A SINGLE THREE PARABOLIC TROUGH COLLECTOR THERMAL EFFICIENCY AND PERFORMANCE

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ABSTRACT

A bank of three Parabolic Trough Collectors in the same plane maintained to face normal incidence of solar radiation in Iraq at (34°35'N, 43°37'E). The influence of rim angle, effective length, and reflector width is being taking care off. A two flow regimes experimented for 0.03 and 0.06 kg/sec in a coated S.S. Steel pipe unshielded. The results showed a remarkable behavior in term of decreasing temperature difference to have an increase in efficiency but with regard to the increasing mass flow rate having a decrease of the losses an increase in efficiency.

Keyword: Concentrated solar power, parabolic trough collector, receiver and heat transfer fluid.

NOMENCLATURES

Ac	Aperture area of the collector,	[m^2]
$Aabs$	Absorber outer surface area,	[m^2]
C	Geometric concentration ratio	
D	Pipe outer diameter,	[m]
D_i	Pipe inner diameter,	[m]
f	focal length	[m]
I_n	Direct normal (beam) irradiance,	[W/m2]
K	Incidence angle modifier	
k_p	Thermal conductivity of pipe	[W/m.K]
K_w	Thermal conductivity of water,	[W/m,k]
k_a	Thermal conductivity of air	[W/m.K]
L_p	Total pipe length	[m]
$\dot{m}$	Mass flow rate	[kg/s]
T_o	Fluid outlet temperature	[K]
Ti	Fluid inlet temperature	[K]
η	Solar collector overall efficiency	
Ψ	Rim angle	

1. INTRODUCTION

The Iraq's deserts alone generate a mean power density of 270-290 W/m^2, and reaching a peak power density of 2,310 kwh/m^2 /year according to The German Aerospace Center (DLR) (Alasady et al,2011, Sørensen 2004). This is given Iraq stand renewable energy supplier in the future. Meanwhile at the geographical position of Tikrit measurement shows that the mean solar radiation attained in the range of 2.5 to 6.5. Kw.h/m^2.day (Fayadh

M. Abed, and Ghazi-Yousif-2010). In recent years, considerable attention has been focused on solar thermal concentrating systems which are regarded as environmentally friendly alternatives to conventional thermal power systems. In solar thermal concentrating systems, incident solar radiation is converted into thermal energy at the focus (Khatib et al., 2009). These systems are classified as either point focus concentrators (parabolic dishes and central receiver systems) or line focus concentrators (parabolic trough collectors and linear Fresnel collectors). The PTC focuses Direct Normal Irradiance DNI or beam radiation onto a focal line on the collector axis. An absorber tube with water or temperature stable synthetic oil flowing inside absorbs the concentrated solar energy and raises its temperature at the focal line. In 1992 each of the Dagan and colleagues (Dagan E., et.al 1992), and in 1996 (Lippke F.) suggested three concepts of Solar Collectors type (DSGC) to generate superheated steam in the first stage, and then make recycling process to generate wet steam for the second stage, and then injecting water into steam to control the quality of the steam flow through the unstable flow inside the tube absorber . In 1994 (Cohen, Kearney) proposed solar collector for steam generation type (DSGC) to get rid of the problems of the oil industry with high costs of heat exchangers for the oil and a replacement of direct water vapor. 1996 (Kalogirou) suggested a design of solar collector type trough with an area of 3.5 square meters and Rim angle of 90 degrees, and the concentration ratio of (21.2). and all the Measurements were tested according to standard 93 ASHRAE 1991. In the same year, Ibrahim (1996) using six Collectors type PTC. Each collector is 1.14 meter length, 0.12 meters width of and an area 0.82 square meters. In 1997, Al-Manza and Jimenez designed Collector type PTC   to get a steam from the use of receiver tube length of 29 meters and 25 cm diameter located in the focal line of the collector with an aperture width 2.5 meter. In 2001 Balbir Singh and Fauziah Sulaiman, calculated the heat transfer coefficient on the surface of the tube at the focal point. For the efficiency of the solar collector a mathematical relationship given in the study to show the effect of changing the diameter of the pipe and the flow velocity in the range of temperatures from zero to 360 ° C for the specific flow rate. In 2006 Ahmed and Mohamed design and testing of

solar collector parabolic-shaped device for water desalination in Saudi Arabia, where the used solar collector with an area of 5.40 square meters and Rim angle of 75 degrees.The results showed that the performance given less than the ideal one which attributes to the relative height of the heat lost resulting from the non-use of evacuated glass casing, and thermal insulation as well as the lack of high-precision tracking.

