until the end of June2018, in order to obtain acceptable results, the weather data were selected in energy analysis on days thaterew clear and cloud-free. Fig.3shows the energy analysis of the solar complex on 27th March 2018, when the oil flow rate was 0.015 kg /sec. The total energy gain from the oil flow through the receiver was about 1636.26 W-h from 3639.21 W-h that reached the receiver, 84% was used to heat the water and the remaining quantity was stored in the tank.

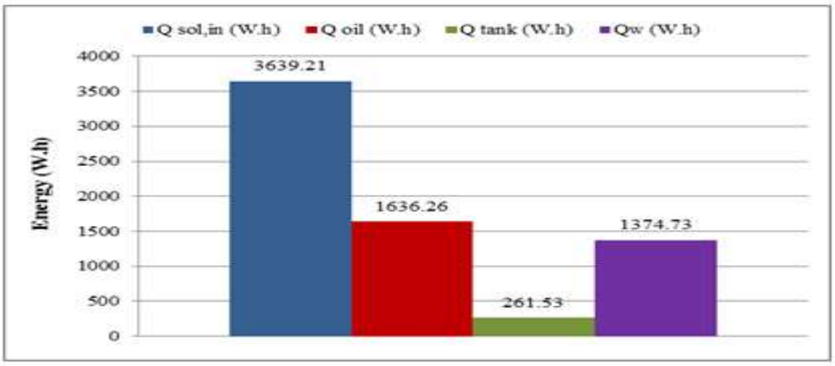


**Fig. 3 Energy analysis for PTC on 27th March**

Figure. 4 show the result of the energy analysis on 17th April 2018, when the oil flow rate was 0.015 kg/sec. Where the total energy gain from the receiver was about 1698.7W-h from 2437.13W-h that reached to the receiver, 51.5% of which was used to water heating and the remaining quantity of energy was stored in the storage tank.

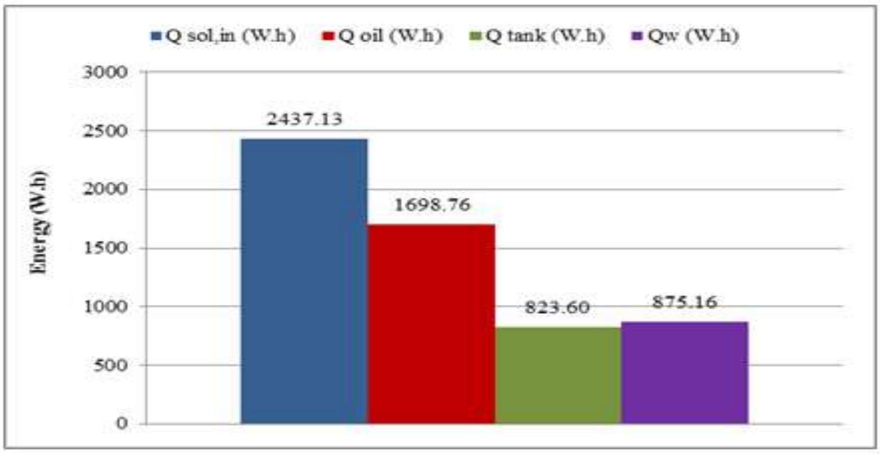


**Fig. 4 Energy analysis for PTC on 17th April**

Figure. 5 refers to energy analysis on 28th May 2018, when the flow rate of the oil mass was about 0.028 kg / s through the receiving tube. The amount of energy that reached the PTC from the reflection of the radiation energy was about 2080.58W-h, of which 58% was transferred to the reservoir by the oil circulation in the closed system between the receiver and the tank, which called useful energy and 19% of it has been converted to water heating, While the remaining portion of the energy is kept inside the tank.

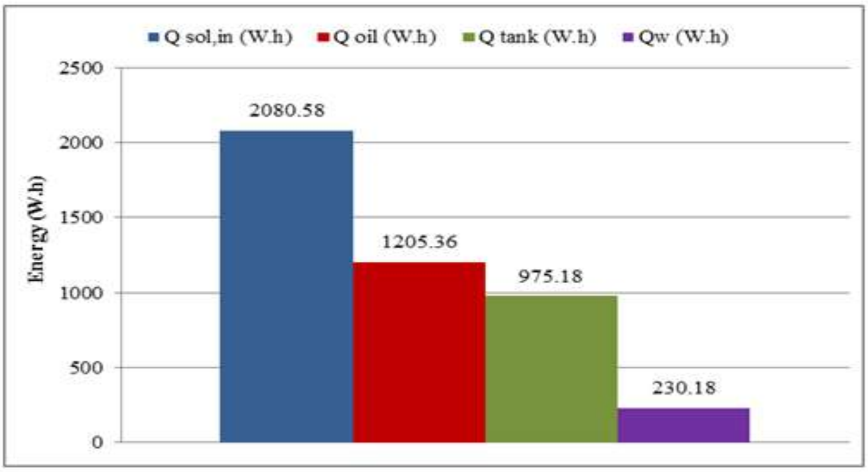


**Fig. 5 Energy analysis for PTC on 28th May**

Figure 6 shows the energy analysis of the PTC system on 10th June 2018, when the oil mass flow was 0.024 kg/sec. The total radiated energy that incident on the receiver surface from the PTC was about 2614.33W-h.60% of the total energy is converted to useful energy, while 72% ofthis energy converted to water heating, while 28% of it kept in the tank.

