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Experimental and theoretical comparison between metallic and mirror reflectors with different receiver tank

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ABSTRACT: In this study, an experimental analysis of a parabolic dish collectors (PDC) has been done. Two models of (PDC) with different dimensions was introduced to study the effect of change reflected materials with different diameter of the dish and depth on the position of focus point, the temperature, pressure of outlet steam and concentration ratio by using several receivers. The parabolic dish solar collector (PSDC) was made from iron with different dimensions. In the first model, the experimental setup is made up of diameter (150cm), focus length (100cm), heat exchanger (radiator) receiver tank (37×47×4) cm^3 and nickel sheet metal reflector with $1.767m^2$ aperture area. It was conducted at location in Karbala city at latitude 32.34°, longitude 44.03° and height 29m, Iraq. The second model is made up of diameter (200cm), focus length (90cm), cylindrical vessel with 13.369cm diameter and 39.5cm length and 567 pieces of mirrors reflector with $3.141m^2$ aperture area at location in Najaf city at latitude 31.57°, longitude 44.15° and height 50m, Iraq. For second model, it was observed that the temperature and pressure of steam 256% respectively comparing to the first one in April 2015 and in April 2018. The focal point temperature increased first then decreased after 12:00 pm. The mirror reflector is complex to set up on the parabolic dish and simply broken so that used metallic nickel sheet is more easily.

KEYWORDS: Parabolic trough collector, solar radiation, parabolic dish solar collector.

INRODUCTION

The solar energy used to drive an engine for conversion thermal energy to electricity is the most hopeful key of renewable tools to lower the need of fossil fuels. Unluckily, this technology limited because of the absence data on the performance and operational parameters resulting limited in detailed description and sizing. solar energy technology, due to the current energy and environment crises, has an main role to play. The technology of solar concentrator has good possible for numerous applications like process heating and power generation applications. Experimental and numerical analysis on parabolic dish collector was conducted by various researchers to investigate and enhance its performance. Since parabolic dishes are always pointing to the sun, they have several important advantages, they usually have a concentration ratio about 600–2000, they are the mainly efficient of all collector systems, and thus are highly efficient of power conversion systems and thermal-energy absorption and they have modular collector and receiver units that can either function independently or as part of a larger system of dishes [1]. In order to show the range of their applicability various types of collectors typical applications presented [2]. Joshua [3] designed and tested a (PDC) system, heat focused from the radiation by black absorbent material, that fixed within the reflector focus purpose. As a result of it heated to terribly warmth the water was converted to steam. In order the sun is always focused to the collector at several period of the day the preparation was mounted on a hinged frame supported with a slotted lever for tilting the parabolic dish reflector to various angles. The result was temperature above 200°C on the average sunny and cloud days. Kongtragool and Wongwises [4] used a conical solar concentrator powering to study the optimum absorber temperature of a differential Stirling engine. Vanita et al. [5] developed a performance examination practice for PDSC system used for process heat applications. Because of the direction of sun at 15-16 pm the thermal efficiency would be maximum. Ghanim et al. [6] used solar concentrated dish to utilize solar energy to produce steam. The results of the incident solar radiation on the dish and reflected to absorbed helical coil which carried water produced steam at 115.7^{o}C through short time in September 2014 at 11:00am in Iraq. Mohamed et al. [7] designed 3.25 m solar dish with 52 plane mirror to reflect the solar radiation on focus. A 217.79 W heat concentration, 1416.125 W useful energy and 55% center efficiency at 400-700 W/m^2. Mehrpooya et al. [8] replaced the plant boilers using parabolic solar collectors and simulated the steam power plant using the Peng-Robinson equation of state. Bareto et al. [9] designed and simulated a DS system to compute optimum concentration ratio, efficiency and energy production. Zou et al. [10] done experimental analysis to calculate the performance of parabolic trough collector using mirror reflector and evacuated aluminum receiver. With solar radiation less than 310W/m^2 the thermal efficiency was 67%. The results was shown with increasing fluid temperature the thermal efficiency improves when temperature of working fluid is under 100°C. Chafie et al. [11] suggested and assembled a parabolic trough collector system of a 10.8 m^2 aperture area to evaluate thermal performance using stainless steel receiver tube with a selective coating and surrounded by an evacuated glass cover and reflector is made up of an aluminum sheet. Results was obtained thermal efficiency 41.09% for sunny days and 28.91% for cloudy days by using selected thermal oil. Ghorbani et al. [12] supplied heat input to the absorption refrigeration cycle generator using solar collectors, used to liquefy hydrogen in the integrated structure. Khakrah et al. [13] used an exergy analysis for parabolic trough solar collector using working fluid of Al_2O_3/synthetic oil. The relative exergy efficiency enhanced about 19% by applying nanoparticles with 5% volume fraction. Shafiey and Zamani [14] used MgO nanofluids on a heat pipe solar collector to increase the thermal efficiency. The results showed increasing in the thermal efficiency as increased of mass flow rate inside the collector and heat transfer coefficient of solar collector improved using nanofluids in place of the base fluids. Korres et al. [15] used Syltherm 800/CuO with 5% nanoparticle concentration as working fluid and evaluated the thermal efficiency of a parabolic trough solar collector. The heat transfer coefficient of the medium improved by 16.16%. Yu et al. [16] used a steel plate receiver to study the concentrated solar heat flux and the distributions of temperature experimentally and compared the results with numerical outcomes by using the commercial software FLUENT. Daabo et al. [17] conducted a numerical study using three different geometries of a cavity receiver conical, cylindrical and spherical solar dish collectors and concluded that the maximum useful was the conical one compering with others. It is observed from the literature review that performance of parabolic dish collector (PDC) is mainly depend on the solar radiation, rim angle, receiver tube, location on the earth, working fluid and material of elements.