In 2010 LIU and QiBin, et al designed a solar system type PTCs for thermal power generation, the performance characteristics with an oil industrial liquid as a heat transfer fluid and different mass flow rate are investigated. The efficiency of the system are ranged from (40% - 60%). From this study found that there is a delay in the temperature of HTF in response to the solar flux which is an important factor in the design of such system. In addition the thermal efficiency losses about (220 W / m when the difference of 180 ° C between the surface temperature of the tube and the ambient temperature, which is increases the losses by about 10%. There are several promising developments going on in the field of PTC and their applications. A comprehensive review of the usage of the PTC for various applications of thermal energy up to 400°C was presented by Fernandez-Garcia *et al*. (Fernandez-Garcia et al., 2010). Lupfert *et al*. (Lupfert et al. , 2007) summarized the various techniques available for the analysis of the PTC's optical performance. Brooks *et al*. (Brooks et al., 2006) conducted the baseline performance study of the PTC, using ASHRAE standard 93. The objective of this work is to study the performance of parabolic trough collector unit for the generation of heat to suit various requirements. Designed and tested system in this site for this purpose. All parameters of the solar radiation, the heated fluid inlet and outlet temperature and its flow and the thermal efficiency have been measured.

2. PARABOLIC TROUGH COLLECTORS

The Parabolic trough collector used in this investigation consists of five major elements which are receiver, reflector, heat transfer fluid, tracking system and support structure. The choice of such system much dependence on the efficiency given of the various collector geometry such as PTC, CPC, FPC is given in Fig.1. This Figure shows that the efficiency in the PTCs remains high at high inlet-water temperatures. PTCs work at an efficiency of about 62%, CPCs at about 32% and the FPC at about 10%. This clearly suggests that the PTC is the best type of collector for this application.

Also following Duffie and Beckman 2006, the end effect correction can be calculated depending on the aperture width (a), the length of the trough (L), the focal length (f) (which is the distance from the focal point to the vertex) and the incidence angle

$$k(\theta) = 1 - \frac{f}{L}\left(1 + \frac{a^2}{48.f^2}\right).\tan(\theta) \tag{1}$$
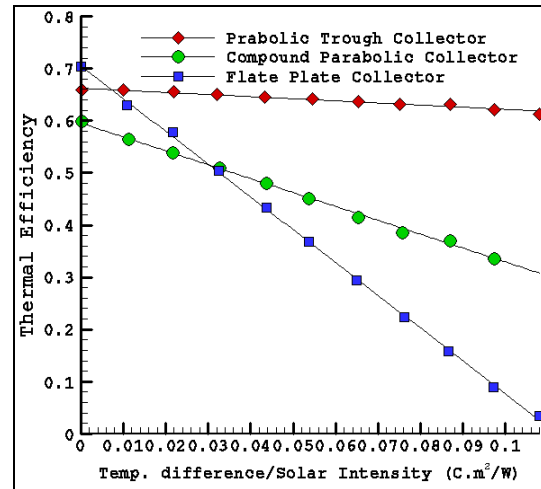

Figure 1 Variation Of Efficiency With Ratio Of Temperature Difference And Solar Intensity (Brook 2006).

