Comparing the effect of using two different reflectors on the performance of a parabolic solar concentrator for boiling water

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Abstract

In this paper, a comparison was presented between the use of two parabolic solar concentrators to boil water with the same aperture diameter (96 cm) with two different reflectors, one made of aluminum foil and the other one made of mirror pieces. The two concentrators were made using a satellite dish of the same diameter. When using aluminum foil as a reflector, it was cut into strips with a width of 10 cm and glued to the inner surface of the dish. As for the mirror pieces, they were cut into pieces (5 * 5 cm) and glued to the surface of the dish. A metal tin can with a volumetric capacity (1 liter) was used as a thermal receiver. Experiments were conducted to boil water from the roof of the house in Nasiriyah, southern Iraq. During these experiments, the optical efficiency of the parabolic solar concentrator, the amount of heat loss from the heat receiver by radiation and convection, the collector efficiency of the solar concentrator were calculated. It was concluded that the optical efficiency of the parabolic solar concentrator depends on the quality of the reflective material of the concentrating dish, the quality, and coating of the surface of the heat receiver, and the area of the reflected shade of the heat receiver on the concentrating dish. The heat losses (Qloss) from the receiver for experiments in which aluminum foil was used as a reflector (38.255, 47.365, 74.78 W), and for experiments in which mirror pieces were used as reflectors (43.32, 51.65, 36.97 W). This indicates that the thermal losses in the experiments of the mirror pieces model were greater than in the aluminum foil model. The efficiency of the collector (ηc) in the three experiments of the aluminum foil model as a reflector was (65.34, 64.4, 61.5%) and in the experiments of the mirror cut model as a reflector was (63.37, 62.33, 61.67%). Where it was noticed that the efficiency of the collector was high in the first and second experiments of the aluminum foil model with the first two experiments in the mirror cutting model due to the low thermal losses.

Keywords: solar concentrator, reflector, optical efficiency, collector efficiency.

1. Introduction:

Specialists in the study of solar energy for a long time have provided a lot of research and made many practical experiments on the topic of using solar concentrators for heating, boiling water, and producing steam, how to improve the efficiency of solar concentrators by using different types of reflectors. There has been a lot of research conducted on solar concentrators, as the idea of using solar energy to boil water and cook food is not new. The first scientist to test using sunlight to boil water was a German physicist named **Tschirnhausen (1651-1708) [1]**. Use a large lens to focus sunlight to boil water in a clay pot. After that, a lot of research was conducted on the exploitation of solar energy in water heating, and improving the efficiency of these concentrators and other important parameters.

Al-Ghazwani et al. (2009) [2] manufactured and tested a parabolic solar dish with a diameter of 220 cm, to improve thermal efficiency, reduce heat losses and achieve steam production from concentrated solar power, and this solar collector was manually tracking the sun. The sun's heat is concentrated on a black absorbent vessel placed in the focal point of the concentrated dish. The researchers found that when the beam solar intensity o was (800 W/m^2) at

noon, the useful concentration heat that could be obtained was 200 watts, and they found that the oil outlet temperature reached 50 at the beginning of the experiment. Then increase after 30 minutes until it reaches the maximum value (80℃). The average concentration ratio is about (150) and the average energy efficiency is between 40% to 77%. They concluded that this device can be used in various applications such as pasteurization and detoxification.

Babalola (2012) [3] manufactured and tested a parabolic concentration dish for boiling water. The concentrator is made of polyester resin reinforced with a fiberglass mesh and equipped with aluminum foil as a reflector. The design consists of a parabolic dish with a diameter of 246 cm, a height of 58.2 cm, and a concentration factor (54). The absorption surface area was 0.0173 m2. The objective of this device was to boil water using solar energy, and they concluded that the water was heated from (27-85 ℃) within 20 minutes, and this solar condenser can be used for domestic use for heating and boiling water.

Sagade and Shinde (2012) [4] experimentally studied the thermal performance of a concentrator dis¹ using a conical helical absorber. Dish with a diameter (140 cm) and focal length (32.2 cm) fitted with reflective material of (0.86) reflectivity, with cone-shaped helical copper receiver

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made up of copper and coated with nickel-chrome at a focal point, and the lower and upper diameters of the receiver were (13.5 cm) and (9.5 cm), respectively. The researchers concluded that the solar energy captured by the receiver increased by 41% during the day, and the average rise in heat loss was 76% compared to the increase in solar radiation and wind speed by 41% and 42%, respectively the collector instantaneous efficiency decreased by 12.3% during the day and an immediate 63.9% efficiency was achieved.

Abd al-Saad and Saad al-Din (2015) [5] studied the utilization of solar energy to produce steam using a (170 cm) diameter concentrator dish. A brass spiral absorbent with a diameter of (20 cm), a length of (3 m) and a diameter of (12.5 mm) was used. The solar radiation falls on the dish and was reflected in the absorbent vessel which contains the coil that carries the water. Solar radiation strikes the dish and is reflected in the absorbent vessel, which contained the water-carrying coil. The findings of this experiment offered a good indication of the creation of steam with a temperature of around 115.7 ℃ in a short time from a concentrated source of sunlight (in Iraq). When the length of the copper receiver coil is increased, it is also feasible to create extremely hot steam.

