Thermal Study of Three Solar Parabolic Cookers in Nasiriya City, Iraq

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Abstract: In this paper, it presents a detailed analysis of the use of the parabolic solar cooker in cooking and boiling water. Three models of parabolic solar cookers were manufactured with aperture diameter (96 cm, 120 cm, and 140 cm) made using satellite dishes of the same diameters and using glossy aluminum foil as a reflector sun ray after being cut into strips 10 cm wide and glued to the inner surface of the dish. A metal tin can (3L) was used as an absorbent receiver instead of a cooking pot. Experiments were conducted to boil water from the roof of the house in Nasiriyah City located in southern Iraq. Through this study, the optical efficiency of the three types of parabolic solar cookers with diameters (96,120, and 140 cm) was calculated, as they were (69,66%), (66.5, 66.35%), and (67.4,66.7%) respectively. The amount of heat gained for the three cookers, respectively (670.665, 556.394W), (1142.6, 1074.83 Watt), and (1535.38, 1460 Watt). The heat loss from the receiver, respectively (68.6, 70.53 W), (118.16, 140.385 W), and (112.69, 96.576 W). The collector efficiency of the three cookers (58.77, 53.32%), (56.16, 53.3%), and (60, 60%), and the cooking power of these cookers (475,875, 264.375 W), (413.8, 434.13 W).), (740.25, 691.44 W). Many tests were conducted on the specified location at the weather in Iraq during the winter season. The results of the experiments showed that the parameters of the solar cooker mentioned above mainly depend on the diameter of the concentrator dish, the quality of the reflector used, the cooking time, and the closing to midday. While the high ambient air speed leads to a decrease in the pot temperature by increasing the heat loses to the surrounding air through convection, thus greatly affected the solar cooker parameters, especially the collector efficiency and cooking power, as well as the accuracy of directing the dish towards the sun, and determining the focus accurately affected on the parameters of the solar cooker too.

Keywords: parabolic solar cookers, reflector, optical efficiency, thermal losses, collector efficiency, cooking power.

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1. Introduction

Researchers have long provided studies, research theory, and practical experience on the topic of how to improve the efficiency of solar cookers and increase their cooking power.

There is a lot of research done on solar cookers, as the idea of a solar cooker is not new, as the first scientist to test solar cooking was a German physicist called Tschirnhausen (1651-1708). Use a large lens to focus the sun's rays and boiling water in a clay pot. His experiment was published in 1767 by Swiss scientist Horace de Saussure who also discovered that wooden "hot boxes" produce enough heat to cook fruits. French scientist Ducurla improved the hot box design by adding mirrors to reflect more sunlight and an isolation box **[1]**. In 1976, Barbara Kerr and Sherry Cole developed a simple cardboard cooker powered by solar energy [2]. Later, a lot of research was done on the exploitation of solar energy in cooking and water heating, and the number of the parameters of these cookers was determined.

Khalifa et al. (1984). [2] They studied the development of safe, simple, portable, and reliable solar cookers for use during the Hajj season to Makkah, and they built and tested a new portable cooker, which does not require any tracking, and allows for cooking in the shade or indoors with heat pipes, which do not require tracking. The cooker has a sealed steam pan and an integrated collector with a reflector. The cooker has achieved satisfactory performance. Cooking times range from 60 to 90 minutes for meat dishes, and run from around 10:00 am until 4:00 pm. Where they proved the possibility of using these stoves during the Hajj.

Kumar et al. (1993) [3] experimentally studied the heat loss of a parabolic solar cooker. This cooker consisted of a parabolic reflector made of mirrors with an opening area of $0.58m^2$, and they used an aluminum cooking pot with a diameter of 0.17 m and a height of 0.065 m. It was experimentally exposed to air from a fan at a speed of (0-50) m∕s. The heat loss factor values of the inclined reflector were calculated and compared with those obtained from the reflector in the horizontal position during different air velocities. It was found that the heat losses strongly depend on the temperature of the pot water and the velocity of the ambient air, and increased with each of these parameters, and decrease with the increase in the inclination of the reflector from its horizontal position.