PARABOLIC DISH COLLECTOR

Parabolic dish collector (PDC) is a heat exchanging type of technology that converts solar energy into thermal energy that helps to produce steam to generate electricity or hot water based on the area of application. It consists mainly of two parts, a reflector, basically a metal sheet or a mirror that curved as parabola with specified dimensions and a receiver tank. Metal sheet or mirror is used to accumulate solar energy and concentrates towards the focal line of reflector. A receiver tank is localized at the focal line of reflector which contains a heat transfer media. In this system, receiver tube takes direct solar radiations on its upper surface and concentrated radiations on its lower surface.

Geometric Parameters

Some of geometric parameters include diameter,, concentration ratio, aperture angle and the collector are shown in Fig.1. All these parameters are numerically related to each other. Rim angle focal length, concentration ratio, aperture width, aperture area and effective aperture area of (PDC) can be calculated by the following equations [18].

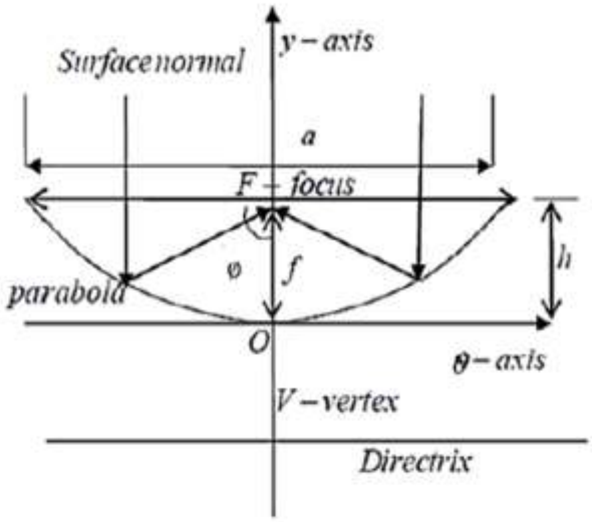

Figure 1. Dimensions and geometry of the solar collector parabolic dish.

• Rim angle (ϕ): It is the angle between the optical axis and the line between focal point and collector rim. It is calculated by using the following relation [18]:

$$\phi = \tan^{-1}\left[\frac{\frac{8f}{D_{ap}}}{16\left(\frac{f}{D_{ap}}\right)^2 - 1}\right] \quad (1)$$

Where D_{ap} is dish diameter (m) and f is the focal length (m).

- Focal length (f): It is the distance between the focal point and collector rim [18].

$$f = \frac{D_{ap}^2}{16h} \quad (2)$$

Where h is parabola depth.

- Concentration ratio (C): It is the ratio of collector's aperture area and receiver's surface area [18].

$$C = \frac{A_a}{A_r} \quad (3)$$

Where A_a is aperture area (m^2) and A_r is receiver's surface area (m^2).