Veremachi et al. (2015) [6] studied the thermal performance of a parabolic concentrator with a diameter of (200 cm) and a focal length of (66.5 cm) covered with a reflective aluminum foil of (0.9) reflectivity, they use absorbent volumetric SiC honeycomb size (105 mm3). Which used atmospheric air as a heat transfer fluid experimentally. The preliminary results show that at the target temperature range, the collector efficiency remained above 70% and that the higher the mass flow rate, the lower the air exiting the collector temperature. Besides, the two flow rates gave a good collector thermal efficiency of about (70%). The results of this study show that a solar concentrator that relies on-air upon as a heat transfer fluid is feasible and workable.

Abed and Dhiab) (2017) [7] studied cylindrical parabolic solar collectors with a length (2.4 m), a width (0.8 m). The collector is equipped with a reflector made of aluminum foil to concentrate the rays on two types of copper absorption tubes with a length of 2.4 m, one of which has an outer diameter of (3 cm) and the inner (2.8 cm) painted black, the other dyed black and covered with an outer diameter glass tube (3.6 cm) and an inner vacuum tube (3.4 cm). The device was equipped with automatic tracking of the sun. The study aimed to obtain the necessary heat to heat the water and to study the thermal performance of the solar collector. The results showed that the system efficiency and the beneficial heat energy obtained with the evacuated glass tube were higher than that obtained from the copper tube and were directly proportional to the water mass flow rate and the amount of solar radiation incident on the surface.

This study aims to study the effect of changing the type of reflector on the parameters of the solar concentrator to reach the most efficient solar concentrator with a diameter of less than (1) meter for use in boiling water in environmental conditions of Nasiriyah.

2. Physical Geometry of The Parabolic Solar concentrator:

2.1 Optical Evaluation:

The parabolic collector geometry is essential for the prototype's proper operation; an error in the geometric calculation would cause the solar radiation to deviate. As a result, there will be no temperature at the focus point, which will result in low thermal efficiency.

To find the values that fulfill the design criteria, such as the diameter of a parabolic dish (d), the height of a concentrator dish (h), a dish's focal length (f), the aperture area of a dish (Aa), the rim angle of a dish (rim), and the concentration ratio, mathematical analysis was used. Figure.1 shows the analytical strategy.
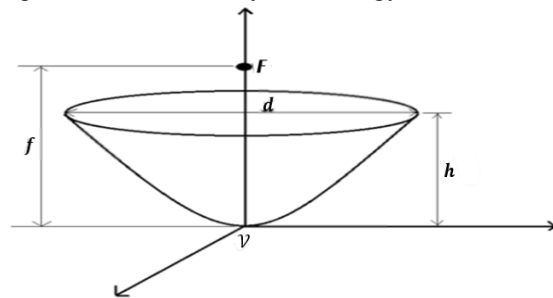

Fig.1 Geometrical parameters [8].

The equation below may be used to calculate the surface area of this parabola [2,9]:

$$S = \frac{\pi 8}{3} f^2 \left\{ [1+(\frac{d}{4f})^2]^{3/2} - 1 \right\} \tag{1}$$

Where:

(f) is the focal length

(d) is opining diameter of the dish

The aperture area of the dish is [10]:

$$A_a = \frac{\pi}{4} d^2 \tag{2}$$

The equation below is used to compute the focal length of the dish. [11]:

$$\frac{f}{d} = \frac{1}{4 \tan(\Psi rim/2)} \tag{3}$$

Where Ψ_{rim} a rim angle of the dish. Fig.2 illustrates the effect of the rim angle on the focal point location at the same diameter. The focal length is demonstrated to be reduced as the rim angle increases [12]. **Fig.1** shows the main parameters of parabolic dish geometry [11].
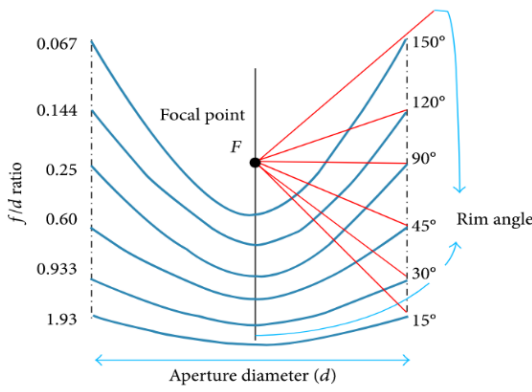
Fig.2 Relation between the focal length and the rim angle for a constant reflector diameter [13].

The following equation describes the depth of the dish [3]:

$$h = \frac{d^2}{16f} \qquad (4)$$

The set equations for parabolic solar concentrator optical behavior are discussed in this section. The two most essential factors in optical design are optical and geometrical concentration ratios. As indicated in the equation below, the first is defined as the ratio of solar heat flux over an absorber (I_{abs}) to solar flux (beam solar intensity) falling on an aperture area of a dish (I_b).:

$$C_{RO} = I_{abs}/I_b \qquad (5)$$

It is considered a true concentration ratio since it shows optical losses [14]. Because the optical concentration ratio does not show the absorber area, it is unrelated to thermal losses and efficiency.