Where the appointed focal depth is 20 cm and aperture width is 80 cm, the end effect correction is shown in Fig 2 for different trough lengths (1.2, 2.4, 4.8,7, and 11m). at the eleven meter shown a minim losses.
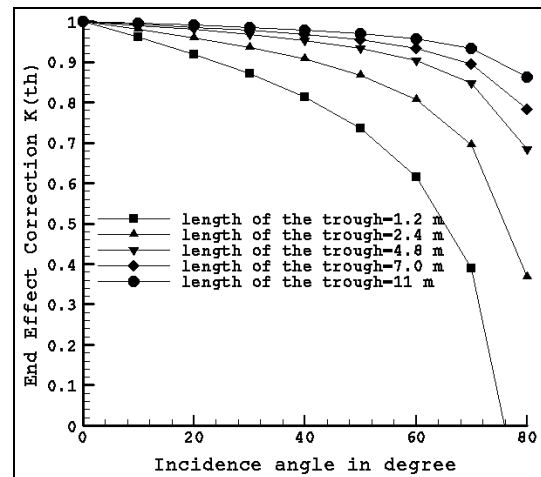

Figure 2 End effect Correction For PTC based on Eq. (1) For Focal length = 0.2m and Aperture width = 0.8m and different trough lengths.

A. REFLECTOR AND RECEIVER

The reflector is made of Carefully prepared of aluminum sheet 0.635 cm (1/4in.) thick, were shaped according to the equation,

$$y = \frac{x^2}{4f} \tag{2}$$

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Where in this case f = 0.20m. An aluminum sheet of aperture width 0.8 m was bent into parabola with a focus at 0.2 m. The fabricated collector parameters were: Aperture area of each collector = 1.92 m^2, Total of three collector area = 5.76 m^2. These three collectors located in the same plane structure with its collector pipe interconnected to each other with a total length of 11 meters. The total receiver length is 7.2 meter. The interconnection pipe length is 3.8 meter. Fig. 3 shows the layout of the reflector and receiver and interconnections. Aperture width = 0.8 m, Focal length = 0.2m, Each Collector length = 2.4 m. Inner diameter of absorber pipe = 0.028 m, outer diameter of absorber pipe = 0.030. The pipe painted with a mat black finish. Concentration ratio = 25.19
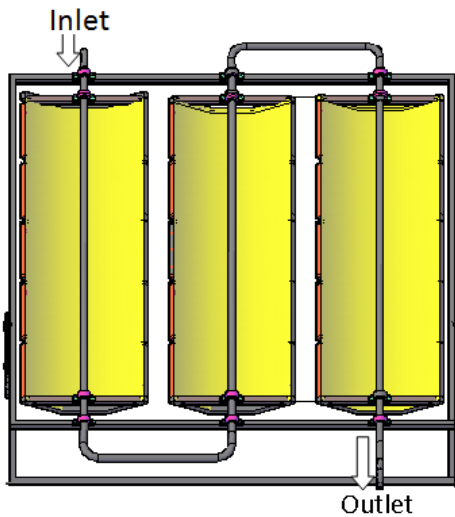

Figure 3 Reflector and ceciever and interconnection layout

B. HEAT TRANSFER FLUID
The heat transfer fluid is water for absorbing the heat from receiver with a two mass flow rate through a total length of 11 meter. A flow meter type gravity calibrated bouncy) is used. The inlet and outlet temperature is monitoring during the daily test. Two thermocouple sensors type k and flow meter are used. The inter connection between each tube collector insulated by a glass wool thermal insulator to decreases heat losses.

C. STRUCTURE AND TRACKING SYSTEM.
The Structure is made of structural steel materials. The dimension is 3 m length 2.8-meter width and 1.2 m in height which is a raged. This structure has to rotate to fellow the sun ray incidence. The tracking system maintained by a mono axial rotation of the trough collector which used a stepping motor that maintained one degree every four minutes, to fellow the movement of the sun sustaining a normal incidence of the sun rays onto the reflector. PTC was manufactured in the laboratories of the Department of Mechanical Engineering, University of Tikrit. Moreover, to avoid over shadowing between the collectors as well as to ensure the all the solar radiation strikes these collectors equally the distance between the collectors is 20 cm in the same plane. Fig.4a,b shows the photo graph of the installation. The Trough specifications are given in table 1.

