International Journal of Engineering &Technology, 7 (4) (2018) 6415-6420

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

doi: 10.14419/ijet.v7i4.20476

Research paper

Experimental investigation of solar parabolic trough collector with a helical coil receiver under Jordan climate conditions

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Abstract

This paper presents an experimental study of parabolic trough solar collector (PTC) with a helical recovers performance under Irbid-Jordan (32.50 N, 35.90 E) climate conditions. The collector was tested during selected days of December, 2014. The various parameters affecting the problem under investigation are including solar radiation intensity, the inclination and tilt angles, and the heat transfer from the beam radiation reflecting to the reserve was investigated. The performance of PTC was evaluated by using outdoor experimental measurements including the outlet temperature of water and the thermal instantaneous efficiency. The experimental measurements for average thermal efficiency and outlet temperature for the water is approximately 64.7% and 55 ˚C respectively, while the theoretical calculation is 69.4% and 57.5˚C respectively.

Keywords: *Solar Radiation; SPTC; Thermal Efficiency.*

1. Introduction

Solar thermal energy is one of the important renewable sources which utilize the concentration of solar radiation. The concentrated solar power radiation moves a thermal engine that acts as a basic drives of generator. Thus, the concentrated solar energy is very close concept to traditional forms of energy generation which depends on the combustion of fossil fuels. Both depend on conversion thermal power to mechanical power and then to electric energy. Currently, there are four main technologies using concentrate solar thermal: (a) parabolic trough systems, (b) Stirling solar dishes systems, (c) Solar energy tower systems, and (d) linear Fresnel Systems. Many studies discussed the best design Simulation of equivalent aquarium systems. [1-4]

Recently, solar research has expanded rapidly in applications in most regions of the world including Arab countries, focusing on ways to increase and develop the efficiency of solar system applications. The regions with a favorable temperate climate with high temperature have the potential to maximize the energy of the solar system with high efficiency. Benefits arising from the installation and operation of solar energy systems fall under the main categories: environmental, social and economic issues. [5-9].

The potential of solar energy in Jordan is enormous as it lies within the solar belt of the world with an average solar radiation of between 5 and 7 kWh /m^2 per day, indicating the possibility of at least 1000 GWh per year annually. Solar energy like other forms of renewable energy is still underutilized in Jordan. The decentralized PV modules in rural and remote villages are currently used for lighting, water pumping and other social services (1000 kW of peak capacity). In addition, about 15% of all households are equipped with solar water heating systems. [10-11].

Solar thermal systems are classified by the US Energy Information Administration to low temperature collectors includes: Flat plate solar collectors and evacuated tube, and higher temperature collectors include: parabolic dish reflector, parabolic trough solar collector and power tower.

A parabolic trough is a type of solar thermal collector that is consists of a reflecting surface mounted on a reflector support structure having parabolic profile. A receiver group with a circular absorption tube is concentrated with an appropriate selective coating and enclosed by a concentric glass layer along the reflector focal line. Maintain the concentration of solar radiation on the receiver assembly. The incident energy is absorbed by a fluid acting through the absorption tube. [13-14].

The mirrors track the sun on one linear axis from north to south during the day. The tube sits above the mirror in the center along the focal line and has a heat-absorbent medium. The collector is generally composed of a single glass mirror, with either silver or aluminum coated on the back side of the glass.

For example, food may be placed at the focal line of a trough, which causes the food to be cooked when the trough is targeted so that the Sun is at the plane of symmetry.

Parabolic trough solar water heating is used in commercial and residential applications to produce high pressure steam for power generation. A small version of this system can be used to produce operating temperatures at moderate temperatures (up to 150°C), which are required by most small plant operations, such as food packaging, paper production, air conditioning, and cooling.

The design parameter of a parabolic trough collector can be classified as geometric and functional. The PTC geometric parameters are the width and length of the aperture, rim angle, focal length, the diameter of the receiver diameter of the glass envelope and the concentration ratio.