The geometrical concentration ratio is the ratio of the aperture (A_a) to the absorber (A_{abs}) area. It influences receiver area selection, which impacts thermal losses. The equation below expresses the geometric concentration ratio. [15]:

$$C_R = A_a/A_{abs} \qquad (6)$$

Optical efficiency is defined as the ratio of radiation absorbed by the receiver (Q_{abs}) to radiation collected by the concentrator's aperture area (Q_s) [15,16]. The following equation describes the optical efficiency:

$$\eta_o = Q_{abs}/Q_s \qquad (7)$$

Where:

$$Q_S = I_b \times A_a \qquad (8)$$

Q_S : Energy captured by the reflector.

The alternative definition of optical efficiency is a combination of material reflectivity, receiver absorptivity and transmissivity, shape factor (interception factor), and the effect of solar radiation entering angle. [9,16].

which can write be in the following equation:

$$\eta_o = \lambda\rho\ \tau\alpha\boldsymbol{\gamma}\ cos\ \theta \qquad (9)$$

where λ is the factor of un-shading or shape factor [10]:

$$\lambda = \frac{Aa - At}{Aa} \qquad (10)$$

Where:

Aa : aperture area.

$At = area$ that shaded by the receiver on the concentrator

ρ is dish reflectance, $\tau\alpha$ is transmittance– absorptance product [12]

$\boldsymbol{\gamma}$ is a receiver's intercept factor, defined as the ratio of energy intercepted by the receiver to energy reflected by the concentrating dish. [17]

$$\gamma = 1 - exp[-820\left(0.7\frac{r}{f}\right)^2 (1 + cos\,\psi)\,] \quad (11)$$

For all the concentrates and receivers used in our research: $\boldsymbol{\gamma} \approx 1$

And ($\boldsymbol{\theta}$) is the angle of incidence. Because the optical axis of the solar parabolic dish concentrator is constantly pointed directly towards the sun to reflect the beam, the incidence angle of the solar beam into the dish is zero degrees, and the cosine loss is zero.

$$\eta_o = \lambda\rho\ \tau\alpha \qquad (12)$$

The reflectivity of aluminum foil which is used in this project was 0.76 And the reflectivity of pieces of the mirror was (0.70-0.84) The transmissivity–absorptivity product 0.94 for black paint [9]. the effect of incident angle can be neglected [9]. The range of the optical efficiency is between (0.85 – 0.9) for high reflective mirrors [10,18].

2.2 Thermal Evaluation:

The receiver makes use of the useful heat. The heat absorbed by water in the receiver Q_u. It may be computed by subtracting the receiver's thermal energy losses. Q_{loss} from the heat energy absorbed by the receiver wall Q_{abs} [12.17] which can be represented in the following equation:

$$Q_{abs} = \eta_{opt}\ Q_S \qquad (13)$$

The amount of useful heat that the thermal receiver exploits refer to the amount of energy transferred to a fluid

through heat transfer by passing through the receiver after subtracting the thermal losses of the receiver from the concentrated heat falling on the surface of this receiver [17]:

$$Q_{useful} = Q_{abs} - Q_{loss} \qquad (14)$$

The rate of thermal losses is divided into two types: radiation (Q_{rad}) and convection (Q_{con}) losses. Equations (17) and (15) provide the formulae for calculating these amounts [18]:

$$Q_{loss} = Q_{rad} + Q_{conv} \qquad (15)$$

$$Q_{conv} = A_{abs} \times h_{air} (T_{abs} - T_{am}) \qquad (16)$$

The heat convection coefficient between the absorber and the ambient may be calculated using the equation below [19]:

$$h_{air} = 2.8 + 3 \cdot V_{air} \qquad (17)$$

The following equation may be used to describe the radiation heat losses from the absorber surface mathematically.

$$Q_{rad} = \varepsilon_{abs}\, \sigma A_{abs} (T_{abs}^4 - T_{am}^4) \qquad (18)$$

So that, the collector efficiency of the system can be written in the following equation [17].

$$\eta_c = \frac{Q_{useful}}{Q_s} \qquad (19)$$

Q_{useful}: useful energy delivered to the working fluid.

Q_s: the energy incident on the concentrator's aperture.

3. practical modeling analysis:

The following is a list of model calculations for six tests in which two models of an analogous solar concentrator were used as shown in the device's working diagram in **Fig.3**, which were produced using satellite dishes with diameters (96 cm). For the first model, aluminum foil was pasted as a reflector with a reflectivity of 74%, In the second model, mirror pieces were pasted as a reflector with a reflectivity of 72%, and a thermal receiver with a volumetric capacity of 1 liter was used as the metal may be painted black.
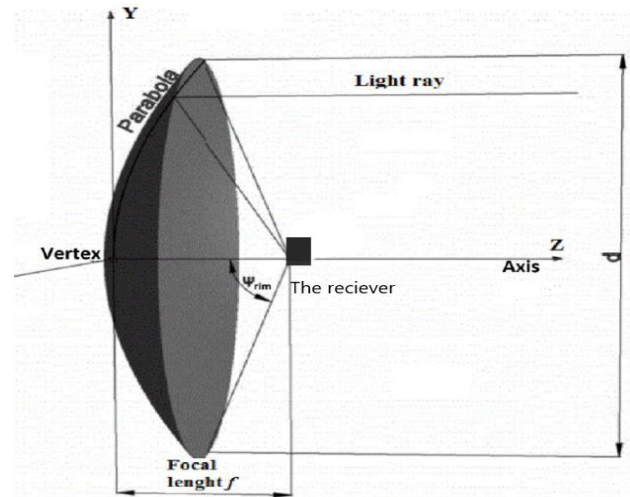

Fig. 3: Diagram of solar concentrator used.