Figure 4a Structure system of solar concentrator trough.

Figure 4b Tracking system of solar concentrator trough

Table 1 PTC specifications

Values	Specifications
5.76 m^2	Collector aperture area
0.8 m	Collector aperture
0.9	Aperture-to-length ratio
90°	Rim angle
30.0 mm	Receiver diameter
0.9506	Collector intercept factor
Timer	Tracking mechanism type
N-S.H	Mode of tracking
25.19	Concentration ratio
2 mm	Collector material thick stick with special foil
Stainless steel	Absorber tube material

3. RELATED CALCULATION OF THE COLLECTED DATA

The useful energy collected per unit time in a solar collector system employing solar concentrators given by (Pelemo, D.A. et.al 2002 and Goswani et.al 2010) :

$$Q_u = mC_p(T_o - T_i)$$

$$= F_r(W - D_o)L\left[S - \frac{U_l(T_i - T_a)}{C}\right]$$ (3)

where Fr, the heat removal factor is expressed as:

$$F_r = \frac{mC_p}{\pi D_o U_l L}\left[1 - Exp\left(\frac{-\pi D_o LU_l F'}{mCp}\right)\right]$$

Equation 2 . is Hotel-Whillier _Bliss equation for the flat plate which is the equivalent to the Parabolic Trough collector. The instantaneous collector efficiency is given by the following equation

$$\eta_i = \frac{Q_u}{I_b r_b WL}$$ (4)

4. THE TEST PROCEDURES.

All the tests are being carried out at every ten minutes from 10 am to 2 pm local time. The flow rate of 0.033 kg/sec and 0.066 kg/sec carried out at the 7th of the each month of Jan. to June and the 21st day of Jan to June respectively. The observed results of the solar parabolic trough collector are presented in table 2 and 3 respectively. The inlet and outlet of the fluid temperature, solar radiation metered by Daystar solar radiation meter, while the air temperature; wind speed and humidity have been recorded by Portlog weather station.

Table 2 Experimental Test at flow rate 0.033 kg/sec in 7 may-2012

Test Time	I_{DN} W/m^2	ΔT °C	η (%)
10:00	665	9.34	34
10:30	765	12.5	39
11:00	812	14.8	44
11:30	838	16.2	47
12:00	858	19.2	54
12:30	856	19.9	56
01:00	870	18.4	51
01:30	768	13.9	44
02:00	638	10.1	38

Table 3 Experimental Test at flow rate 0.066 kg/sec in 21 may 2012

Test Time	I_{DN} W/m^2	ΔT (°C)	η (%)
10:00	644	5.64	42
10:30	755	6.89	44
11:00	850	8.32	50
11:30	876	9.61	53
12:00	896	10.91	59
12:30	884	10.65	58
01:00	870	10.02	55
01:30	755	7.81	50
02:00	644	5.76	43

5. RESULTS AND DISCUSSION

The presented results have taken for unshielded collector tube where the system suffered heat losses to the ambient air. The measured solar radiation at the 7th day of every month for the seven months from January to July. The trends shown in figure 5a for the fluid flow rate at 0.033kg/.sec. the maximum solar radiation attained around the middle of the day and has a maximum energy obtained at 1 kw /m^2 for July and at 700 w/m^2 for January. While for the flow of 0.066kg/sec the measurement where carried out at the 21st day of every day maintained through the month above due to the case that the system is involved is a single unit. The profile is shown in Figure 5b. However, the obtained temperatures for both flow regimes of 0.033kg/sec and the 0.066 kg/sec for inlet and the outlet. The gained temperature are shown in figure 6a,b respectively. Also the obtained maximum temperature of the fluid at mid-day for both maintained flow of the fluid. Figure 6a,b give the thermal efficiency for both flow regimes and for the 7th and 21st day of each month which shown an increases in thermal efficiency with respect to the increased the flow of the fluid in the system. This is attributed marginally to lower period of stagnation of the fluid in the heated tube which is reducing the losses. As well as despite that both flow regimes have a greater temperature difference as shown in fig.7 but the efficiency remain to have a marginal difference which is a contribution of losses to the ambient as shown in fig.8.
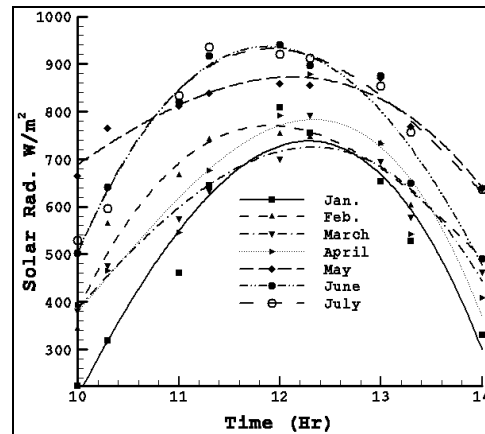

