# Parabolic Trough Solar Collector – Design, Construction and Testing

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## Abstract:

This paper presents the design, construction and investigates an experimental study of a parabolic Trough Solar Collector (PTSC). It is constructed of multi – piece glass mirror to form the parabolic reflector (1.8 m × 2.8 m) its form were checked with help of a laser and carbon steel rectangular as receiver. Sun tracker has been developed (using two – axis) to track solar PTSC according to the direction of beam propagation of solar radiation. Using synthetic oil as a heat transfer its capability to heat transfer and load high temperature (≈400 $^o$c). The storage tank is fabricated with stainless steel of size 50 L. The experimental tests have been carried out in Baghdad climatic conditions (33.3$^o$ N, 44.4$^o$ E) during selective days of the months October and November. 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 oil. The storage tank oil temperature is increased from 30$^o$c at 9:30h to 136$^o$c at 13:30h without draw – off oil. The experimental result shows the average thermal efficiency was 42% which is fairly acceptable assessment results of a PTSC locally.

**Key words: Solar energy, parabolic trough solar collector, collector efficiency**

## 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

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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 36c to 73c. 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.

## Description of the Parabolic Trough Solar Collector

A small scale model has been designed, construction and tested in the open area of the solar energy center (at the roof of ministry of science and technology, 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).

## 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. The first group for the tilting motion containing two electrical actuators and the materials of the parts to be selected carefully to withstand the hard working conditions i.e. environment conditions, bending stress, torsion stress. The second group for the axial motion containing: axial motion guide with two types of discs, one stationary disc to be welded with the whole system base and the other rotational to be connected with the rotational parts, which must be rotate by the worm gear motor.

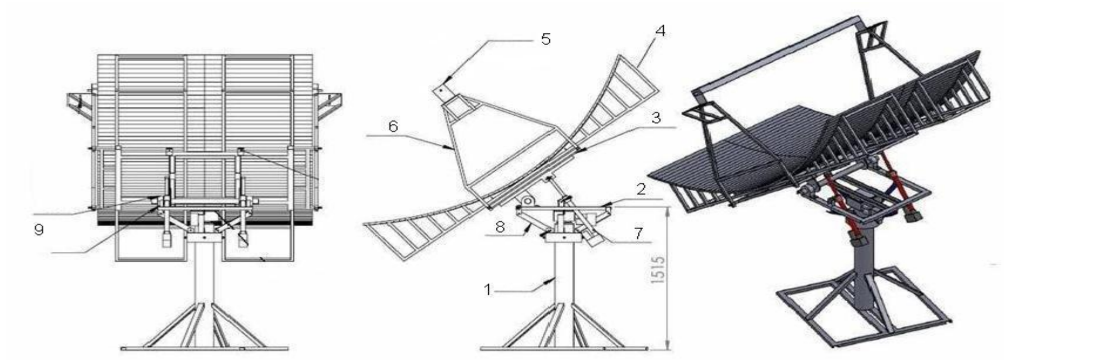


**Fig (1) The schematic of PTSC (1) Axial Motion Guide Ass. (2) Tilting Motion Base (3) Tilting Motion Ass. (4) Reflecting Ass. (5) Thermal Receiver Ass. (6) Heat Receiver Support (7) DC actuator motor (8) Side Support Angle (9) Bracate ∅ 50.**

## 2. Reflecting Parts Assembly

The reflector is designed to sit the focal point (f) 1.04 m from the vertex (V) the aperture of the system (D) is 2.8 m so the equation of the designed system will be

$x^2 = 4.16y$ …………………… (1)

The designed dimension, aperture distance is 3 m and the maximum height at the end of the parabola is 0.47 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.

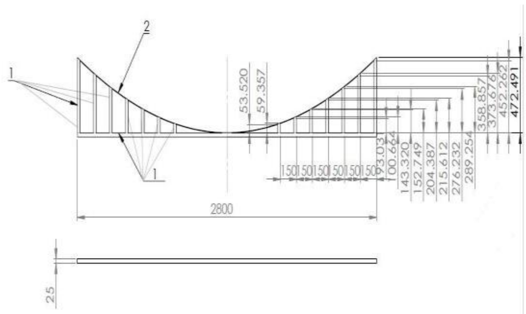


**Fig. (2): Schematic of reflecting base parts (1) steel tubes (2) steel flat bar**

## 3. Heat Collection Elements

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: receiver jacket, receiver tube, support plate and insulator. The parts are made of the materials; carbon steel and glass wool. The receiver tube as rectangle carbon steel, 180 cm – long with cross section (8×4) cm. This tube has been insulated by a glass wool with thickness 2 cm in three faces. The forth face its section 8 cm have no insulation, because it will be the focus said of parabolic reflector.

## 4. Tracking and Control System

A parabolic trough solar collector with automatic two axes sun tracking system was constructed, operated and tested to overcome the need for frequent tracking. This procedure causes an increase in the out put power of the PTSC by making the solar angle of incidence between the beam of the solar radiation and the normal on the surface of the trough equal to zero (the geometrical losses become zero). The system consists of electro optic part represent as Photo Sensors (PS) by using, four photodiodes (PIN silicon photodiodes).