Table 1 presents the dimensions used in the design of the two solar concentrators.

Table 1 Data and dimensions used for the design of the parabolic solar concentrator.

Data	Aluminum foil reflector model	Mirror pieces reflector model	Unit
Diameter of parabolic dish (d)	0.96	0.96	m
Depth of concentrator dish (h)	0.0.08	0.0.08	m
The focal length of a dish (f)	0.72	0.72	m
Material of parabolic dish	Galvanized steel	Galvanized steel	-
Aperture area of a dish (A_a)	0.724	0.724	m^2
Rim angle of a dish (Y_{rim})	36.87	36.87	degree
Geometric concentration ratio: $C_R = Aa/A_{abs}$	$C_R = 39.35$ $Aa = 0.724 m^2$ Ar=0.0184 m^2	$C_R = 39.35$ $Aa = 0.724 m^2$ Ar=0.0184 m^2	-
Ratio (Focal length/Diameter of the dish)	0.75	0.75	-
rim angle of the dish (Ψ)	63.32	63.32	degree
dish reflectance ρ	0.74	0.72	-

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transmittance–absorptance τα	0.97	0.97	-
The emissivity of the absorber ε	0.97	0.97	-
specific heat of water Cp_W	4.23	4.23	kJ/kg K
Stefan–Boltzmann constant σ	5:670367×10^{-8}	5:670367×10^{-8}	W/m^2

Following the theoretical study for the construction of the parabolic solar concentrator, thermal and optical analyses were supplied for two samples of experiments for each solar throughout three time periods, with the receiver capacity set at (1 liter) for all experiments and all parameters contained in the tables (5,7 and 10).

3.1 Calculations of the three experiments conducted using a parabolic solar concentrator using an aluminum foil reflector:

Table 2 Experiment data used in a concentration dish with AL-foil reflector with 1- liter receiver at (9:31 am-9:51 am).

Time	Ib (W/m²)	Tw (°C)	Tabs (°C)	Tamb (°C)	Vair (m/s)
9:31	940	10	240	22.6	0.2
9:51	973	100	310	24.6	0.2

Table 3 Experiment data used in a concentration dish with AL-foil reflector with 1- liter receiver at (12:42 pm-12:55 pm).

Time	Ib (W/m²)	Tw (°C)	Tabs (°C)	Tamb (°C)	Vair (m/s)
12:42	942	18	296	23.8	0
12:55	951	102	298	23.7	0.2

Table 4 Experiment data used in a concentration dish with AL-foil reflector with 1- liter receiver at (2:18 pm-2:31 pm)

Time	Ib (W/m²)	Tw (°C)	Tabs (°C)	Tamb (°C)	Vair (m/s)
2:18	1048	22	478	35.4	0.3
2:31	1068	101	488	32.2	0.3

Table 5 Experimental results when using a parabolic solar concentrator with an aluminum foil reflector.

Time of experiment (s)	9:31- 9:51	12:42-12:55	2:18-2:31
optical efficiency η_o (%)	70.78	71.32	71.4
Energy captured by the reflector Qs (W)	692.5	685.266	766
thermal losses Q$_{loss}$ (W	38.255	47.365	74.78
useful heat from receiver Q$_{useful}$ (W)	452.515	441.365	472.12
collector efficiency η_c (%)	65.34	64.4	61.63

3.2 Calculations of the three experiments that conducted using a parabolic solar concentrator using pieces of mirrors reflector:

Table 6 Experiment data used in a concentration dish with pieces of mirrors reflector with 1- liter receiver at (10:33 am-11:06 am).

Time	Ib (W/m²)	Tw (°C)	Tabs (°C)	Tamb (°C)	Vair (m/s)
10:33	919	21	141	26.3	0.2
10:53	919	89	152	27.1	0.2
11:06	937	100	148	27.5	0.2

Table 7 Experiment data used in a concentration dish with pieces of mirrors reflector with 1- liter receiver at (11:41 am-12:01 pm).

Time	Ib (W/m²)	Tw (°C)	Tabs (°C)	Tamb (°C)	Vair (m/s)
11:41	1080	13	168	18.4	0.3
12:01	1076	101	182	19.2	0.3

Table 8 Experiment data used in a concentration dish with pieces of mirrors reflector with 1- liter receiver at (2:48 pm-3:05 pm).

Time	Ib (W/m²)	Tw (°C)	Tabs (°C)	Tamb (°C)	Vair (m/s)
2:48	693	21	157	25.4	0.1
3:05	773	103	161	23.9	0.2

Table 9 Experimental results when using a parabolic solar concentrator with pieces of mirror reflector.

