Improving the Solar Concentrator for Hot Water Generation

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ABSTRACT

The aim of this research project is to improve the design of collector trough in terms of efficiency, lessen the heat losses and attending the sun tracker mechanism. Parabolic Trough Solar Collector (PTSC), it is constructed of multi - piece glass mirror to form the parabolic reflector (0.8×1.8 m) its form were checked with help of a laser and evacuated glass as receiver. Sun tracker has been developed (using two - axis) to track solar PTSC according to the direction of beam propagation of solar radiation. The storage tank is fabricated with stainless steel of size 40 L using water as a heat transfer. The experimental tests have been carried out in Baghdad climatic conditions (33.3^o N, 44.4^o E) during selective days of the month October. The performance of PTSC is evaluated using outdoor experimental measurements including the useful heat gain, the thermal instantaneous efficiency and the energy gained by the storage tank. The storage tank water temperature is increased from 25^{o}c at 9:30h to 94^{o}c at 13:30h without draw – off water. The experimental result shows the average thermal efficiency was 50% which is fairly acceptable assessment results of a PTSC locally.

Keywords: Solar energy, parabolic trough solar collector, collector efficiency.

1. INTRODUCTION

In response to the energy crisis of 2003 and subsequent 20-fold increase in oil prices, the awareness to use alternate energy sources, including solar energy, has gained momentum in Iraq. Theoretically, Iraq is considered the second level of solar exposure radiation, the annual averaged of energy received daily from the sun ranges between 4.5 – 5.4 kWh/m^2 thus; Iraq is most suitable for solar applications [1]. Concentrating Solar Power (CSP) technologies are usually categorized in three different concepts: Troughs, Towers and Dishes. Among them Parabolic Trough Solar Collector (PTSC) is currently the most proven solar thermal electric technology [2]. PTSC widely used in generating power for irrigation, heating for water, air conditioning, and with Rankine cycle to produce power for electric generation [3,4]. The PTSC has been studied analytically and experimentally by many investigators [5-8]. Clark [9] studied the principle design factors that influence the performance of a PTSC. Factors such as spectral directional reflectivity of the mirror system, the mirror-receiver tube intercept factor, the incident angle modifier, the end loss, effect of tracking errors and receiver tube misalignment were considered for analysis Jeter et al [10] studied geometrical effects on the performance of PTSC, it concentrated on end-effect. The results show the significance of end-effects particularly increases when short troughs are considered and elimination of this effect is important in obtaining test results. Thomas [11] developed a sample structure of PTSC to study its deflection and optical characteristics under various load conditions. In the absence wind tunnel facilities, the test gives sufficient information about the effect of wind load on the optical performance of a PTSC. Umamaheswaran [12] presented study details the construction, testing and analysis of PTSC for small scale domestic purpose water distillation application. Ground water is heated by the solar radiation as it circulates along the solar collector within an absorber pipe in order to generate steam directly into the absorber pipe. Arasu and Sornalcumar [13] developed a new PTSC for hot water generation. The variation of collector water outlet temperature and the storage tank water temperature is increased from 36 ^{o}c to 73 ^{o}c. Kassem [14] predicted natural convection heat transfer in an annular space between a circular receiver tube and a glass envelope of a PTSC. Dirk et al. [15]. Investigated the solar thermal parabolic trough collectors called solitem PTC-1800 to provide heat for desalination, cooling and electricity generation. The results showed that thermal testing of the collector has revealed comparably low thermal losses and still significant optical losses. Altogether the collector is well applicable for medium temperature applications in the range of 150° to 190°C. The high incident solar radiation in Iraq encourages the local manufacture of the PTSC, receiver, and tracking systems. Therefore, this paper presents the testing results of an attempt to design and manufacture a parabolic trough collector along with its tracking system utilizing the local raw materials and expertise.

2 EXPERIMENTAL PART

This part contains a description of Parabolic Trough Solar Collector (PTSC) and a detailed explanation of how the individual components of the system work. The design, implementation and testing of the system were conducted on the roof of the college of Science of Baghdad in university in Jadaria, Baghdad. This model consists of the mechanical unit (metal support frame), reflecting parts assembly, heat collection element, tracking and control system as shown in figure (1).