- Edge radius (maximum distance) (r_r) or value existing between the focal point and the paraboloid extreme [18].

$$r_r = \frac{2f}{1+\cos\phi} \quad (4)$$

EXPERIMENTAL METHODOLOGY

A parabolic dish collector (PDC) system was fabricated on the basis of the designed parameters. The specifications of experimental setup for first and second models are listed in table 1 and 2 respectively. This experimental setup consists of PDC (reflector), receiver and supporting stand. The reflector was made of nickel sheet metal and 567 pieces of mirrors which is held on a frame built from stainless steel ribs. The receiver tanks were radiator heat exchanger and cylindrical vessel localized at the focal line of reflector to receive the focused heat flux from the reflector for the two models by connecting member. The experiments on the first system (shown in Fig.2) was conducted at location in Karbala city at latitude 32.34°, longitude 44.03° and height 29m, Iraq [19]. The system is oriented manually south-west direction to track the sun rays to obtain the maximum amount of incident solar radiation. The experiments were conducted in the month of May 2018. The second system (shown in Fig.3) was conducted at location in Najaf city at latitude 31.57°, longitude 44.15° and height

50m, Iraq [19]. The system is oriented manually south-west direction to track the sun rays to obtain the maximum amount of incident solar radiation. The experiments were conducted in the month of April 2015.

Table 1. Specification of PDC for the first system.

PDC	1^{st} Model
Location of the plant	Karbala
Aperture diameter D_a	1.5m
Depth collector h	12cm
Focal length (f)	117cm
Rim angle (ϕ)	35.54^o
Aperture area (A_a)	1.767m^2
Dimensions of the receiver	$(37\times47\times4)cm^3$
Concentration ratio	399

Table 2. Specification of PDC for the second system.

PDC	2^{st} Model
Location of the plant	Najaf
Aperture diameter D_a	2m
Depth collector h	18cm
Focal length (f)	138cm
Rim angle (ϕ)	39.83^o
Aperture area (A_a)	3.141m^2
Size of the receiver	5.5 lit
Concentration ratio	128

Figure 2. Experimental setup of PDC for 1^{st} model.

Figure 3. Experimental setup of PDC for 2nd model.

Calculation of Efficiency

Thermal efficiency of collector is outlined as the ratio of the instant useful heat gained by the heat transfer fluid and the instant direct solar radiation incident (I_d) on the given aperture area (A_a) of the collector.

$$\eta = \frac{Q_u}{Q_a} \tag{5}$$

The heat gain across the receiver is:

$$Q_u = \dot{m}.C_p.(T_{out}-T_{in}) \tag{6}$$

Instantaneous incident solar beam radiation (I_d) on the given aperture area (A_a) of the collector is:

$$Q_a = A_a.I_a \tag{7}$$

Where, $\dot{m}$ is the mass flow rate (kg/s), C_p is specific heat capacity (J/kg.K), I_d is the direct solar radiation (W/m^2) from Ministry of Science and Technology, Iraq[20], T_{out} is outlet temperature, T_{in} inlet temperature through the receiver.

Table 3. Experimental uncertainties

Independent parameter (e)	Uncertainty (w)
Temperature	± 0.25˚C
Pressure drop	± 1.2pa
Diameter	±0.0007m
Length	±0.0007m

RESULTS AND DISCUSSION

Model-1

The temperature variation for nickel sheet metal reflector with radiator heat exchanger receiver tank is shown in Fig.4. It can be realized from the figure that the temperature of the water in stays constant during the work but the temperature of water in the receiver tank raises progressively until reaching the maximum value about (105^{o}C) at (11:10 am) and after opening the valve it would decrease during April. But at various time of the day for the same period of time, at (14:17 pm) the maximum temperature reached (120ºC) as shown in Fig.5. It was found for the region of the work that the temperature and the pressure of the steam raised after (12:00 pm) higher than before this time as shown in Fig.6. It can be seen for May, June and July that the temperature variation and pressure variation nearly the same as April results.