Time of experiment (s)	10:33-11:06	11:40-12:01	2:48-3:05
optical efficiency η_o (%)	69.84	68.95	68.65
Energy captured by the reflector Qs (W)	669.7	780.5	530.7
thermal losses Q$_{loss}$ (W	43.32	51.65	36.97
useful heat from receiver Q$_{useful}$ (W)	424.38	486.5	327.33
collector efficiency η_c	63.37	62.33	61.67

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(%)

4. Experimental results and discussion:

The two parabolic solar concentrators were tested in Nasiriyah, southern Iraq, at the location (31.058°N 46.2573°E) [20]. Three experiments were conducted for both solar concentrators at different times so that one experiment was before midday, another near midday, and the third experiment after midday. A (1 liter) metal tin can coat with dark black paint was used as a thermal receiver in all experiments as shown in **Fig.4** and **Fig.5**.

Fig.4 Experiments when using a parabolic solar concentrator with an Al- foil reflector.

Fig.5 Experiments when using a parabolic solar concentrator with pieces of mirror reflector.

The following outputs were calculated: the optical efficiency of the parabolic solar concentrator (opt), the power captured by the reflector (Q_s), the heat lost due to radiation and convection (Q_{loss}), the amount of heat gained (Q_{useful}), as well as the measurement of the efficiency of the concentrating solar collector (η_c). This requires recording important experiment data that we need in calculating important outputs: such as the beam solar intensity (I_b) that falls on the aperture area of the dish (A_a), which is measured with a solar meter, the temperature of the water (T_w), the receiver surface temperature at the location of the concentrated ray incidence (T_{abs}), the ambient temperature (T_{amb}), these temperatures are measured by thermocouples, as is the velocity of the ambient air around the working device (V_{air}), which is measured by an anemometer. This data is calculated and recorded every 20 minutes, and using this data to calculate the above parameters (η_{opt}, Q_s, Q_{loss}, Q_{useful}, η_c). The data from these experiments are used to draw curves showing the change of these variables during the time of heating water from its initial temperature until it reaches the boiling point.

Fig. (6-8) show that in the experiments in which a parabolic solar concentrator was used with an aluminum foil reflector, that Tw and Tabs rise with the increase in the solar beam intensity (I_b) and the accuracy of tracking the sun. It can be noted that (T_{abs}) in these three experiments is high, ranging between (240-488 °C) and this increase in the concentrating temperature is to reduce the boiling period of water, and that the time for boiling water in these three experiments is limited between (13-20 minutes) and the short boiling period of water is caused by the high beam solar intensity, which ranges between (940-1068 W/m^2) and the accuracy of sun-tracking, as for the ambient temperature It was relatively low in these experiments, as it was between (22.6-35.4 °C) and this decrease was the reason for the increase in thermal losses by convection and radiation, and the ambient air velocity was between (0-0.3 m/s) and this affects the increase in thermal losses by convection too.

Fig.6 shows that (T_w) rose from 10 °C at 9:31 am until it reached its maximum value of 100 °C as the water was boiling at 9:51 am. The solar beam intensity (I_b) rose from 940 W/m^2 at 9:31 am to 973 W/m^2 at 9:51 am. The concentrating temperature (T_{abs}) was raised from 240 °C to 310 °C to increase the beam solar intensity (I_b) and tracking accuracy. As for (T_{am}), there was a slight increase as it rose by 2 °C, and because this rise was small, the change in (T_{am}) appeared in the form of a horizontal line very close to the horizontal axis, while for the ambient air velocity (V_{air}) it was stable at (0.2) and it appeared as a horizontal line.
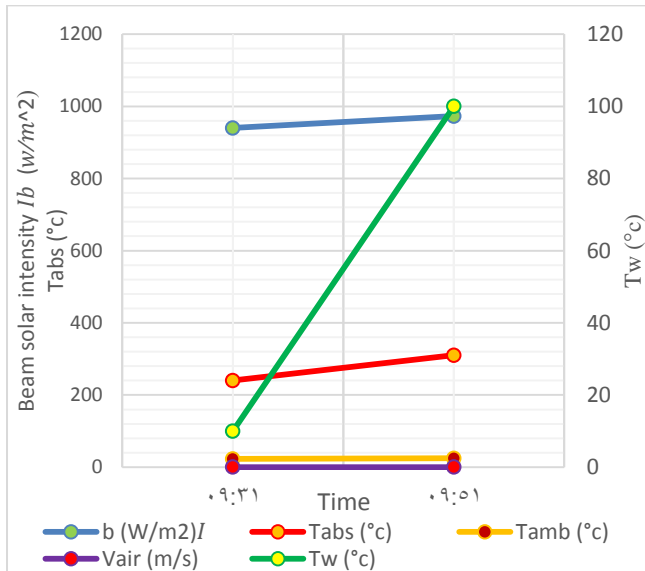
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Fig.6 The experiment using a parabolic solar concentrator with AL-foil reflector with 1- liter receiver at (9:31 am-9:51 am).