The functional parameters of the PTC are optical efficiency, instantaneous and all day thermal efficiency and thermal losses for the receiver. These parameters are greatly affected by the absorptive of the absorber. Experience a significant difference in optical

efficiency with great decreasing in efficiency during the winter season.
Parabolic troughs are more suitable for small applications because of their simplicity, ease of manufacturing, and high efficiency in collecting energy per unit cost over other collector's methods. A parabolic trough is activated by reversing and concentrating the thermal energy it receives from the sun into a pipe carrying a heat transfer fluid (HTF) that is placed appropriately along the focal length and consequently absorbed by the HTF. Then HTF flows into storage tanks where it will be stored for using again.
Parabolic trough solar collector system uses heat exchangers to transfer solar energy absorbed in solar collectors to the liquid or air used to heat water or space.
Heat exchangers is selected to be a twisted tube which can be made of steel, copper, bronze, stainless steel, aluminum, or cast iron. Copper solar heating systems are usually used, because they have good thermal conductivity and have greater resistance to corrosion. Helically coiled exchangers offer certain advantages. Compact size provides a distinct benefit.
The Helical geometry allows handling of high temperatures and sharp differences in temperature without high induced stresses or costly expansion joints. High-pressure capability and the ability to fully clean the service-fluid flow area add to the exchanger's advantages.
The objective of this paper is to study the theoretical and experimental design and fabrication of a parabolic trough solar collector to convert the incident solar energy to thermal energy to achieve some important applications in the use of thermal solar energy and evaluate the performance of the system in Irbid - Jordan environment.

2. Theoretical analysis

Changes in earth-sun geometry cause the seasons to change. These annual changes in earth-sun geometry dramatically change the amount of energy that a given place (on the earth's surface) receives from the sun. There are three principal relations:
Shape of the earth's orbit around the sun, Distance from the sun to the earth, Solar Constant
Solar Radiation
The solar radiation is a flow of energy outward from the sun constantly and simultaneously in all directions. The solar radiation can be divided into two types: extraterrestrial solar radiation and terrestrial solar radiation.
Extraterrestrial solar radiation
Solar radiation outside the earth's atmosphere is called extraterrestrial solar radiation (ETR) (Io). This depends on many factors such as the distance and orientation. I_o varies by the inverse square law, as shown in the following equation:

$$I_o = I_{sc}\left[\frac{Dm}{De\_s}\right]^2 \quad (1)$$

Where:

Dm: The mean sun earth distance.
De_s: The distance between the earth and the sun.
Io: is approximated by the following empirical equation:

$$I_o = I_{sc}[1 + 0.034\cos(360dn/365.25)] \quad (2)$$

Where:
Isc: The solar constant 1366.1.
dn: The day number during the year ($1 \le dn \le 360$)
Terrestrial solar radiation
The amount of solar radiation that actually reaches the earth's surface is reduced through reflection, absorption and scattering of light by gas molecules located in the atmosphere. The total radiation incident on a surface (at earth's surface) is comprised of two forms: beam radiation I_b and diffuse radiation I_d.
The sum of the beam and diffuse radiation is referred to as global (total) radiation or terrestrial solar radiation.
The beam solar radiation at normal incidence, I_b,is given by Equation(3)

$$I_b = I_o\left[a_0 + a_1 e^{-(kAM)}\right] \quad (3)$$

Where:

$$a_0 = 0.94[0.4237 - 0.00821(6 - AL)^2] \quad (4)$$

$$a_1 = 0.98[0.555 - 0.00595(6.5 - AL)^2] \quad (5)$$

$$\alpha 1 = 0.98\ [0.5.55 - 0.00595\ (6.5 - AL)^2] \quad (6)$$

$$k = 1.02[0.2711 - 0.01858\ (2.5 - AL)^2] \quad (7)$$

AM: The air mass (which equal to $\frac{1}{\cos z}$ or $\frac{1}{\sin \alpha}$)
AL: The altitude of location above mean sea level (km), (which equal (0.647km) for Al-huson University College)
For tilted surface the beam radiation received is related to incident angle, θ given by the equation:

$$Ibt = Ib\cos(\theta) \quad (8)$$

The diffused solar irradiance on a horizontal surface may be calculated by using the following equation:

$$Id = I_o\cos(z)\left[0.271 - 0.2939\left(a_o + \left(e^{-KAM}\right)\right)\right] \quad (9)$$