## Experimental Setup and procedure

The experimental setup used for testing the manufactured PTSC is shown schematically in figure (3) and as a photo in figure (4). It consists of the constructed PTSC (1), a 50 liter storage tank (2), a circulated pump (3) with maximum mass flow rate of 0.02 Kg/sec, and a control system (4). The pump is driven by a 180 Watt AC motor. In the current experiment, the oil circuit is a closed one. The collecting tank is filled to up from main oil supply. At the edge of the absorbing pipes, a flexible tube is used for conveyance of the heat transfer fluid. A pump circulates oil from the collecting tank through the receiver tube of the solar collector back to the collecting tank. The oil 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.

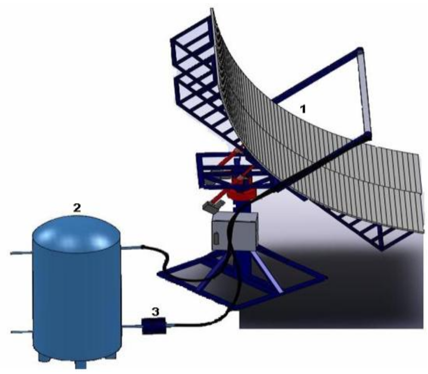


**Fig. (3) A schematic diagram of the experimental setup**

**Fig. (4) Photographic of PTSC setup**

## 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, $Q_u$, is calculated from the measurement of the inlet and outlet oil temperatures and the oil mass flow rate, $m^{\cdot}$ as follows [16]:

$$Q_u = \dot{m}_{oil} C_p \left(T_{out} - T_{in}\right) \qquad (2)$$

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

$$\eta_{th} = \frac{\dot{m}_{oil} C_p (T_{out} - T_{in})}{I_b A_a} \qquad (3)$$

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

$$Q_s = m_{oil} C_p (T_{initial} - T_{final}) \qquad (4)$$

Where $m_{oil}$ is mass of oil 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 oil, $T_{initial}$ is the initial storage tank oil temperature ($^oC$) and $T_{final}$ is the storage tank oil temperature after 15 minutes time interval ($^oC$).

## Results and Discussions:

A period of five clear sky days ($10^{th}$, $13^{th}$, $17^{th}$, $19^{th}$, $25^{th}$ October 2010) has been selected for measuring all necessary data to analysis the performance of the PTSC. Figure (5) shows the total solar radiation on the collector, the ambient temperature, inlet and outlet temperatures of the receiver also the upper and lower temperatures of the storage are shown. It can be seen that the temperature difference between the outlet and inlet of the heat transfer fluid (HTF) increases progressively with time due to the increase in solar radiation which varies from 550 to 750 $W/m^2$. The HTF (synthetic oil) is recirculated through a storage tank of capacity 50 liters and the flow rate of the HTH was 0.02 Kg/s. The storage tank oil temperature increases steadily from an initial temperature of $40^oC$ at 9:30 h and reach a maximum value of $136^oC$ at 13:30 h as without draw-off energy from the storage tank during the collection period. It was noted that there is no difference between upper and lower temperatures of storage in the afternoon. This is due to obtained a well-mixed storage tank in which the oil temperature is uniform throughout, while the stratification phenomenon is demonstrate in the morning then drop slowly when decreasing in solar radiation.

Figure (6) shows the relationship between the useful heat gain, $Q_u$, and the beam solar radiation, $I_b$, from morning to afternoon. The experiment was carried out from 9:30 h to 13:30 h. it was found that the $Q_u$ 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. The calculated energy gained, $Q_s$, by the storage tank oil per quarter hour is plotted in figure (7) against the local time from 9:30 to 13:30 h for variation wind speed. This figure shows clearly that the $Q_s$ increases with reducing wind speed, which is mainly ascribed to the improvement in heat transfer from the absorber wall to the oil flowing inside it due to the decrease in heat loss.