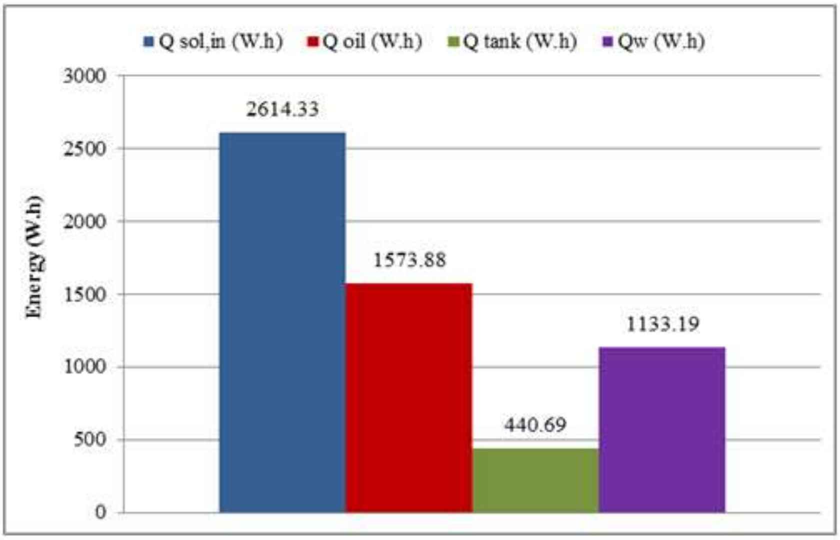


**Fig. 6 Energy analysis for PTC on 10st June**

Figure 7shows the thermal efficiency of selected experimental days in four monthsstarting from 18th March to the end of 21st June. It was noted that the instantaneous effects of the system these days have changed from 43.85% to 69.33%. From above shows that March efficiency was less efficient than the following three months, which did not exceed 44.9% and the highest efficiency occurs in April, ranged between 56% and 69.33%, while in May the efficiency did not exceed 60.8% and in June is about 48%.

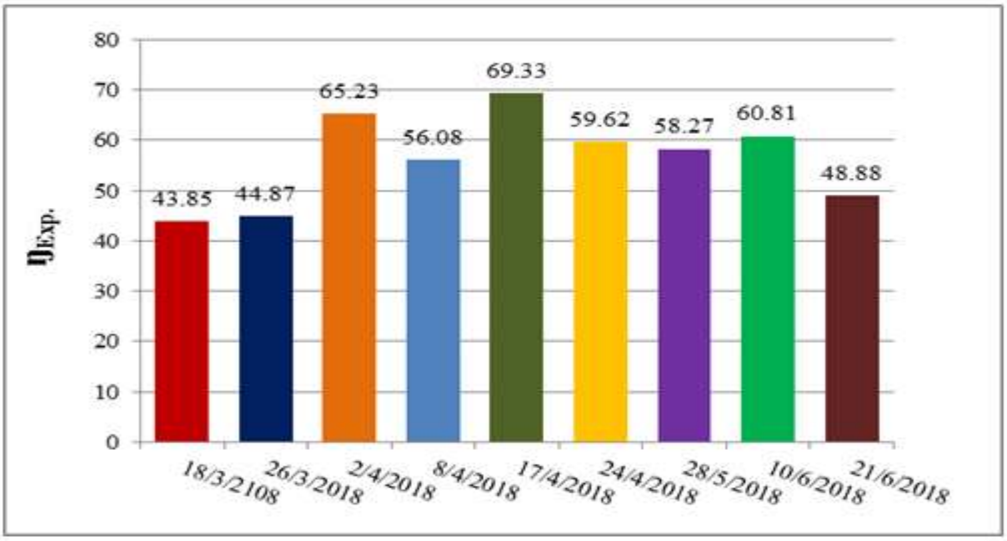


**Fig. 7 Instantaneous thermal efficiency for experiment days**

**B. The performance curve of the PTC**

The PTC performance curve is described in accordance with ASHRAE standard 93 (1986) under a steady state condition [14]. Theoretical efficiency is plotted against $\frac{T_{o,in}-T_{amb}}{I_b}$for all days of the experiment as shown in Fig. 8. The observed data in Figure can be associated as a linear relation, which is the best relation to represent this data and can be expressed the line equation as below.