2.1. Thermal analysis of PTC

The heat collector element (HCE) performance model is based on an energy balance about the collector and the HCE. The energy balance includes the direct normal solar irradiation incident on the collector, optical losses from both the collector and HCE, thermal losses from the HCE, and the heat gain into the heat transfer fluid (HTF). For short receivers (< 100 m) a one-dimensional energy balance gives reasonable results; for longer receivers a two-dimensional energy balance becomes necessary.
The working fluid in the receiver tube absorbs solar energy and transfers it to water in heat exchangers to produce hot water or steam. The receiver is covered by a glass tube to reduce thermal radiation as well as convection heat loss to the free air which moves around the receiver. To reduce further the heat losses from the absorber, air is evacuated from the space between absorber and glass cover.
Heat transfer from the absorber tubes includes $q_{conv\text{-}g\text{-}sky}$ and $q_{rad\text{-}g\text{-}sky}$, the convective and radiation heat transfer loss from the outer surface of glass tube to the environment.

$$q_{thermal\ loss} = q_{conv-g-sky} + q_{rad-g-sky} \quad (10)$$

$$q_{conv\text{-}g\text{-}a} = h_c(T_g - T_a)A_{glass} \quad (11)$$

Where Tg and Ta are glass temperature and ambient temperature, A_{glass} is glass envelope area and h_c is the convective heat transfer coefficient of air, which is calculated from Mullick & Nanda correlation:

$$h_c = 4d^{-0.42}v_w^{0.5} \quad (12)$$

Where $v_w$the wind velocity in m/s and d is is the outer diameter of the glass cover in m.

$$q_{rad-g-sky} = \sigma\epsilon g\left(T_g^4 - T_{sky}^4\right)A_{glass} \quad (13)$$

Where σ is Stephan Boltzman coefficient, εg is glass envelope emissivity and T_{sky} is sky temperature.
Heat losses

Experimental and numerical method are used to calculate heat loss for 3 different types:-

1) Vacuum jacket tube
2) Lost vacuum tube
3) Broken glass tube

Parabolic trough collector's specification is tabulated in Table (1).

Table 1: Collectors Specifications

Absorber tube length	4.06 m	Absorptivity of absorber tube	0.94
Outer diameter of absorber tube	7 cm	Geometric concentration ratio (Gc)	14
Inner diameter of absorber tube	6.56 cm	Aperture of collector	3.1 m
Outer diameter of glass tube	12.5 cm	Width	3.4 m
Inner diameter of glass tube	11cm	Focal length	88 cm
Emissivity of absorber tube	0.15		

Heat Transfer to Fluid

The analysis of the helical coil heat exchanger is carried out through following procedure:

1) The range of Re considered for the analysis is about 100 to 6000.
2) The velocity of the fluid flowing through the tube is calculated by considering the tube diameter (d) as 8mm, 10 mm and 12 mm. The properties of the fluid flowing through the tube are taken at average temperature of 60°C (for the values of ρ and μ)

$$V = \frac{(R_e \times \mu)}{(\rho \times d)} \tag{14a}$$

1) Mass flow rate is calculated as

$$m = \rho \times A \times V \tag{14b}$$

2) Dean Number (De) is calculated as

$$D_e = R_e \times \left(\frac{d}{D}\right)^{0.5} \tag{15}$$

3) Helix Number (He) is calculated as

$$H_e = \left(\frac{D_e}{(1+\gamma^2)^{0.5}}\right) \tag{16}$$

4) Nu is calculated by various correlations at specified conditions:

a) M.R. Salimpour [15]

$$N_u = 0.152 {D_e}^{0.431} {p_r}^{1.06} \gamma^{-0.277} \tag{17}$$

$$for D_e < 3000$$

b) Kalb et al. [16]