Figure 5a Solar Radiation Profile at different test time of 7th day from Jan. to July 2012
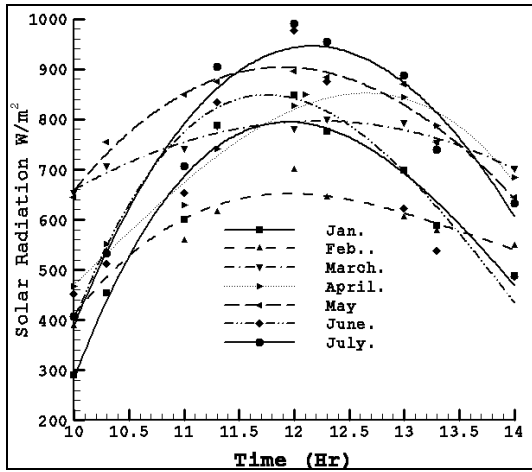
Figure 5b Solar Radiation Profile at different test time of 21st day from Jan. to July 2012
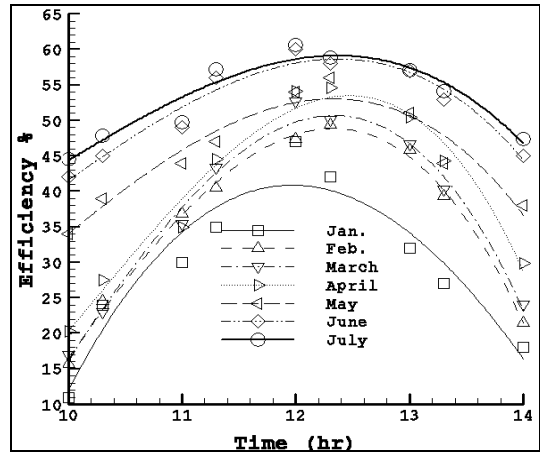

Figure 7a Parabolic Trough Collector Thermal Efficiency Profile at different test time 7th day from Jan. to July 2012 with 0.033 kg./sec
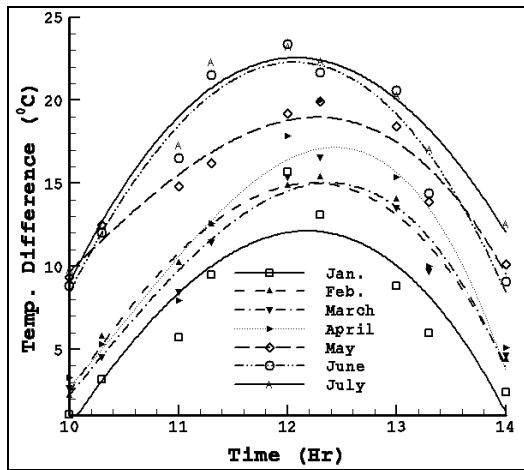