As for **Fig.7** (T_w) started to rise from 18 °C at 12:42 pm until it reached the boiling temperature at 12:55 pm. There was a slight increase in the beam solar intensity as it rose from 942 W/m^2 at (12:42 pm) until it reached 951 W/m^2 (12:55 pm). As for the concentration temperature on the surface of the absorbing receiver (T_{abs}) it was 296 °C at the beginning of heating and then it became 298 ℃ at 12:55 pm. (T_{am}) was 23.8 °C at the beginning of heating at (12:42 pm) and when boiling was 23.7 °C, so the result was that the drawing was almost a horizontal line, as for the velocity of the ambient air, it changed during the experiment period from rest at the beginning of the experiment to (0.2 m/s) when boiling at the end of the experiment.
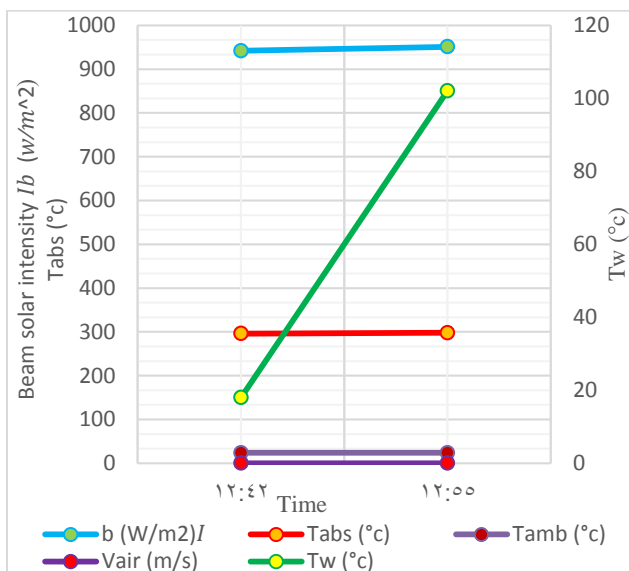

Fig.7 The experiment using a parabolic solar concentrator with AL-foil reflector with 1- liter receiver at (12:42 pm-12:55 pm).

Fig.8 shows the temperature of the water (T_w) started to rise from 22 at 2:18 pm until it reached 102 °C at 2:31 pm as the water was boiling. As the beam solar intensity was 1048 W/m^2 at the beginning of the experiment, then it increased to 1068 W/m^2 after 13 minutes, when the experiment ended. As for the (T_{abs}), it was 478 °C at the beginning at 2:18 pm and then rose to 488 ℃ at 2:31 pm at the end of the experiment, and this rise is caused by the accuracy of tracking the sun and the clarity of the sky. The ambient air temperatures (T_{am}) were close to each other at the time of measurement, as it was 35.4 °C at the beginning of heating and decreased at the boiling point to 32.2 °C, and thus the result was that the drawing was almost a horizontal line, and as the velocity of the ambient air was almost stable at (0.3 m/s) during the experiment, its graph appears as a horizontal line close to the horizontal axis.
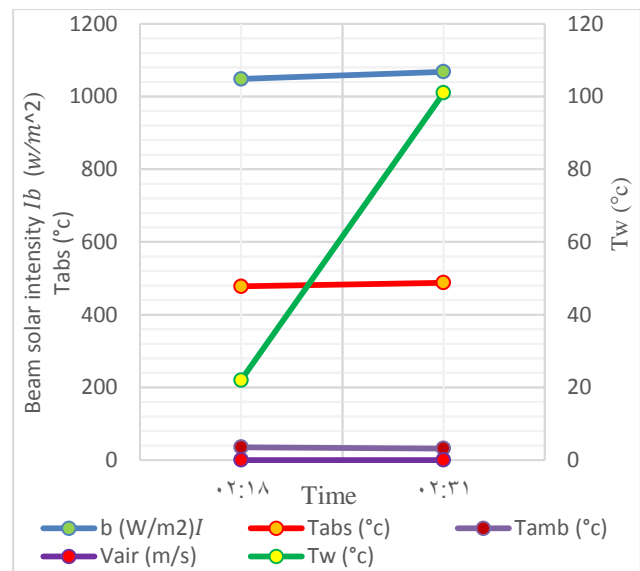

Fig.8 The experiment using a parabolic solar concentrator with AL-foil reflector with 1- liter receiver at (2:18 pm-2:31 pm).

Fig.(9-11) when using a parabolic solar concentrator with pieces of mirror reflector shows that (T_w) and (T_{abs}) increase with the increase in the beam solar intensity (I_b) and the accuracy of tracking the sun, as well as the time for water boiling decreases with the increase in the beam solar intensity and the accuracy of the parabolic dish orientation towards the sun, a decrease in the ambient air temperature leads to an increase in thermal losses, as well as an increase in the speed of air movement surrounding the solar center leads to an increase in thermal losses also through convection.

Fig.9 shows the water temperature (T_w) began to rise from 21 °C at 10:33 am until it reached 89 °C at 10:53 am, and