$$N_u = 0.836 {D_e}^{0.5} {p_r}^{0.1} \tag{18}$$

$$for D_e \geq 80 \; and \; 0.7 < p_r < 5$$

c) Xin et al. [17]

$$N_u = \left(2.153 + 0.318 {D_e}^{0.643}\right) {p_r}^{0.177} \tag{19}$$

$$for\; 20 < D_e < 2000; 0.7 < p_r < 175 \; and \; d/D < 0.0884$$

d) Roger et al. [18]

$$N_u = 0.023 {R_e}^{0.85} {p_r}^{0.4} \delta^{0.1} \tag{20}$$

$$for\; R_e > 2000$$

5) Calculate hi (Heat Transfer coefficient inside the tube)

$$h_i = \frac{N_u \times k}{d} \tag{21}$$

Overall Heat Transfer Coefficient and Factors

The overall heat transfer coefficient (U_o) is the coefficient for heat transfer from the surroundings to the fluid, based on the outer diameter of the receiver tube this is given by following equation:

$$U_o = \left[\frac{1}{U_L} + \frac{D_{r,o}}{h_f D_{r,i}} + \frac{D_{r,o} \ln\left(\frac{D_{r,o}}{D_{r,i}}\right)}{2K}\right]^{-1} \tag{22}$$

Where: K is the thermal conductivity of receiver tube material.

It is convenient to define a collector efficiency factor (F') as the ratio of actual useful energy collected to the useful energy collected if the entire absorber surface is at the mean fluid temperature.

$$F' = \frac{U_o}{U_L} \tag{23}$$

Now the above equation can be written in the following form

$$F' = \frac{\frac{1}{U_L}}{\frac{1}{U_L} + \frac{D_{r,o}}{h_f D_{r,i}} + \frac{D_{r,o} \ln\left(\frac{D_{r,o}}{D_{r,i}}\right)}{2K}} \tag{24}$$

The heat removal factor or correction factor, , having a value between 0 < F_R < 1, can be interpreted as the ratio of the actual useful energy collected to that which would be collected if the entire absorbed surface is at the temperature of the fluid entering the collector. F_R is a measure of the efficiency of the receiver when viewed as a heat exchanger, that is, the effectiveness with which the absorber radiation energy is transferred to the working fluid. Its value is governed by the working fluid flow rate and its properties as well as the thermal properties of the receiver material.

$$F_R = \frac{\dot{m}_f c_p}{A_r U_L}\left[1 - exp\left(-\frac{A_r U_L F'}{\dot{m}_f c_p}\right)\right] \tag{25}$$

Where: c_p is the specific heat of the fluid.

The collector flow factor is then calculated from following equation

$$F'' = \frac{F_R}{F'} = \frac{\dot{m}_f c_p}{A_r U_L F'}\left[1 - exp\left(-\frac{A_r U_L F'}{\dot{m}_f c_p}\right)\right] \tag{26}$$

Thermal Efficiency of a PTSC

The instantaneous thermal efficiency η_{th} of a solar concentrator may be calculated from an energy balance on the receiver. The useful heat gain, Q_u, delivered by the receiver can be written in terms of optical and thermal losses, where optical losses are represented by the optical efficiency, η_o.

$$Q_u = \eta_o I_b A_a - U_L (T_r - T_{amb}) A_r \tag{27}$$

Where A_a is the aperture area, since the receiver surface temperature is difficult to determine, it is convenient to express the Q_u in terms of the inlet fluid temperature by means of heat removal factor F_R as:

$$Q_u = A_a F_R \left[S - \frac{U_L (T_{f,i} - T_{amb})}{C}\right] \tag{28}$$

The useful heat is related to the flow rate can also be defined on the base of fluid difference temperature as:

$$Q_u = \dot{m} C_p (T_o - T_i) \tag{29}$$

Where: T_i, T_o and T_{amb} represent the inlet fluid, exit fluid and ambient temperatures, respectively.