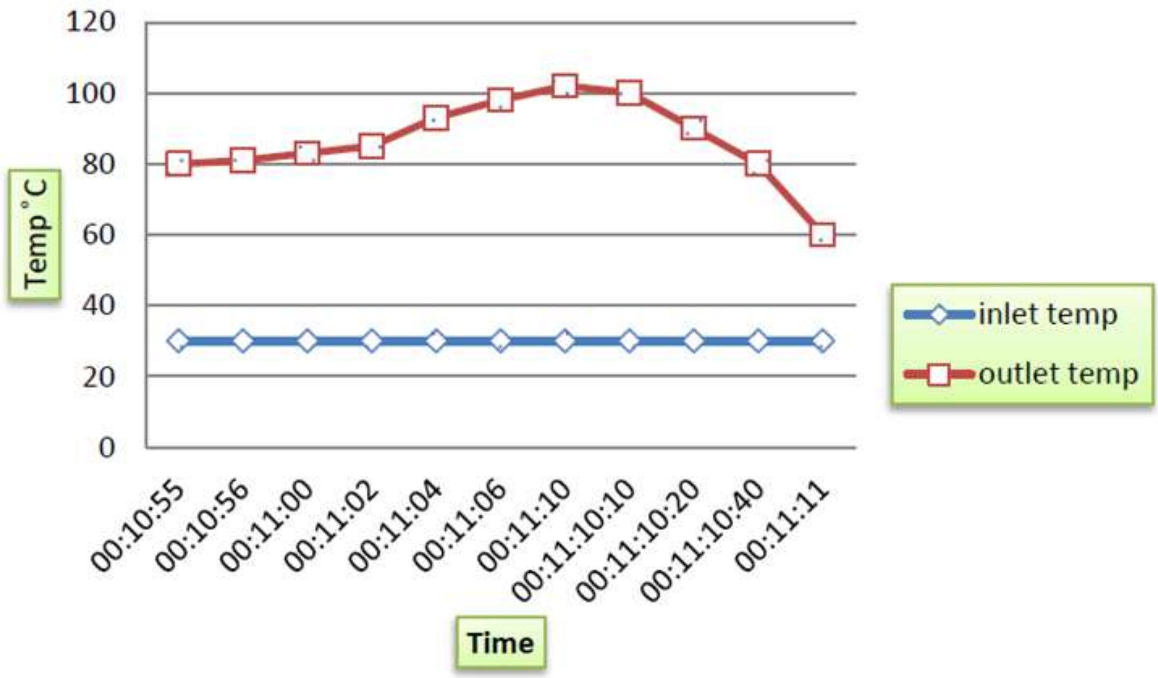

Figure 4. Temperature variation for nickel sheet metal reflector with radiator heat exchanger receiver tank for April.

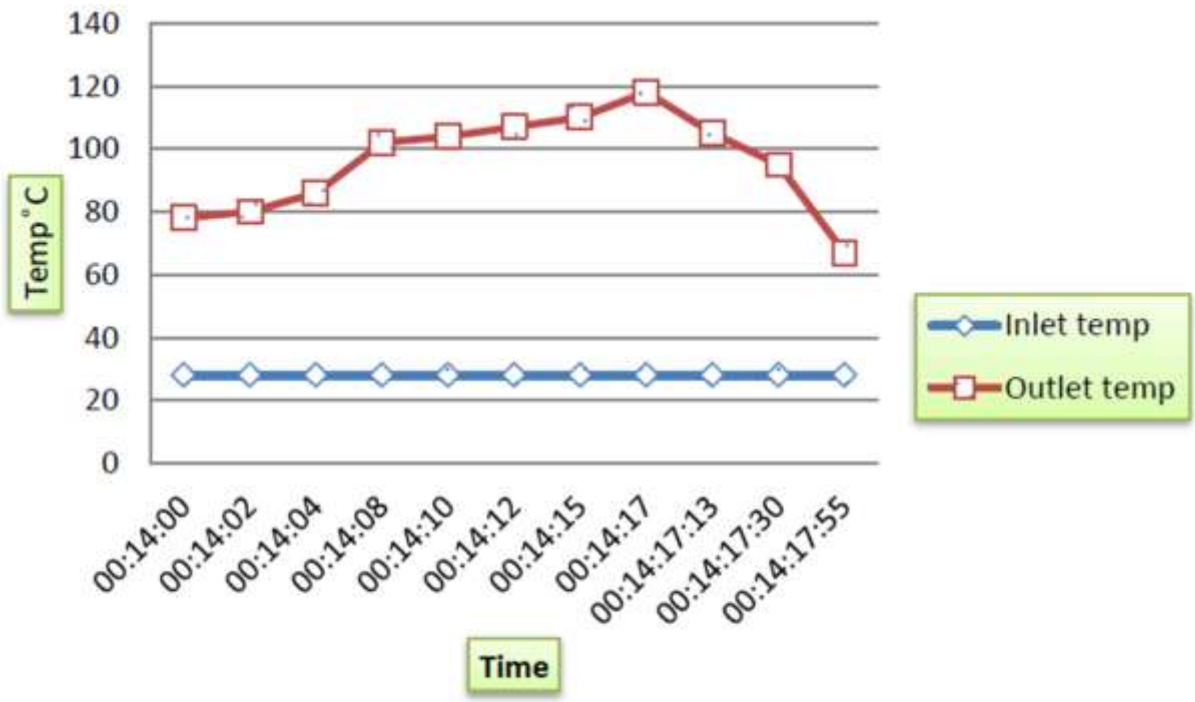

Figure 5. Temperature variation for nickel sheet metal reflector with radiator heat exchanger receiver tank for April.