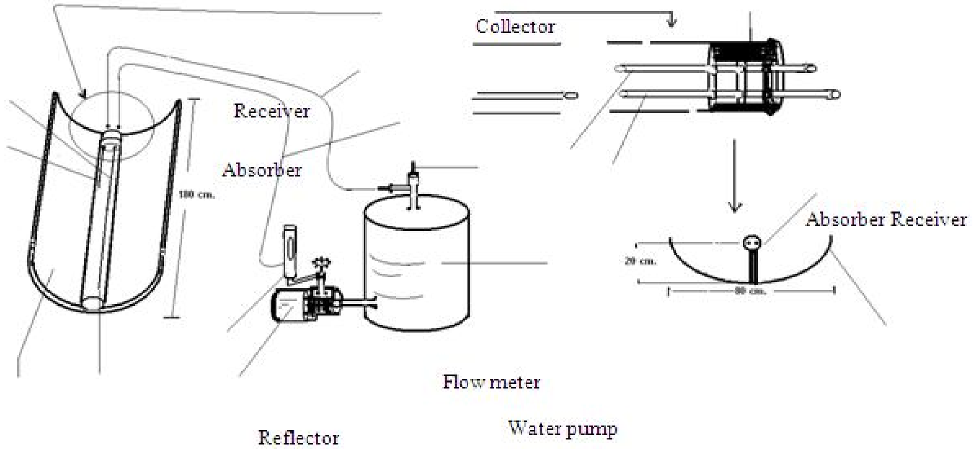


Figure 1: Schematic diagram of the PTSC.

2.1 Mechanical unit

Mechanical unit (metal support frame) consists of two mechanical assemblies: stationary base assembly and moving assembly. The idea of the design fixed base has been put in order to undergo the hard weather conditions, achieve the bearing and supporting requirement through the solar energy system operation and to satisfy the functional specifications that to be done by the moving assembly which are supporting by this important assembly. The system has two motions, so it has two groups of the moving assembly as shown in Figure 2.

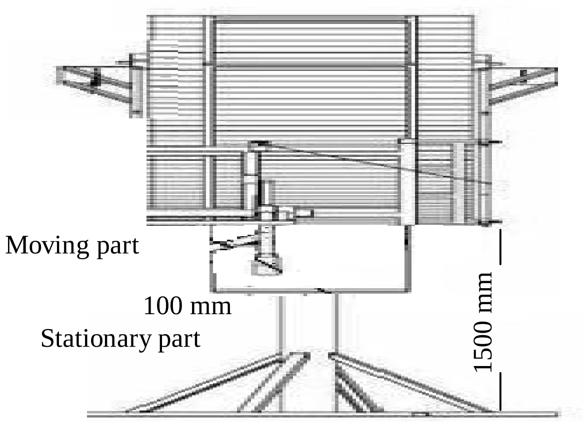


Figure 2: Schematic diagram of the mechanical unit.

2.2 Reflecting parts assembly

The reflector is designed to sit the focal point (f) 0.2 m from the vertex (V) the aperture of the system (D) is 0.8 m, so the equation of the designed system will be

$$x^2 = 0.8y \tag{1}$$

The designed dimension, aperture distance is 0.92 m and the maximum height at the end of the parabola is 0.2 m. Practically, the reflector assembly consists of two parts, first part parabolic base it is made of several pieces of steel flat bar. This material was elastic and soft that is easily to performed and to make the reflector profile depending upon the concerned design drawing the resulted form must be supported by steel hollow bar (tube) which is caring by the moving assembly. To obtain the parabolic shape characterized in figure (2). The other part, the reflector consists of several segments or pieces of mirrors with width of 5 cm. these mirrors must be fixed by sticky material on the parabolic form of the flat bar so the resulted form will be profile of glass mirror. Obviously, the shape of parabolic surface will not deflect the reflected rays out of focus.