The thermal efficiency of the solar thermal collector can also be simplified as Equation (30):

$$\eta_{th} = \frac{Q_u}{I_b A_a} \tag{30}$$

The thermal efficiency of the collector can now be re-written from Eq. (28) and Eq. (30) as follow:

$$\eta_{th} = F_R\left[\eta_o - \frac{U_L(T_{f,i}-T_{amb})}{CI_b}\right] \tag{31}$$

The thermal efficiency depends upon two types of quantities namely the concentrator design parameters and the parameters characterizing the operating conditions. The optical efficiency, heat loss coefficient and heat removal factor are the design dependent parameters while the solar flux, inlet fluid temperature and the ambient temperature define the operating conditions.
The exit fluid temperature T_o, the temperature rise (T_o - T_i) and the efficiency can be calculated using the following equation:

$$\eta_{th} = \frac{\dot{m}c_p(T_{f,o}-T_{f,i})}{I_b A_a} \tag{32}$$

System description and operation
A theoretical calculation and experimental measurements on the parabolic trough solar collector which was designed and fabricated in this research work.
A parabolic trough solar collector that takes the radiant energy from the sun and converts it to useful thermal energy in the heat transfer fluid (HTF) that circulates through the helical tube.
When expose the parabolic trough solar collector to the sun's face and with keeping the fluid flowing through the helical receiver, with measuring the inlet water temperature, after period of time the steam was get steam high temperature and goes out from the another side of the helical receiver, the inlet fluid earned the energy to convert to steam from the concentration radiation of the sun.
This system is located at the Roof top of the "Al-Huson Center for Career Development" in Irbid-Jordan with climatic conditions (32.5˚N, 35.9˚E) as shown in figure (1).

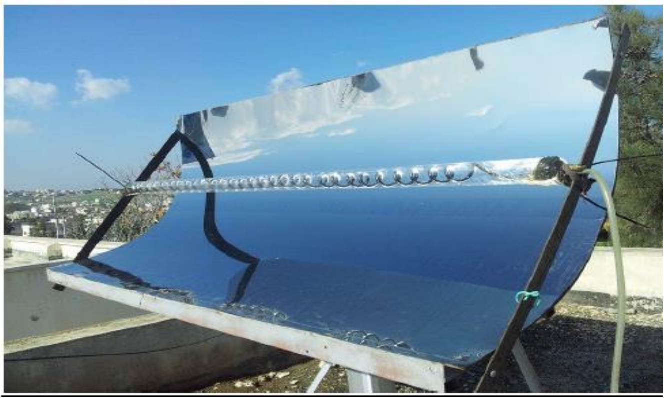

Fig. 1: Parabolic Trough Solar Collector under Consideration.

3. Results and discussion

The results for four days of measurements (15, 16, 17 and 18 December 2014) on the time 10:00 am to 3:00 pm are presented in the next tables and figures.

Table 2: Monday 15 December 2014

Time	T_{in} (°C)	T_{out} (°C)	ΔT (°C)	*cp* ($J/Kg.°C$)	□ (Kg/s)	I_b (W/m^2)	*Q* (*W*)	*η* (%)
10:00	12.2	49.9	37.7	4187	0.00496	912	783.03	56.04
11:00	12.9	57.8	44.9	4187	0.00496	977	932.57	62.27
12:00	14.7	66.3	51.6	4187	0.00496	1112	1071.73	62.90
13:00	15.5	69.7	54.2	4187	0.00496	1203	1125.73	61.08
14:00	15.4	63	47.6	4187	0.00496	1001	988.65	64.46
15:00	15	61	46	4187	0.00496	989	955.42	63.05

Table 3: Tuesday 16 December 2014

Time	T_{in} (°C)	T_{out} (°C)	ΔT (°C)	*cp* ($J/Kg.°C$)	□ (Kg/s)	I_b (W/m^2)	*Q* (*W*)	*η* (%)
10:00	11.7	54	42.3	4187	0.00496	925	878.60	61.99
11:00	13.7	59.9	46.2	4187	0.00496	992	959.72	63.14
12:00	14.9	66.1	51.2	4187	0.00496	1060	1063.40	65.48
13:00	16.1	72	55.9	4187	0.00496	1221	1161.04	62.06
14:00	15.8	63.3	47.5	4187	0.00496	997	986.63	64.59
15:00	14.9	57.9	43	4187	0.00496	964	893.11	60.42