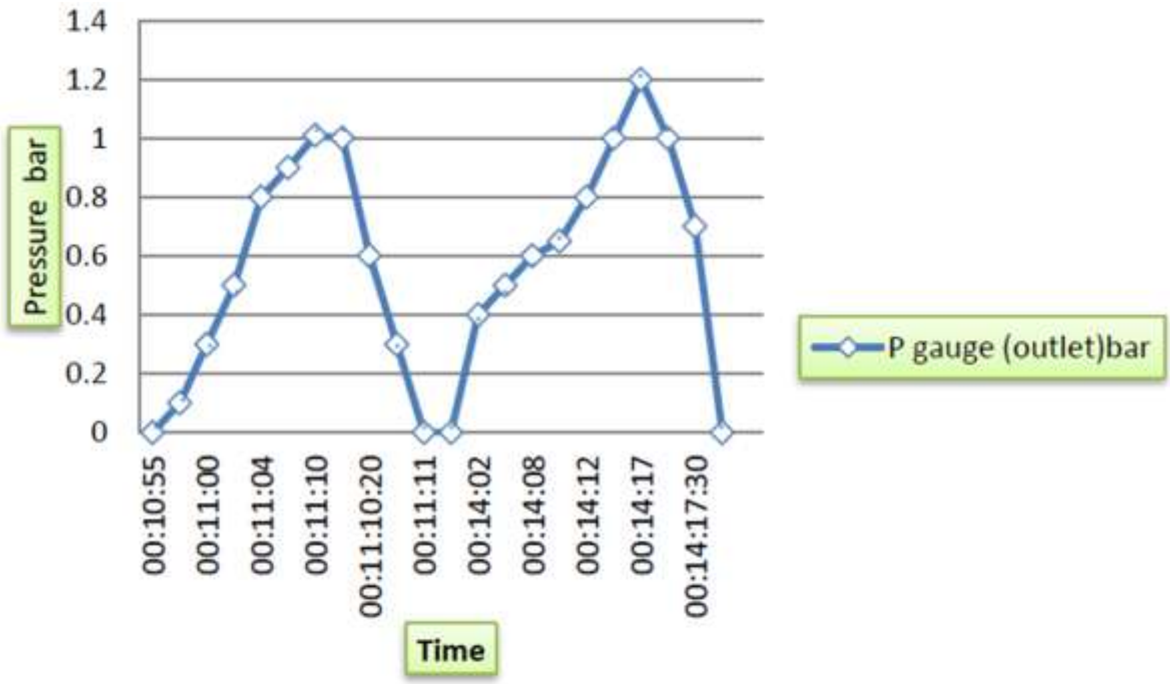

Figure 5. Pressure variation for nickel sheet metal reflector with radiator heat exchanger receiver tank for April.