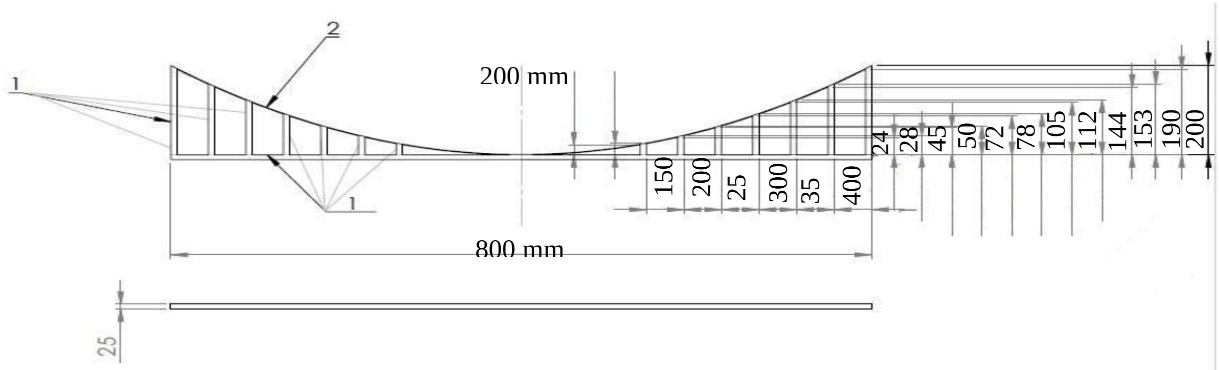


Figure 3: Schematic of reflecting base parts (1) steel tubes (2) steel flat bar.

2.3 Evacuated glass receiver

It is a mechanical structure used for collecting the concentrate solar rays in limited line which is called focal line, so the receiver must be designed to receive and absorb that collected rays. It consists of the parts: evacuated glass receiver, support plate and insulator. Evacuated tube is composed of two coaxialborosilicate glass tubes with one open end for inlet and outlet and the another end sealed; the outer of 58mm diameter (1800mm) length (cover tube) and the inner 47mm diameter and (1720mm) length (absorbing tube).

2.4 Solar tracking

The sensor LEDs provide input voltage for two comparators on the LM339 chip with the variable resistor R2 providing a "dead zone" or sensitivity adjustment Figure 4 illustrated the circuit of tracking system was used. Each comparator output is fed into a transistor (Darlington pair) which in turn drives the DC motor. The rail voltages are provided by two batteries connected in series with the center tap providing the ground reference. This circuit with 2 single cell lithium-ion batteries providing +/- 4.2 volts and two 12 volt lead batteries, the LM339 is rated for input voltages from +/- 2 volts to +/- 18 volts.

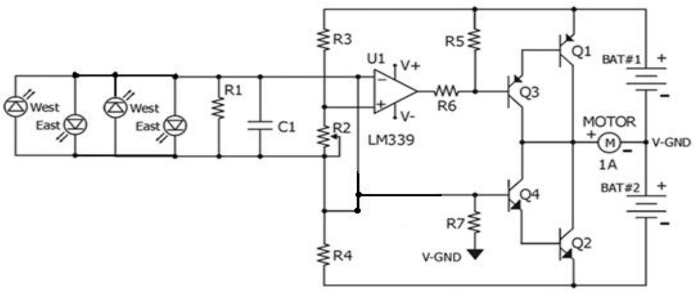


Figure 4: circuit diagram of tracking system.

3 Experimental Setup and Procedure

The experimental setup used for testing the manufactured PTSC is shown in Figure 5. It consists of the constructed PTSC (1), a 40 liter storage tank (2), a circulated pump (3) with different mass flow rates, and a control system (4). The pump is driven by a 370 Watt AC motor. In the current experiment, the water circuit is a closed one. The collecting tank is filled to up from main water supply. At the edge of the absorbing pipes, a flexible tube is used for conveyance of the heat transfer fluid. A pump circulates water from the collecting tank through the receiver tube of the solar collector back to the collecting tank. The water temperatures at inlet and outlet of the receiver tube, upper and lower of the storage tank, and solar radiation intensity are continuously measured during the experiment.

Figure 5: Photographic of PTSC setup.

4 PERFORMANCE TESTING OF THE PTSC

The performance of the PTSC is determined by obtaining values of instantaneous thermal efficiency and the system efficiency for different combinations of incident radiation, ambient temperature and inlet oil temperature. The useful energy, Qu, is calculated from the measurement of the inlet and outlet water temperatures and the water mass flow rate, m. as follows [16]:

$$Q_u = m^{\cdot}_{water} C_p \left(T_{out} - T_{in}\right) \tag{2}$$

The instantaneous thermal efficiency (η_{th}) is calculated as follows [17]:

$$\eta_{th} = \frac{m^{\cdot}_{water} C_p \left(T_{out} - T_{in}\right)}{I_b A_a} \tag{3}$$