Ashok and Sudhir (2009) [4] proposed a new protocol for a solar cooker test. They measured other important parameters of the cooker in addition to its thermal efficiency such as its stagnation power, cost per watt delivered, the weight of the cooker, ease of handling, and beauty. They also standardized their results within the established standards so that they can be easily understood by ordinary people who want to use this cooker.

Lokeswaran and Eswaramoorthy (2012) [5] presented an experimental analysis to enhance heat transfer in a parabolic solar cooker by a porous medium. They used a parabolic dish with a diameter of 1.2 m, a focal length of 0.3 m, and a cooking pot as a compound receiver

underneath a pot 8 cm high containing a porous medium consisting of copper foil 1.5 cm long and 0.5-1 mm thick. The daily convection performance of the cooker with and without porous medium was obtained as 23% and 34%, respectively. The stagnation temperature of the receiver with the porous medium receiver was about 8 °C higher than the stagnation temperature of the normal receiver. The water temperature with the porous medium receiver was 3 and 11 °C higher than the normal receiver during the initial and final states respectively. The minimum optimum heat loss factor was 14 and 20 for the medium porous receiver and the normal receiver respectively. The optical efficiency increases rapidly until it reaches the maximum values of 61% and 57% for the porous receiver and the normal receiver respectively.

Aidan (2014) [6] constructed and evaluated a solar parabolic dish assembly suitable under Yola climatic conditions using international standard procedures for evaluating solar parabolic cookers. The optical efficiency of the collector is about 17.86%, the total heat loss coefficient is (8,896 W/m² K) and the modified cooking power measuring its performance is found to be 96.53 watts. Families can use the Yola cooker to cut back on buying other types of cooking fuels at least for their afternoon meals. This solar cooker can be used especially between the hours of 11:00 AM and 3:00 PM when the solar radiation is at its highest.

Kumara and Singh (2018) [7] designed, manufactured, and tested a parabolic solar cooker with an aperture diameter of 1.39 m, a depth of 0.45 m, and a focal length of 0.26 m. After testing, it was found that the parabolic solar cooker achieved sufficient temperature and was required to cook different types of foods. This cooker had many advantages such as ease of manufacture, low price, lightweight and better efficiency. Also, aluminum cookware and GI plates were studied and compared experimentally. It was found that the time taken to boil water in an aluminum pot was less than that taken in a GI pot.

This paper aims to calculate the optical efficiency, the amount of useful heat, thermal losses, the collector efficiency, and the cooking power using a parabolic solar cooker with three diameters (96 cm, 120 cm, and 140 cm) and the use of an aluminum foil reflector, as for the thermal receiver, metal tin can was used with capacity of 3 liters with the three cookers instead of cooking pots, they were painted with a matte black paint to increase the absorptivity of concentrated heat and reduce the emissivity.

2. Types of solar cookers:

A survey of solar cookers worldwide shows that a wide variety of cookers had been designed. However, the available designs of solar cookers fall into four main categories namely, the solar box cookers or popularly known as solar ovens, panel cookers, collector cookers, and concentrating or reflector cookers. The feature common to each design is the shiny reflective surface that directs the sun's rays onto the cooking area and dark inner walls of the cooking area and cooking vessel. Each type of

solar cooker has advantages when compared to its cooking ability, ease of construction, and safety of use [8].

3. Physical geometry of the parabolic solar cooker
3.1. Prototype Geometry

The parabolic solar cooker geometry is fundamental to guarantee the proper functioning of the prototype; an error during the geometric calculation would represent the deviation of the solar rays; consequently, the absence of temperature at the focal point, which would give way to obtaining low thermal efficiency.

To calculate the parabola, mathematical analysis was performed to find the values that satisfy the design criteria, like parabolic dish diameter (d), Depth of concentrator dish (h), Focal length of a dish (f), Aperture area of dish (Aa) Rim angle of a dish (Υrim), and concentration ratio. The scheme used for the analysis is shown in **Fig.1**.
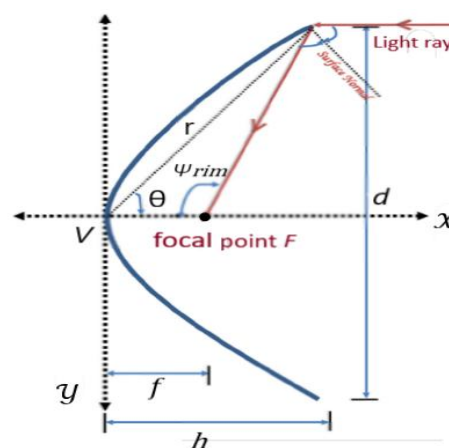
Fig.1 The parabola intersection [7].

$$y^2 = 4fx \tag{1}$$

Where f is the focal length [9].