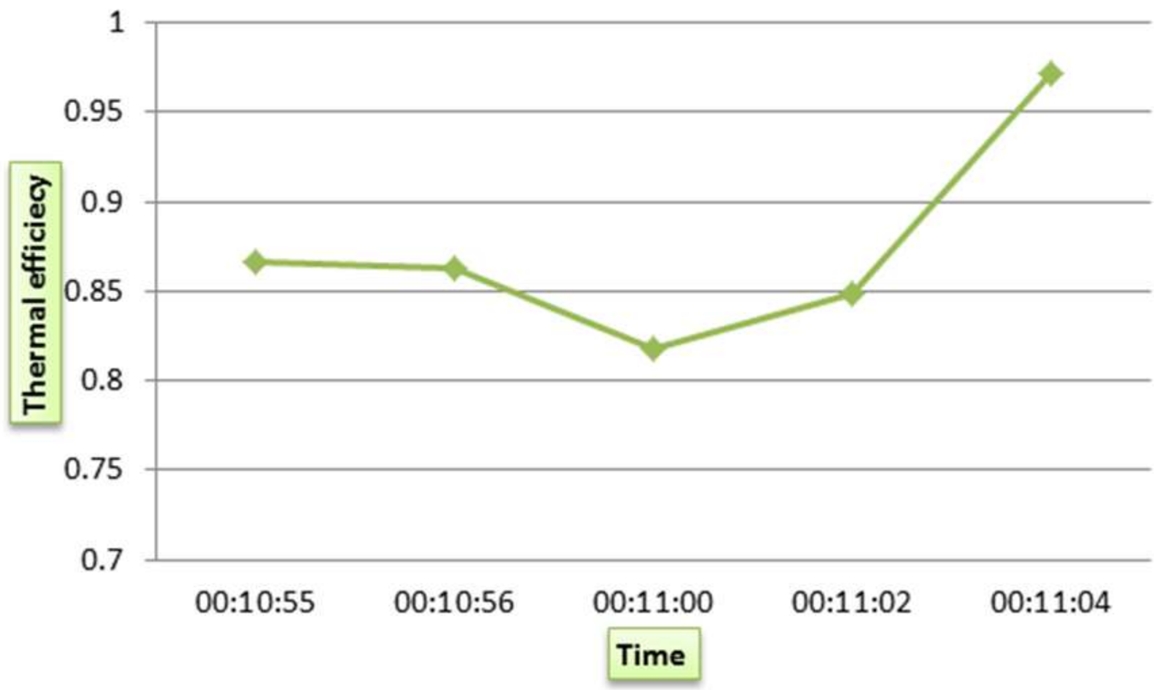

Figure 6. Thermal efficiency with time for nickel sheet metal reflector with radiator heat exchanger receiver tank for April.

Model-2

The temperature variation for mirror reflector with cylindrical vessel receiver tank is shown in Fig.7. It can be realized from the figure that the temperature of water in the receiver tank raises gradually until it reaches 130ºC at (10:00 am) and then drops after opening the valve during April. And at several time of the day, the maximum temperature reached about (110ºC) at (15:00 pm) as shown in Fig.8. It was found for the region of the work that the temperature of the focal point increased before (12:00 pm) more than after this time as shown in Fig.10. It can be seen for May, June and July that the temperature variation and pressure variation nearly the same as April results.

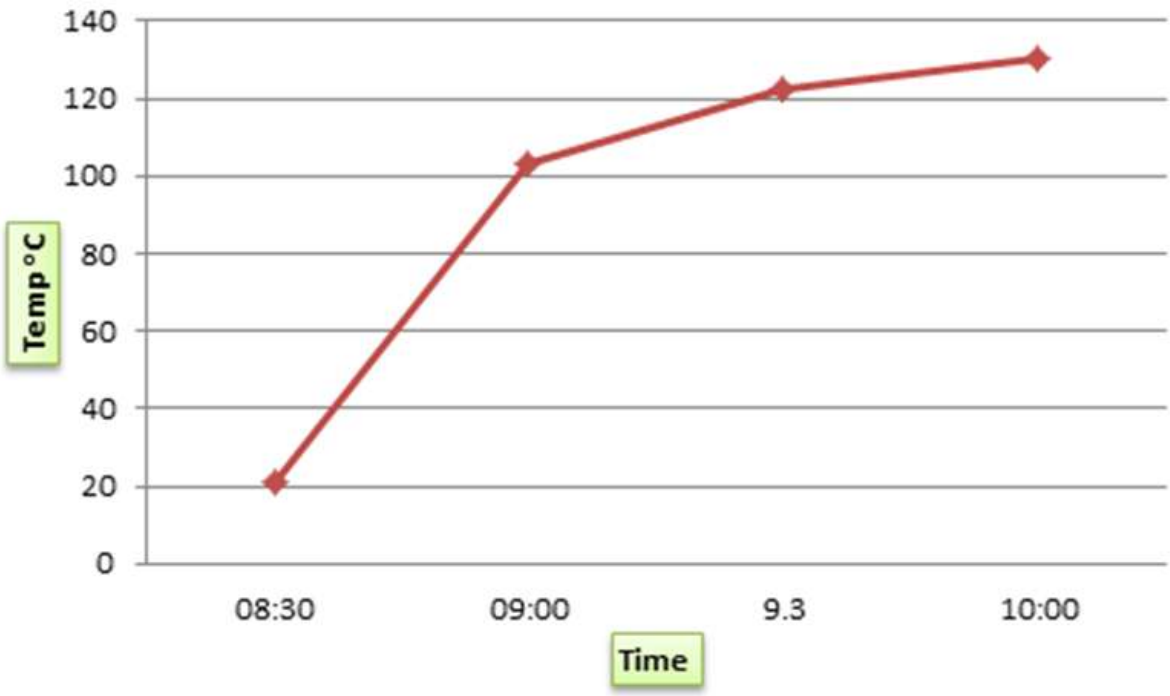

Figure 7. Outlet temperature variation for mirror reflector with cylindrical vessel receiver tank for April.