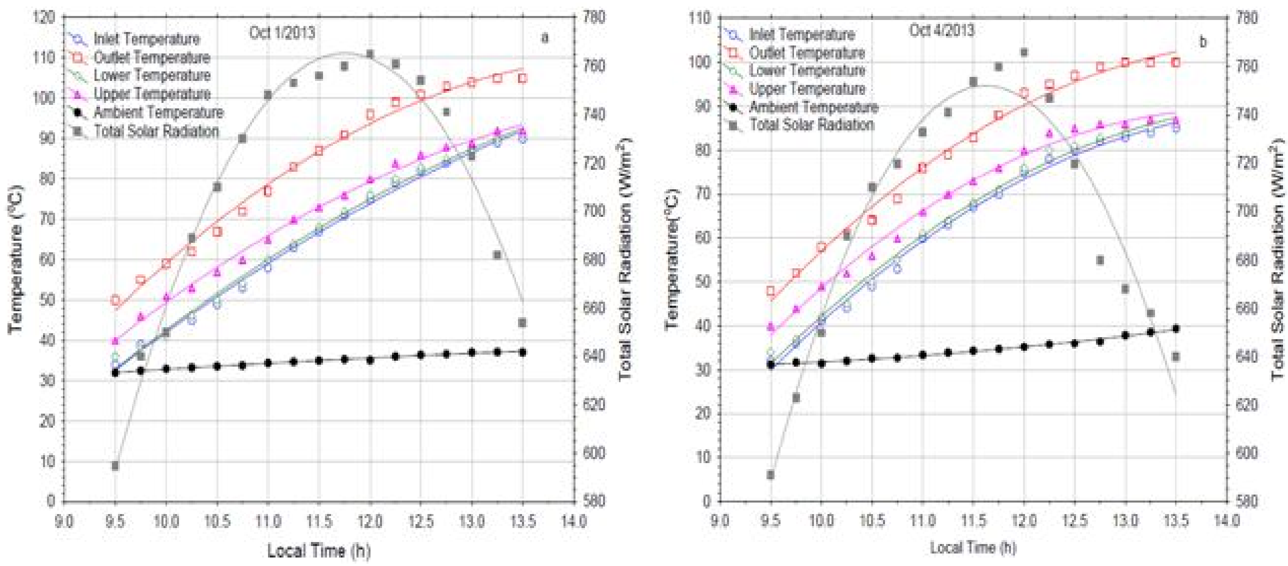
The rate of energy gained (Q_s) by the oil in the storage for a time interval of quarter hour is given by [13]:

$$Q_s = m_{water} C_p \left(T_{initial} - T_{final}\right) \tag{4}$$

Where m_{water} is mass of water in the storage tank (Kg), I_b is beam radiation (W/m^2), A_a is collector aperture area (m^2), C_p is specific heat of the water, $T_{initial}$ is the initial storage tank water temperature (^{o}C) and T_{final} is the storage tank oil temperature after 15 minutes time interval (^{o}C).

5 RESULTS AND DISCUSSION

A period of four clear sky days (10th, 13th, 17th, 25th October 2010) have been selected for measuring all necessary data for analysis of the performance of the PTSC by using a evacuated receiver. A typical data obtained in these days are showing in figure (5.a-d), with different flow rates of the water 0.0041 kg/sec, 0.0055 kg/sec, 0.0069 kg/sec and 0.0083 kg/sec, respectively. T_a, T_s, T_{in}, T_{out} and I_{total} stand for the ambient temperature, storage tank temperature, the inlet and outlet temperatures of water and total solar radiation, respectively. Which figures show the ambient temperature measured at the site during the test hours for the five days of the experimental part, higher temperatures were observed during the day time occurring between 12:00 pm and 13:30 pm. The total solar radiation was measured during the test period exhibited, higher values of total solar radiation between 11:30 am and 12:30 pm with a peak occurring at about 12:00 o'clock. an increase in outlet water temperature was noticed during early hours of the day until it reaches maximum values around mid noon when total solar radiation values are the highest. After that, outlet water temperature decreases due to the afternoon. The water temperature inside the receiver reached 105^{o}C in clear October day, where the maximum registered ambient temperature was 37^{o}C. It was noticed that the water temperature inside the receiver increases when the ambient temperatures is higher or when the solar intensity is abundant. It is noticed that the lower temperature of the storage tank is equal to inlet water temperature, approximately. The temperature of the fluid in storage tank will be raised and thus, by convection. This rising is proportional with that of incident solar radiation until solar noon, then temperature of storage tank leaves the storage to the inlet of the receiver. Temperature will continuously increase due to the fact the temperature of water in storage tank is proportional directly with useful heat energy, this energy will increase continuously with time whenever, the solar radiation is available. The average maximum storage tank water temperature has been measured as 92^{o}C, when no energy is withdrawn from the tank to the load during the collection period.