Table 4: Wednesday 17 December 2014

Time	T_{in} (°C)	T_{out} (°C)	ΔT (°C)	*cp* ($J/Kg.°C$)	□ (Kg/s)	I_b (W/m^2)	*Q* (*W*)	*η* (%)
10:00	11	49	38	4187	0.00496	873	789.26	59.00
11:00	12.2	44.3	32.1	4187	0.00496	811	666.72	53.65
12:00	13.6	53.4	39.8	4187	0.00496	860	826.65	62.73
13:00	14.7	56	41.3	4187	0.00496	890	857.80	62.90
14:00	14.5	53.2	38.7	4187	0.00496	799	803.79	65.66
15:00	14.3	46.1	31.8	4187	0.00496	761	660.49	56.64

Table 5: Thursday 18 December 2014

Time	T_{in} (°C)	T_{out} (°C)	ΔT (°C)	*cp* ($J/Kg.°C$)	□ (Kg/s)	I_b (W/m^2)	*Q* (*W*)	*η* (%)
10:00	10.2	40.4	30.2	4187	0.00496	689	629.25	59.40
11:00	11.9	43.3	31.4	4187	0.00496	691	652.18	61.63
12:00	12.2	52.1	39.9	4187	0.00496	870	828.72	62.17
13:00	13.7	51.3	37.6	4187	0.00496	821	780.95	62.08
14:00	13.1	47.2	34.1	4187	0.00496	770	708.25	60.01
15:00	13	43.3	30.3	4187	0.00496	685	629.33	59.96

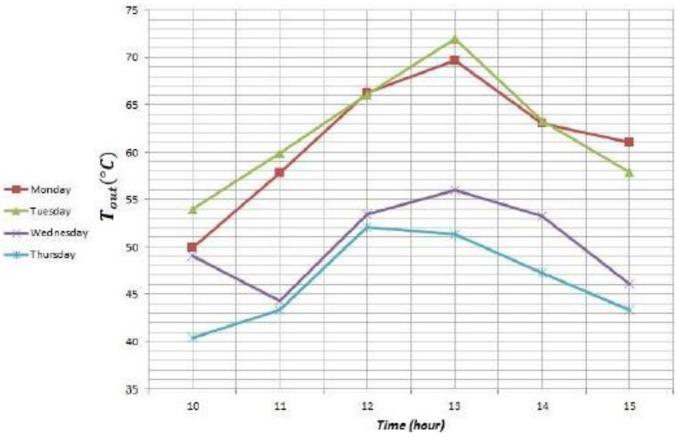

Fig. 2: The Temperature Outlet Variation with Time for the four Days under consideration.

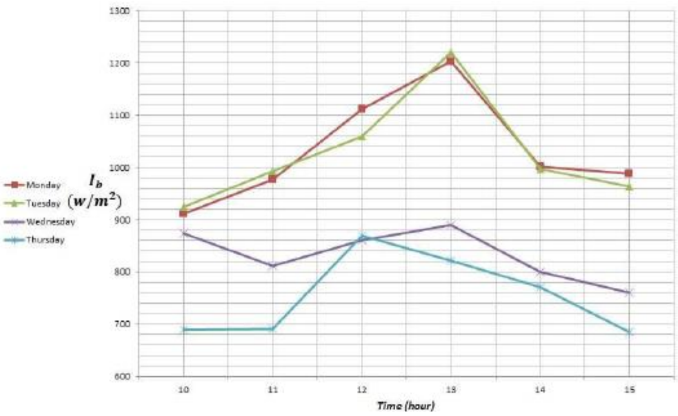

Fig. 3: The Beam Radiation Variation with Time for the four Days under consideration.