then continued to rise until it reached the boiling point at 11.06 am. The beam solar intensity was 919 W/m^2 at 10:33 am and remained at the same value until it began to rise after 10:53 am until it reached the highest value at boiling 937 W/m^2 at 11:06 am due to the inaccuracy of tracking the sun. As for the concentration temperature (T$_{abs}$), it was 141 °C at the beginning at 10:33 am and rose until it reached 152 °C at 10:53 am, then it began to decrease until it reached 148 °C due to the inaccuracy of tracking the sun. The ambient air temperature was close to each other at the time of measurement, as it was 26.3 °C at the beginning of heating and at the boiling point ambient air temperature was 27.5 °C, so the result was that the graph was almost a horizontal line, and the velocity of the ambient air was constant at (0.2 m/s), and its graph appeared in the form of a horizontal line close to the horizontal axis.
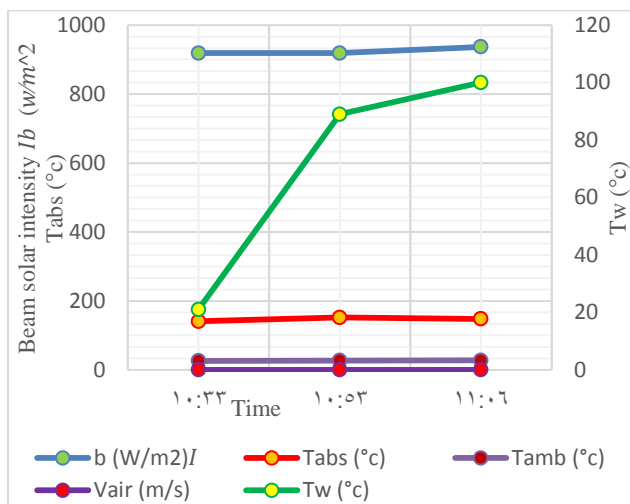

Fig.9 The experiment using a parabolic solar concentrator with pieces of mirror reflector with 1- liter receiver at (10:33 am-11:06 am).

Fig.10 (T$_w$) started to rise from 13°C at 11:41 am until it reached its boiling point at 12:01 pm after which the water continued to boil. The beam solar intensity was 1080 W/m^2 at (11:41 am) until it reached 1076 W/m^2 at (12:01 pm), and this decrease in the beam solar intensity was a result of the inaccuracy of tracking the sun. The temperature of the concentration temperature (T$_{abs}$) was 168 °C at the beginning of heating and then increased to 182 °C at 12:01 pm. As for the ambient air temperature (T$_{am}$) was 18.4 °C at the beginning of heating and rose slightly at the boiling point to 19.2 °C, so the result was that the graph was almost a horizontal line, as well as the case for the ambient air velocity, it remained almost constant during the experiment period at (0.3 m/s), so its graph is a horizontal line very close to the horizontal axis.
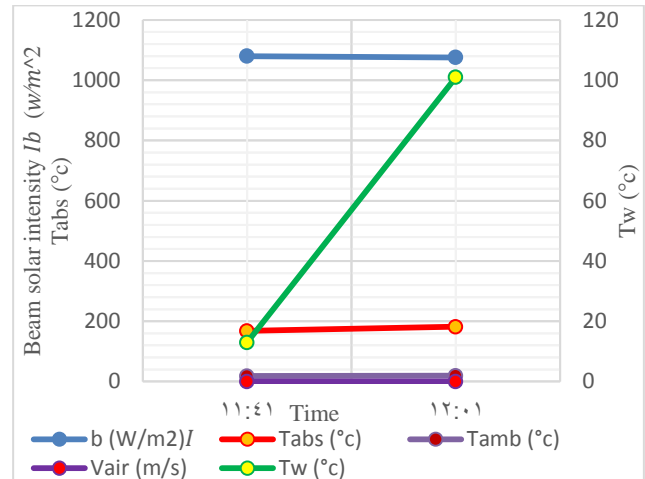

Fig.10 The experiment using a parabolic solar concentrator with pieces of mirror reflector with 1- liter receiver at (11:40 am-12:01 pm).

Fig.11 shows that the water temperature (T$_w$) started to rise from 21°C at 2:48 pm until it reached the boiling point at 3:05 pm, after which the water continued to boil. The beam solar intensity was 693 W/m^2 at (2:48 pm) until it reached 773 W/m^2 at (3:05 pm), and this change in the beam solar intensity (I$_b$) was a result of the inaccurate tracking of the sun. As for the concentration temperature at the receiver surface (T$_{abs}$) it was 157 °C at the beginning of heating, then it rose slightly to 161 °C at 3:05 pm due to the high beam solar intensity. As for the ambient air temperature (T$_{am}$) was 25.4 °C at the beginning of heating and began to decrease gradually until it reached 23.9 °C at the boiling state, so the result was that the graph was almost a horizontal line, for the ambient air velocity (V$_{air}$) it was at the beginning of the experiment at (0.1 m/s) It rose to (0.2 m/s) at the end of the experiment at 3:05 pm, so its graph is a horizontal line that was very close to the horizontal axis for being low.
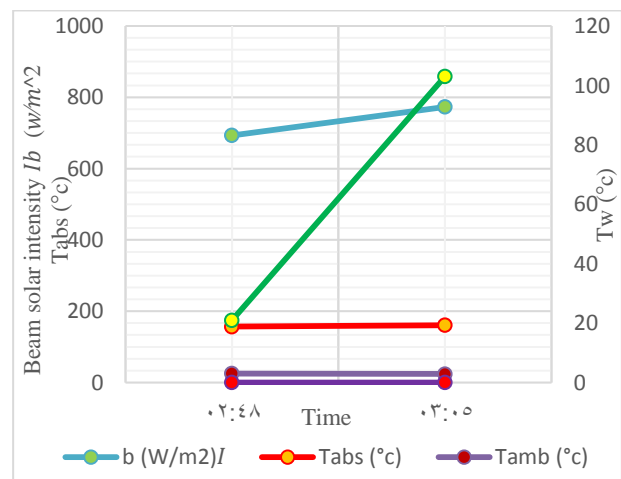
Raheem Muter Koban[†], Rafid M. Hannun [‡]