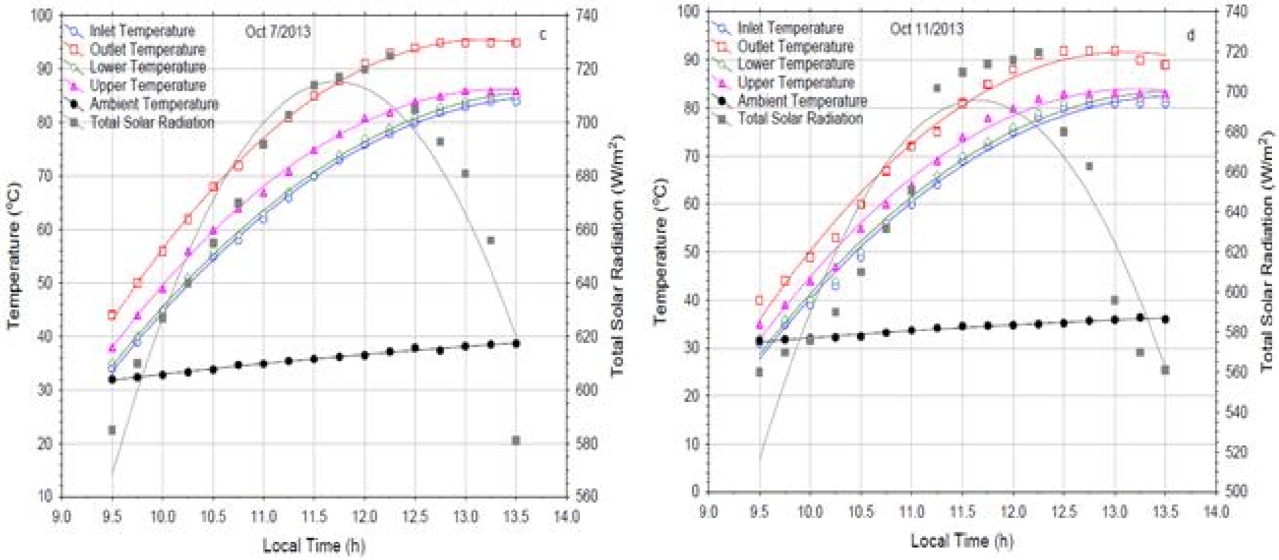


Figure .5,a,b,c&d: show variation of total solar radiation and history temperatures of PTSC for different clear October days.

The useful heat gain is calculated from the measurements of the inlet and outlet water temperatures and mass flow rate as demonstrated in equation 2. Figure 6 shows the relationship between the useful heat gain, Qu, and the local time from morning to afternoon. The experiment was carried out from 9:30 h to 13:30 h. it was found that the Qu in the afternoon was higher than in the morning. This is due to the fact that the useful heat gain is strongly influenced by the incident beam radiation and therefore follows its variation. This figure shows clearly that the Qu increases with reducing wind speed, which is mainly ascribed to the improvement in heat transfer from the absorber wall to the water flowing inside it due to the decrease in heat loss.