The aperture area of the dish is [10]:

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

Where (d) is the aperture diameter of the dish

The focal length of the dish is given by the following equation [11]:

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

Where Ψ is the rim angle of the dish. The effect of the rim angle on the focal point position at the same diameter can be shown in Fig. (2). It is shown that the focal length is decreased when the rim angle increases [11].
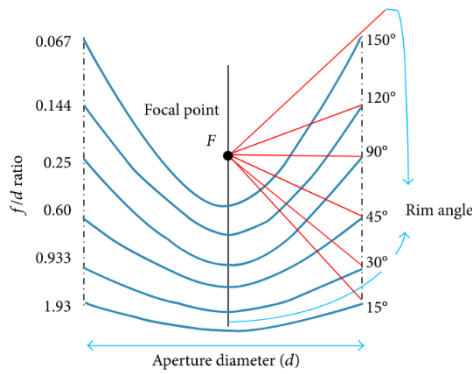
Fig.2 Relation between the focal length and the rim angle for a constant reflector diameter [12].

The depth of the dish is described by the following equation [12]:

$$h = \frac{d^2}{16f} \tag{4}$$

3.2 Optical Analysis Model:

This part of designing is specialized with set equations of the optical behavior of parabolic solar cooker (PSC). The two main parameters in optical design are optical and geometrical concentration ratios .

The first is defined as the ratio between solar heat flux over on absorber (Iabs) and solar flux (beam solar intensity) falling on an aperture area of a dish (Ib) as shown in the following equation:

$$C_{RO} = Iabs \ / \ Ib \tag{5}$$

It is considered a true concentration ratio because it indicates the optical losses [8]. The optical concentration ratio is not related to thermal losses and efficiency because not indicate the absorber area.

The geometrical concentration ratio is defined as a ratio between aperture area (Aa)to the absorber area (A_{abs}). It affects the choice of the receiver area which affects thermal losses. The geometric concentration ratio can be represented in the following equation [13]:

$$C_R = Aa / Aabs \tag{6}$$

The optical efficiency is defined as a ratio between the radiation absorbed by a receiver (Q_{abs}) to the radiation captured by the aperture area of the concentrator (Q_s) [13]. The following equation describes the optical efficiency:

$$\eta_o = \frac{Qabs}{Qs} \tag{7}$$

Where:

$$Qs = I_b \times A_a \tag{8}$$

Qs: Energy captured by the reflector.

The other definition of optical efficiency is a product of many properties of dish and absorber surface such as reflectivity of material, absorptivity and transmissivity of absorber material, shape factor (interception factor), and the effect of incident angle of solar radiation [15].

which can write be in the following equation:

$$\eta_o = \lambda \rho \ \tau \alpha \gamma \ cos \ \theta \tag{9}$$

where λ is the factor of un-shading or shape factor [15]:

$$\lambda = \frac{Aa - At}{Aa} \tag{10}$$

Where:

Aa : aperture area.

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

ρ is dish reflectance, $\tau\alpha$ is transmittance– absorptance product [14]

γ is the intercept factor of a receiver, which is defined as the ratio of the energy intercepted by the receiver to the energy reflected by the focusing device [17]

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

For all the concentrates and receivers used in our research:

$\gamma \approx ١$

And (θ) is the angle of incidence. As the solar parabolic dish concentrator maintains its optical axis always pointing directly towards the sun to reflect the beam, which means the incidence angle of the solar beam into the dish is zero degrees, and the cosine loss equals zero.

$$\eta_o = \lambda \rho \ \tau \alpha \tag{12}$$

The reflectivity of aluminum foil which is used in this project was 0.72. And The reflectivity of pieces of the mirror was (0.70-0.84) The transmissivity–absorptivity product was 0.94 for black paint [14]. the effect of incident angle can be neglected [14]. The range of the optical efficiency is between (0.85 – 0.9) for high reflective mirrors [14,19].