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Fig11 The experiment using a parabolic solar concentrator with pieces of mirror reflector with 1- liter receiver at(2:48 pm-3:05 pm)

By discussing the parameters obtained from the six experiments listed in table 5 for the parameters of the first model (the three experiments that were conducted using the solar concentrator with a reflector of aluminum foil) and table 9 for the parameters of the second model (the three experiments that were carried out using the solar concentrator with pieces of a mirror as a reflector). The following points can be reached:

1- The optical efficiency (η_o) in the three experiments that were conducted using the aluminum foil model (70.78, 71.32, and 71.4%). The reason for the low optical efficiency in the first experiment is due to the large receiver shade reflected on the concentrating dish. The optical efficiency in the three experiments, which were conducted using the mirror pieces model, was (69.84, 68.95, and 68.65%). It is also noted that the optical efficiency in the third experiment is relatively less compared to the other two experiments in this model of experiments due to the large shade of the heat receiver reflected on the concentrator. This indicates that the optical efficiency is controlled by the quality of the reflector, the quality of the absorbing surface of the receiver, and the area of shade reflected on the surface of the focus dish.

2- As for the radiation heat captured by the concentrator aperture area (Q_s) in the experiments of the aluminum foil model, it was (692.5, 685.226, and 766 W), where the beam solar intensity was greater in the third case and the heat (Q_s) in the three experiments that were conducted using the mirror pieces model. It was (696.7, 780.5, and 530.7 W) and the reason for the difference in the amount of heat captured by the concentrator aperture area in the experiments of the mirror pieces model is due to the beam solar intensity. It is noted that this captured heat is controlled by the beam solar intensity because the area of the aperture is fixed in the two models of experiments.

3- The heat losses from the receiver (Q_{loss}) were for the aluminum foil model experiments (38.255, 47.365, and 74.78 W), and for the mirror pieces model experiments (43.32, 51.65, and 36.97 W). This indicates that the thermal losses in the experiments of the mirror pieces model were greater than they were in the first model, except for the third experiment of the first model, where the thermal losses are high due to the high concentration temperature, and from it can conclude that the high temperature of the concentration on the surface of

the receiver and the movement of the ambient air cause an increase in thermal losses from the receiver.

4- As for the useful heat that the receiver exploits for the three experiments of the aluminum foil model, it was (452.515, 441.365, and 464.576 W), and the useful heat in the three experiments that were conducted using the second model was (424.38, 486.5, and 327.33 W). The useful heat in the first and third experiments of the aluminum foil model was higher than in the mirror pieces model due to the high beam solar intensity and the decrease of heat losses. As for the second experiment of the mirror pieces model, it was higher than in the aluminum foil model due to the high intensity of solar radiation.

5- The collector efficiency (η_c) in the three experiments of the aluminum foil model was (65.34, 64.4, and 61.5%) and in the experiments of the mirror pieces model it was (63.37, 62.33, and 61.67%). Where it was noted that the efficiency of the collector was high in the first and second experiments of the aluminum foil model with the first two experiments in the mirror pieces model due to the low thermal losses. While the losses were high in the third experiment of the aluminum foil model, which led to lower efficiency of the collector than in the third experiment of the mirror pieces model. The difference in the efficiency of the collector was due to the difference in the amount of heat losses.

6- The period for boiling water in the experiments of a model that uses aluminum foil as a reflector was less, as it took (20, 13, and 13 minutes), respectively, while the experiments that used mirror pieces as a reflector took (33, 20, 17 minutes), respectively, and this indicates that the type of water boils the reflector affects the boiling time.

5. Conclusions:

This research paper presented a practical study of two models of solar concentrators with a diameter of (96 cm), as these two models were designed using simple, cheap materials, and available in the local market. Water was used as a liquid prepared for boiling under the conditions of these samples from the experiments conducted in Nasiriyah city, southern Iraq. This study was characterized by the following points:

1- Working on two parabolic solar concentrators with a diameter of (96 cm) made with satellite dishes of the same diameters.

2- Using aluminum foil as a reflective material in the first model, and pieces of mirrors as a reflector in the second model, and both reflectors are available in the local market at a not high price.

3- The sun was manually tracked by rotating the concentrator dish at an angle of 20 and changing the altitude every 20 minutes with small distances.

4- Using a receiver with a capacity of (1 liter).

As a result of these findings, it was found that:

1- The optical efficiency of the solar concentrator with a reflector of aluminum foil is higher than the optical efficiency of the solar concentrator with a reflector of mirror pieces.

2- The amount of heat captured by the concentrator aperture(Qs) is not affected by the quality of the reflector, but rather depends on the diameter of the reflector, and it rises with the increase in the beam solar intensity, and the best period for using solar energy is near midday.

3- Thermal losses depend on the focal area and the conditions surrounding the solar concentrator from the ambient temperature and the speed of air movement.

4- The amount of useful heat is affected by the quality of the reflector due to its dependence on the optical efficiency, as well as affected by the thermal losses from the receiver.

5- The quality of the reflector has an impact on the collector efficiency, as its increases by improving the quality of the collector, which in turn increases the amount of captured solar heat.

6- In terms of economic cost and ease of transportation and movement, it was better to use the solar concentrator with an aluminum foil reflector.

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