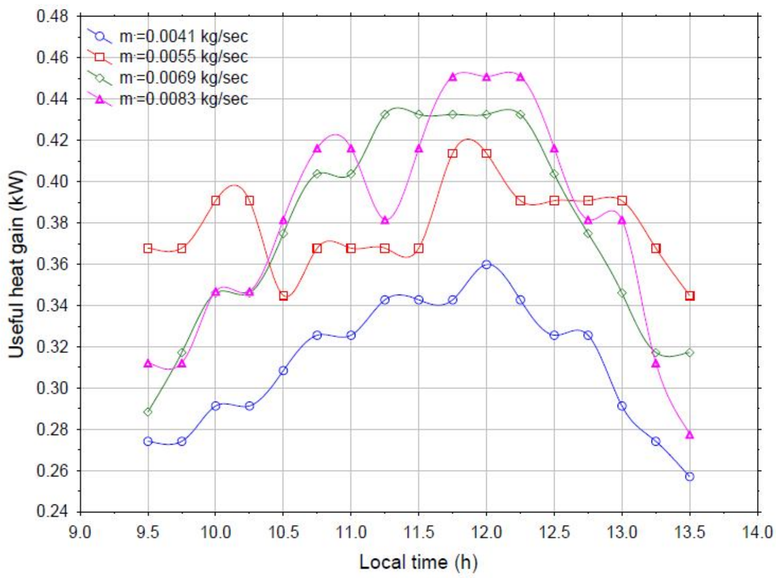


Figure 6: Variation of Qu with time for different flow rates at October month

The thermal efficiency of a PTSC can be described by ASHRAE Standard 93 (1986) [18] as demonstrated in Eq.(3). If the thermal efficiency from equation $\eta_{th} = F_R\eta_o - \frac{F_R U_L}{C}\left(\frac{T_{in} - T_{amb}}{I_b}\right)$ is plotted against $\left(T_{in} - T_{amb}\right)/ I_b$ a straight line will result provided U_L is constant. The intercept is $F_R\eta_o$ and the slope is $F_R U_L /C$.

The performance curve of the PTSC, is derived from a series of tests conducted by the use of evacuated receiver. Five tests were conducted to generate the thermal efficiency curve of the PTSC, which is shown in figure 7.

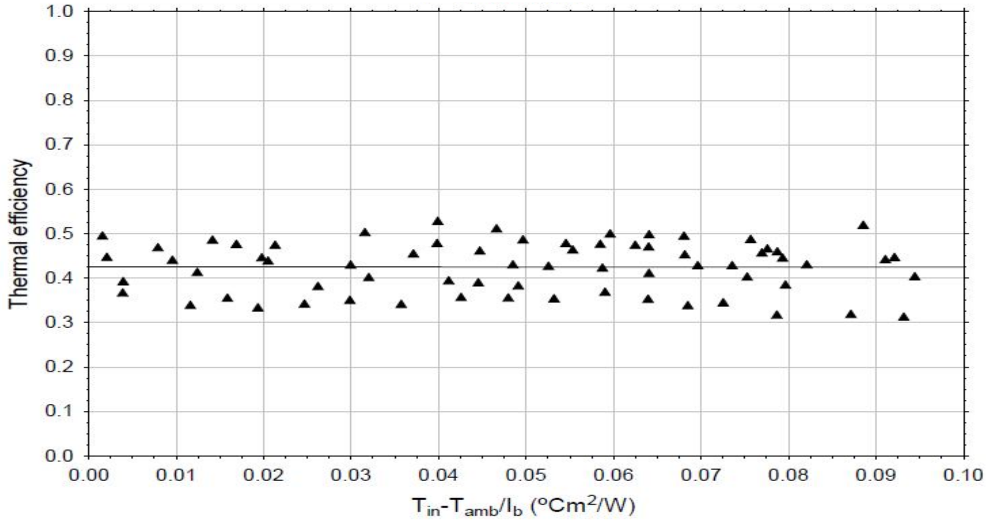


Figure 7: Thermal efficiency curve for PTSC.

The best fit curve in figure 7 is obtained which is shown as a solid line. This yielded the thermal performance equation for the collector with evacuated receiver.

$$\eta_{th} = 0.43 - 0.68\left(\frac{T_{in} - T_{amb}}{I_b}\right)$$

From above equation, ($A_r U_L F_R / A_a$) = 0.68 W/°cm^2 and $F_R \eta_o$ =0.43. For a geometric concentration ratio (A_a/A_r) of 14 the gradient of above equation gives $U_L F_R$ =10.88 W/°cm^2. The optical efficiency can be calculated which η_o =0.64, this result gives in a heat removal factor (F_R) of 0.67. The heat removal factor represents the ratio of actual useful energy gain of the collector to the useful gain if the whole receiver were at the fluid inlet temperature. This in turn yields an overall heat loss coefficient (U_L) of 16.2 W/°cm^2.

6. CONCLUSIONS

Parabolic Trough Solar Collector (PTSC), with its two axes sun tracking system have been designed, manufactured and tested. The performance of the PTSC was experimentally investigated with water as the circulate heat transfer fluid (HTF), without draw-off water from storage to load. The thermal efficiency of the PTSC can be obtained in the range 50% - 40%. It was also found that receiver can easily achieve during operation relatively high fluid temperature levels approaching 105°C. This research can be used for large field for the domestic applications such as space heating and water heating.

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