Figure (2) and (3) shows the relation between the outlet temperatures and the beam radiation variation with time. The experiments were carried out from 10:00 am to 3:00 pm for the four days under consideration. It is clear that the T_{out} varies from 40.4 to 72ºC when the beam radiation varied from 685 W/m^2 to 1221 W/m^2.
In this experiment the outlet temperature is increasing gradually with the time till it reaches the maximum value at an 13:00 clock, then began decreases gradually. This behavior can be explained by the fact of solar radiation intensity during the day and the effect of the clouds in the sky.

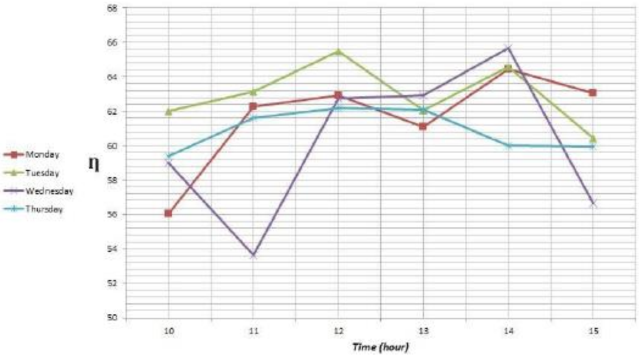

Fig. 4: Thermal Efficiency Variation with Time for Four Days under consideration.

Figure (4) shows the efficiency variation with the time during the day, it can be seen that the maximum value of efficiency depends on the outlet temperature, useful energy and beam radiation, the figure shows that the collector efficiency is varied from (53.7) % to (65.7) % for varied beam radiation along a day.

Theoretical Results

To compare the experimental with the theoretical results that was obtained by applying the theoretical equation.

Table 6: Monday 15 December 2014

Time	T_{amb} (°C)	T_{in} (°C)	ΔT (°C)	cp ($J/Kg.°C$)	□ (Kg/s)	I_b (W/m^2)	η (%)	Q (W)	T_{ou} (°C
10:00	12	12.2	0.2	4187	0.00496	912	64.79	904.89	55.
11:00	13	12.9	0.1	4187	0.00496	977	64.80	969.47	59.
12:00	14	14.7	0.7	4187	0.00496	1112	64.77	1102.99	68.
13:00	15	15.5	0.5	4187	0.00496	1203	64.78	1193.45	72.
14:00	15	15.4	0.4	4187	0.00496	1001	64.79	997.11	64.
15:00	13	15	2	4187	0.00496	989	64.71	979.97	63.1

Table 7: Tuesday 16 December 2014

Time	T_{amb} (°C)	T_{in} (°C)	ΔT (°C)	cp ($J/Kg.°C$)	□ (Kg/s)	I_b (W/m^2)	η (%)	Q (W)	T_{ou} (°C
10:00	11	11.7	0.7	4187	0.00496	925	64.77	917.42	55.
11:00	13	13.7	0.7	4187	0.00496	992	64.74	983.91	61.
12:00	14	14.9	0.9	4187	0.00496	1060	64.76	1051.24	66.
13:00	16	16.1	0.1	4187	0.00496	1221	64.80	1211.61	74.
14:00	16	15.8	0.2	4187	0.00496	997	64. 80	983.29	65.1
15:00	15	14.9	0.1	4187	0.00496	964	64.81	956.57	60.

Table 8: Wednesday 17 December 2014

Time	T_{amb} (°C)	T_{in} (°C)	ΔT (°C)	cp ($J/Kg.°C$)	□ (Kg/s)	I_b (W/m^2)	η (%)	Q (W)	T_{ou} (°C
10:00	11.2	11	0.2	4187	0.00496	873	64.78	866.95	52.7
11:00	11	12.2	1.2	4187	0.00496	811	64.73	803.92	50.9
12:00	13	13.6	0.6	4187	0.00496	860	64.77	852.99	55.7
13:00	13	14.7	1.7	4187	0.00496	890	64.71	881.95	57.6
14:00	14	14.5	0.5	4187	0.00496	799	64.79	792.68	52.6
15:00	14	14.3	0.3	4187	0.00496	761	64.78	754.97	50.6