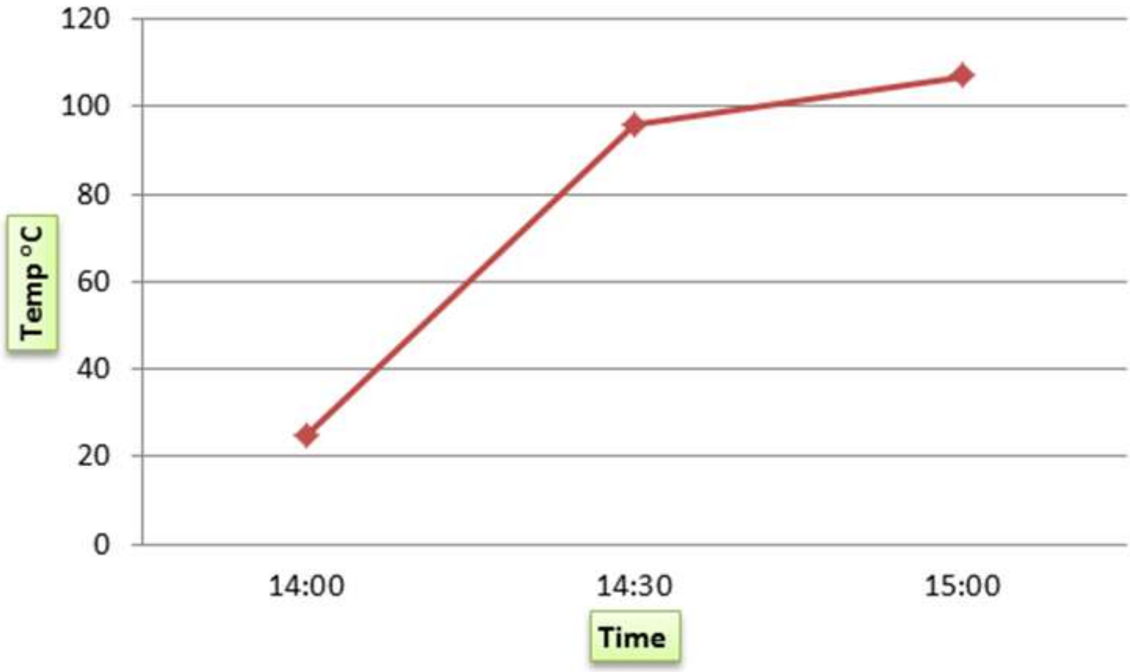

Figure 8. Outlet temperature variation for mirror reflector with cylindrical vessel receiver tank for April.