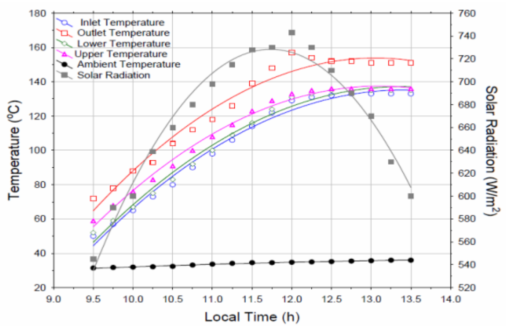


**Fig (5) Total solar radiation and temperatures history of PTSC**

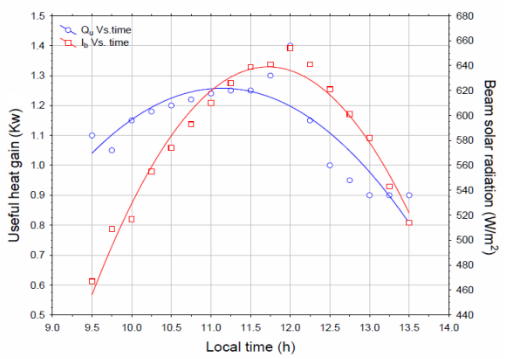


**Fig (6) Variation of beam radiation and useful heat gain with time**

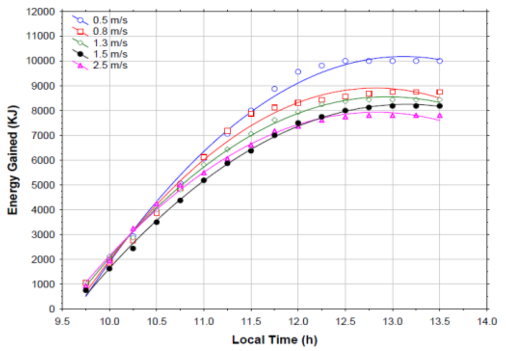


**Fig (7) Variation of energy gained and wind speed with time**

The thermal efficiency, $\eta_{th}$, of a PTSC can be described by ASHRAE [18].

$$\eta_{th} = F_R\eta_o - \frac{F_R U_L}{C}\left(\frac{T_{in} - T_{amb}}{I_b}\right) \quad (5)$$

If the thermal efficiency from Eq. (5) is plotted against $(T_{in}-T_{amb})/I_b$, which is shown in figure (8). The best fitted curve is obtained which is shown as a solid line. The intercept is $F_R\eta_o$ = 0.446 and the slope $(F_RU_L/C)$ = 0.538 $W/m^2K$. For a geometric concentration ratio C which equal to $(A_a/A_r)$ (aperture area/receiver area) of 35 the gradient of equation 5 gives $U_LF_R$ = 18.85 $W/m^2K$. The optical efficiency can be calculated $\eta_o$ = 0.407. This results in a heat removal factor $(F_R)$ of 0.913. 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 20.65 $W/m^2k$. Therefore, the collector thermal efficiency equation (5) for PTSC can be written as;

$$\eta_{th} = 0.446 - 0.538\left(\frac{T_{in} - T_{amb}}{I_b}\right) \quad (6)$$

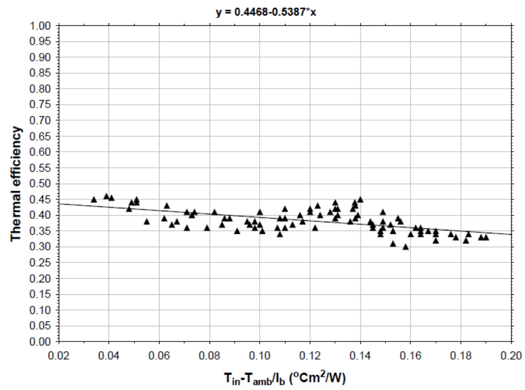


**Fig (8) Thermal efficiency curve of the collector**

## 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 synthetic oil as the circulate heat transfer fluid (HTF), without draw-off oil from storage to load. The thermal efficiency of the PTSC can be obtained in the range 45% - 35%. It was also found that receiver can easily achieve during operation relatively high oil temperature levels approaching 150°C. This research can be used for large field for the domestic applications such as space heating and water heating.

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# تصميم وتركيب واختبار مركز شمسي حوضي ذو قطع مكافىء

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**الخلاصة:**

هذا البحث يمثل دراسة عملية لمركز شمسي اسطواني ذو قطع مكافئ وجهاز التوجيه الشمسي تم تصميمهم وتصنيعهم باستخدام التقنيات العراقية والمواد المتاحة محليا. وقد صنع مركز شمسي بمساحة كلية بلغت $5.4\ m^2$ وقد تم ترتيب قطع المرايا بعرض 5cm على السطح الداخلي للمركز حيث استخدمت كسطح عاكس للاشعة . صنع الجزء المستلم من معدن الفولاذ الكاربوني كسطح امتصاص واستخدم زيت المكائن الصناعي كوسط ناقل للحرارة لما يمتاز به من قابلية على نقل الحرارة وتحمله لدرجات حرارة عالية. زودت المنظومة بخزان ووضع داخل الخزان زيت ذو سعة 50 L لخزن الطاقة الحرارية , جهاز التوجيه الشمسي من العناصر الكهربائية والالكترونية بمحورين في اقتفاء الاشعاع الشمسي المباشر. التجارب العملية تم انجازها تحت الظروف المناخية لمدينة بغداد خلال شهري تشرين الاول والثاني , خلال هذه التجارب بلغت اقصى درجة حرارة خروج الزيت من المستلم $150^oC$ اما درجة حرارة الزيت داخل الخزان زادت من $30^oC$ الى $136^oC$ خلال اربع ساعات تشغيل. اظهرت النتائج العملية ان معدل كفاءة المنظومة كانت 42% وهي مقبولة باعتبار ان هذه المحاولة الاولى لتصنيع مثل هذا المجمع محليا.