3.3 Thermal Analysis:

Useful heat that was exploited by the receiver Q_u is equal to the heat absorbed by the fluid in the receiver. It can be calculated by subtracting the heat energy losses of the receiver Q_{loss} from the heat energy absorbed by the receiver wall Q_{abs} [14] which can be represented in the following equation:

$$Q_{abs} = \eta_{opt}\, Q_s \tag{13}$$

Net energy is transmitted by the area catching the radiation concentrated by the reflector. The net energy for a solar thermal absorber is the amount of thermal energy leaving the absorber, which generally means the amount of energy being added to a fluid by thermal transfer through passing into the receptor or the converter that is [18]:

$$Q_{useful} = Q_{abs} - Q_{loss} \tag{14}$$

The rate of thermal losses is separated into radiation (Q_{rad}) and convection (Q_{con}) losses. Equations (17) and (15) give the formulas for estimating these quantities [20]:

$$Q_{loss} = Q_{rad} + Q_{conv} \tag{2)}$$

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

The heat convection coefficient between absorber and ambient can be calculated by the following equation [21]:

$$h_{air} = 2.8 + 3 \cdot V_{air} \tag{17}$$

A mathematical model of the radiation heat losses from the absorber surface can be described in the following equation [21].

$$Q_r = \varepsilon_{abs}\, \sigma A_{abs}\,(T_{abs}^4 - T_{am}^4) \tag{18}$$

So that, the collector efficiency of the system can be written in the following equation [22].

$$\eta_c = \frac{Qu}{Qs} \tag{19}$$

Qu: useful energy delivered to the working fluid.

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

The cooking power of the different solar cookers was calculated using the equation as follows [23]:

$$P = \frac{T_{w_2} - T_{w_1}}{t}\, m_w\, Cp_w \tag{20}$$

Where:
P = cooking power (w).
T_{w_2} = final water temperature (°C).
Tw_1 = initial water temperature (°C).
t = time(s).
m_w = mass of water (kg).
Cp $_w$: specific heat of water which can be calculated at any temperature between the rang (273.2 – 600) K by the following equation [24].

$$Cp_w = 1.7850 \times 10^{-7}\ T^3 - 1.9149 \times 10^{-4}\ T^2 + 6.7953 \times 10^{-2}\ T - 3.7559 \tag{3)}$$

Where:

$$T = \frac{Tw_1 + Tw_2}{2} \tag{22}$$

4. practical modeling analysis:

Below list of the sample calculations for several experiments in which three models of a parabolic solar cooker were used, which were manufactured using satellite dishes in diameters (96 cm, 120 cm, and 140 cm), and the reflective aluminum foil was affixed with a reflection rate of 72%, and using a receiver with a volumetric capacity of (3 liters) was a metal can paint black.

Table No. (1) displays the dimensions used in designing the parabolic solar cookers.

Table 1 Data and dimensions used for the design of the parabolic solar cooker with (d= 140 cm, 120 cm, 96 cm).

Parameter	Value			Unit
Diameter of parabolic dish (d)	1.4	1.2	0.96	m
Depth of concentrator dish (h)	0.18	0.185	0.0.08	m
Focal length of dish (f)	0.68	0.4865	0.72	m
Material of parabolic dish	Galvanized steel			
Material of the reflector	Glossy Aluminum foil			
Aperture area of dish (A_a)	1.54	1.131	0.724	m^2
Geometric concentration ratio: $C_R = {}^{Aa}/_{Aabs}$ When $Aabs = 0.03\ m^2$	51.333	37.7	24.133	-
Ratio (f / d)	0.4857	0.392	0.75	-
rim angle of the dish (Ψ)	54.47	63.32	36.87	degree
dish reflectance ρ	0.72	0.72	0.72	-
Transmittance-absorptance τα	0.97	0.97	0.97	-
Emissivity of the absorber ε	0.97	0.97	0.97	-
specific heat of water Cp_w	4.23			kJ/kg K
Stefan–Boltzmann constant σ	5:670367×10^{-8}			$W/m^2\ K^4$

After performing the theoretical analysis to construction of the parabolic solar cooker, thermal and optical analysis was provided for two samples of experiments for each solar cooker in three periods of time and the receiver capacity will be fixed at (3 liters) for all experiments, and all the parameters will be included in the tables (4,7 and 10).