Table 9: Thursday 18 December 2014

Time	T_{amb} (°C)	T_{in} (°C)	ΔT (°C)	cp ($J/Kg.°C$)	□ (Kg/s)	I_b (W/m^2)	η (%)	Q (W)	T_{out} (°C)
10:00	10	10.2	0.2	4187	0.00496	689	64.79	683.59	43.1
11:00	12	11.9	0.1	4187	0.00496	691	64.81	685.65	44.91
12:00	12	12.2	0.2	4187	0.00496	870	64.79	863.21	53.7
13:00	13	13.7	0.7	4187	0.00496	821	64.76	714.53	52.9
14:00	14	13.1	0.9	4187	0.00496	770	64.75	763.45	49.8
15:00	11	13	2	4187	0.00496	685	64.66	678.29	45.6

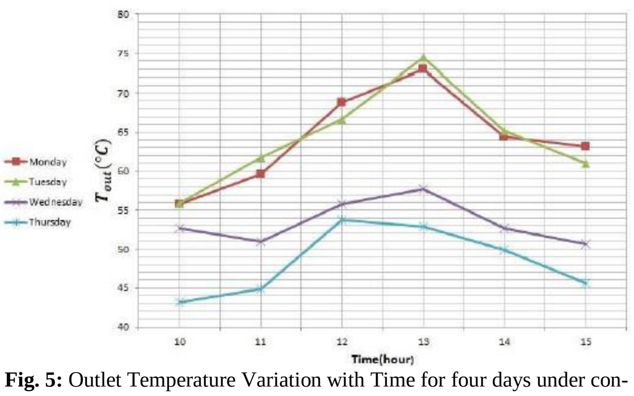

Fig. 5: Outlet Temperature Variation with Time for four days under consideration.

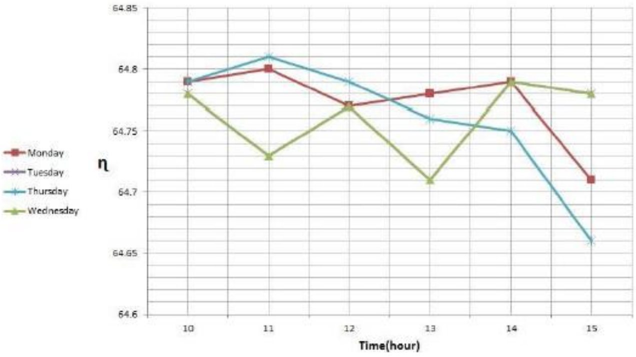

Fig. 6: Thermal Efficiency Variation with Time for Four Days under consideration.

The difference between the practical measurements with theoretical analysis can be attributed to the following reasons.

1. The calculations in this work was in winter season (December, month), which is characterized by low temperatures compared to the other months of the year.
2. Thermal losses since the receiver is not fully evacuated this cause convection heat transfer from the receiver to glass and that reduce the useful energy gain. In addition to the effect of the wind which leads to reduce the outlet temperature.
3. The intensity of beam radiation is not strong enough and varies from day to day and from hour to hour especially in winter.
4. Some hours the sky is covered with clouds, thus this obscures the sun's rays from reaching to the PTC.

4. Conclusion

The performance of a parabolic trough solar collector (PTC) with a helical recovers under Irbid-Jordan climate conditions is experimentally studied. The PTC was tested during selected days of December month in the year 2014. The various parameters affecting the problem at hand are the solar radiation intensity, the tilt angles, and the heat transfer from the beam radiation reflecting to the receiver. The influences of the above parameters were experimentally examined deeply. The performance of PTC was evaluated by using outdoor experimental measurements including the outlet temperature of water and the thermal instantaneous efficiency. The experimental measurements for average thermal efficiency and outlet temperature for the water is found approximately 64.7% and 55 ˚C respectively, while the theoretical calculation is 69.4% and 57.5˚C respectively.

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