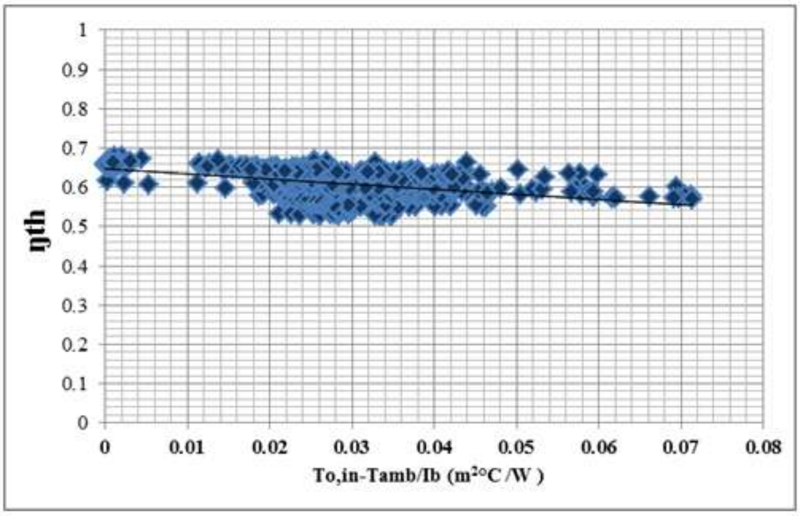


**Fig. 8 Collector thermal performance curve**

$$\eta_{th} = 0.6461 - \left[1.3146 * \left(\frac{T_{o,in}-T_{amb}}{I_b}\right)\right] \quad (19)$$

Where the intercept and slope have described the performance of the collector. By comparing Eq. (12) and Eq. (19) and $F_R\eta_0$ represent the intercept and its equal to 0.6461, while the $F_RU_L/C_R$ reprecents the slope and its equals to 1.3146. If compare the Eq. 19 with the other equations found by other researchers in similar works, it was observed that there was a great agreement in the form of the equation and thought to be within the acceptable limits.

## VI. CONCLUSION

Through the experimental days on the PTC for four months we have observed that the instantaneous thermal efficiency of PTC increases with a decline in direct solar radiation and with increasing the temperature difference between inlet and outlet of HTF. So the maximum instantaneous thermal efficiency of PTC was equal to 69.33% on 17$^{th}$ April 2018. And the maximum energy gain was in April and it was about 1698.76 W.h when the oil flow rates were 0.015 kg/s while the energy used for water heating reached 84% when the water flow rate was at the maximum amount 0.044 kg/s. the highest amount of the storage tank's energy was 957.18 W.h.

## REFERENCES


[1]. Z. Şen, Solar energy fundamentals and modeling techniques: Atmosphere, environment, climate change and renewable energy. 2008.
[2]. A. Maczulak, Renewable Energy Sources Watt Committee Report Number 22. 2010.
[3]. G. Harper, Solar Energy projects for the Evil Genius. 2007.
[4]. S. A. Kalogirou, "Solar thermal collectors and applications," Prog. Energy Combust. Sci., vol. 30, no. 3, pp. 231–295, 2004.
[5]. G. Coccia, G. Di Nicola, and M. Sotte, "Design, manufacture, and test of a prototype for a parabolic trough collector for industrial process heat," Renew. Energy, vol. 74, pp. 727–736, 2014.
[6]. A. ValanArasu and T. Sornakumar, "Design, manufacture and testing of fiberglass reinforced parabola trough for parabolic trough solar collectors," Sol. Energy, vol. 81, no. 10, pp. 1273–1279, 2007.
[7]. S. Kalogirou, "Solar Energy Engineering: Processes and Systems," Sol. Energy Eng., 2009.
[8]. J. C. McVEIGH, Sun Power: AN INTRODUCTION TO THE APPLICATIONS OF SOLAR ENERGY. 1983.
[9]. G. Coccia, G. Di Nicola, and A. Hidalgo, Parabolic Trough Collector Prototypes for Low-Temperature Process Heat. 2016.
[10]. J. a. Duffie, W. a. Beckman, and W. M. Worek, Solar Engineering of Thermal Processes, 4nd ed., vol. 116. 2003.
[11]. P. Selvakumar, P. Somasundaram, and P. Thangavel, "Performance study on evacuated tube solar collector using therminol D-12 as heat transfer fluid coupled with parabolic trough," Energy Convers. Manag., vol. 85, pp. 505–510, 2014.
[12]. S. A. Kalogirou, S. Lloyd, J. Ward, and P. Eleftheriou, "Design and performance characteristics of a parabolic-trough solar-collector system," Appl. Energy, vol. 47, no. 4, pp. 341–354, 1994.
[13]. Cengel YA, Heat and Mass Transfer A Practical Approach. 2006.
[14]. Ashrae, "Methods of testing to determine the thermal performance of solar collectors," vol. 2010, no. Ra, p. 41, 1993.


Fatima A. Abdulkareem" Experimental investigation of the thermal performance on an evacuated parabolic trough collector" American Journal of Engineering Research (AJER), vol.8, no.02, 2019, pp.24-30