Figure 6a Outlet and Inlet flow Temperature Difference Profile at different test time 7th day from Jan. to July 2012 with 0.033 kg./sec
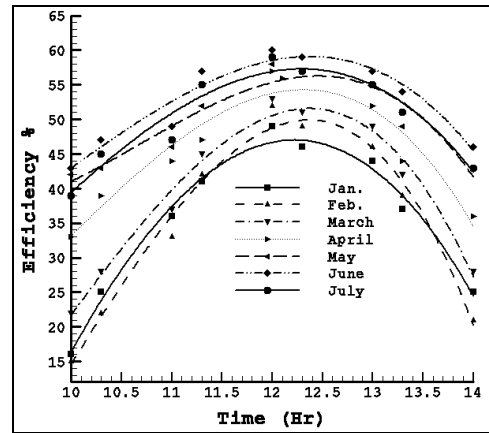

Figure 7b Parabolic Trough Collector Thermal Efficiency Profile at different test time 21st day from Jan. to July 2012 with 0.066 kg./sec
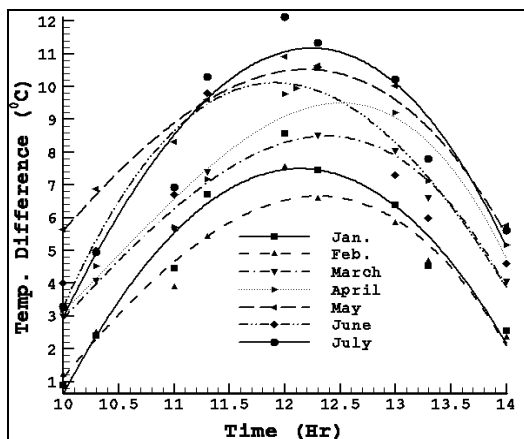

Figure 6b Outlet and Inlet flow Temperature Difference Profile at different test time 21st day from Jan. to July 2012 with 0.066 kg./sec
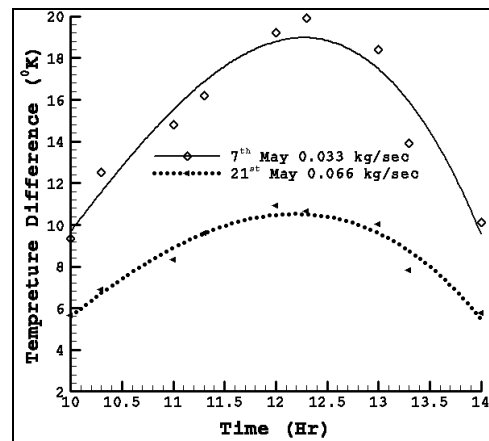

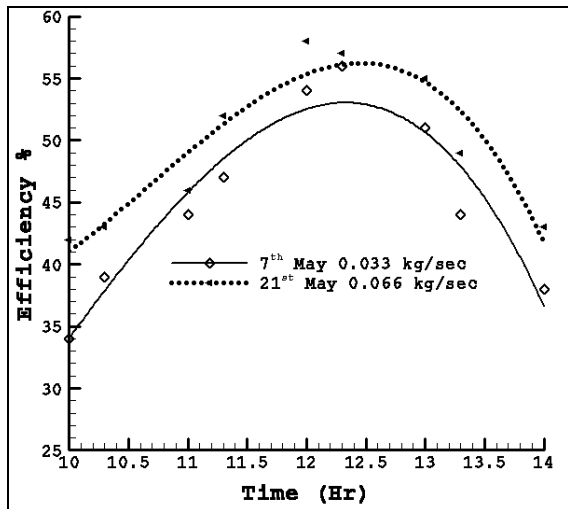Figure 8 Parabolic Trough Collector Temperatures difference with the two flow rate (0.033 kg/sec and 0.066 kg./sec)

Figure 9 Parabolic Trough Collector Thermal efficiency with the two flow rate (0.033 kg/sec and 0.066 kg./sec)

6. CONCLUSIONS

The noticeable effective results with respect to variable of input energy with respect to mass flow rate and the difference between the input and output temperature. These have shown a remarkable behavior in term of decreasing temperature difference to have an increase in efficiency but with regard to the increasing mass flow rate having a decrease of the losses increase in efficiency as well.

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