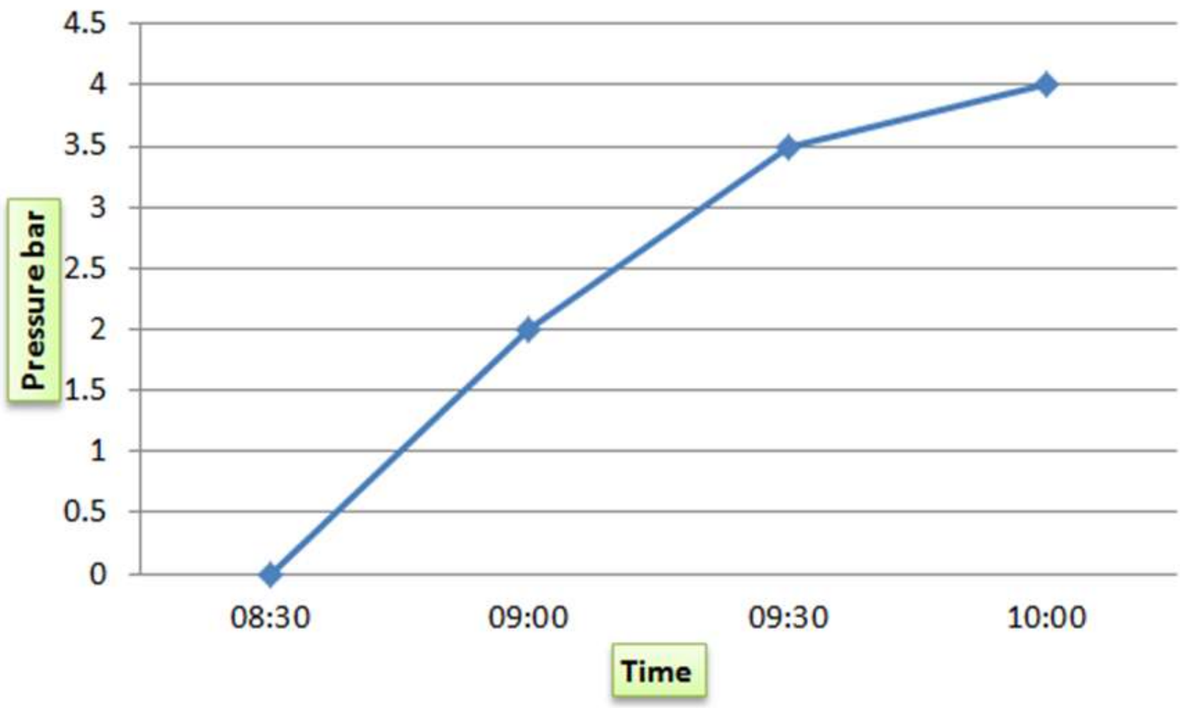

Figure 9. Pressure variation for mirror reflector with cylindrical vessel receiver tank for April.

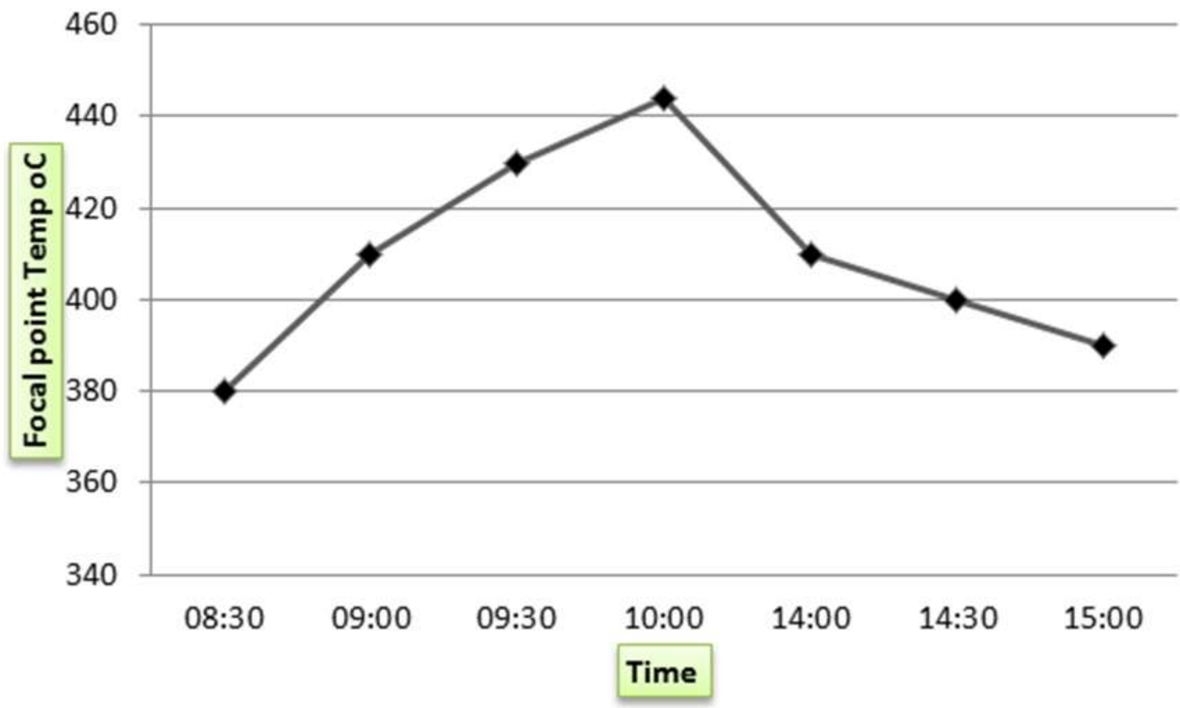

Figure 10. Focal point temperature for mirror reflector with cylindrical vessel receiver tank for April.

CONCLUSION

The experimental study was conducted on two solar parabolic dish collectors at different locations in Iraq with different reflectors and different receiver tank using water as the heat transfer fluid. The position of the focus and its distance depends on the dish diameter and the degree of inclination angle. It was observed that the operational temperature and pressure for the second model were 112%, 256% respectively comparing to the first one. The focal point temperature increased first then decreased after 12:00 pm. The mirror reflector is complex to set up on the dish and simply broken so that used metallic nickel sheet is more easily.

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