4.1 The calculation of experiment conducted using parabolic solar cooker D=96 cm with 3-liter receiver:

Table 2 Experiment data used in a concentration dish (d = 96 cm) with a receiver 3 liters at a time (10: 15 am- 10: 55 am)

Time	I_b (w/	Tw (°c)	Tabs (°c)	Tamb (°c)	Vair (m/s)
10:15	911	11	384	20	0.2
10:35	928	68	324	21.6	0.1
10:55	940	101	254	22.6	0.2

Table 3 Experiment data used in a concentration dish (d = 96 cm) with a receiver 3 liters at a time (3: 40 pm-4: 40 pm)

Time	I_b (w/	Tw (°c)	Tabs (°c)	Tamb (°c)	Vair (m/s)
3:40	787	23	225	29.2	0.2
4:00	836	75	209	28.8	0.2
4:20	761	91	193	28.6	0.3
4:40	663	98	206	28.2	0.3

Table 4 Experimental results when using a solar cooker with a diameter of (96 cm).

Time of experiment (s)	10:15 - 10:55	3:40 - 4:40
optical efficiency η_o (%)	69	66
Energy captured by the reflector Qs (*W*)	670.665	556.394
thermal losses Q_{loss} (*W*	68.6	70.53
useful heat from receiver Q_{useful} (*W*)	394.16	246.69
collector efficiency η_c (%)	394.16	246.69
Cooking power (W)	475.875	264.375

4.2 The calculation of experiment conducted using parabolic solar cooker D=120 cm with 3-liter receiver:

Table 5 Experiment data used in a concentration dish (d = 120 cm) with a receiver 3 liters at a time (10: 22 am-11: 08 am).

Time	I_b(w/m2)	T_w(°c)	T_{abs}(°c)	T_{amb}(°c)	V_{air}(m/s)
10:22	983	11	341	22.1	0.2
10:42	1008	73	323	22	0.2
11:02	1020	94	326	22.3	0.2
11:08	1030	101	322	23	0.2

Table 6 Experiment data used in a concentration dish (d = 120 cm) with a receiver 3 liters at a time (14: 52 pm-15: 30 pm)

Time	I_b(w/2)	T_w(°c)	T_{abs}(°c)	T_{amb}(°c)	V_{air}(m/s)
2:52	981	23	354	31.7	0.3
3:12	954	88	357	29.8	0.6
3:30	916	101	309	30.1	0.3

Table 7 Experimental results when using a solar cooker with a diameter of (120 cm).

Time of experiment (s)	10:22- 11:08	2:52- 3:30
optical efficiency η_o (%)	66.5	66.35
Energy captured by the reflector Qs (*W*)	66.35	1074.83
thermal losses Q_{loss} (*W*	118.16	140.385
useful heat from receiver Q_{useful} (*W*)	641.6	572.765
collector efficiency η_c (%)	56.16	53.3
Cooking power (W)	413.8	434.13

4.3 The calculation of experiment conducted using parabolic solar cooker D=140 cm with 3-liter receiver:

Table 8 Experiment data used in a concentration dish (d = 140 cm) with a 3-liter receiver at a time (11: 24 am-11: 48 am)

Time	I_b (W/m^2)	T_w (°c)	T_{abs}(°c)	T_{amb} (°c)	V_{air} (m/s)
11:24	985	17	176	23.9	0.2
11:44	996	92	232	24.6	0.3
11:48	1010	101	232	24.6	0.3

Table 9 Experiment data used in a concentration dish (d = 140 cm) with a 3-liter receiver at a time (2: 18 pm -2: 44 pm).

Time	I_b (W/m^2)	T_w (°c)	T_{abs}(°c)	T_{amb} (°c)	V_{air} (m/s)
2:18	950	16	223	27.1	0.1
2:38	948	92	209	27.3	0.1
2:44	946	101	171	27.2	0.2

Table 10 Experimental results when using a solar cooker with a diameter of (140 cm).

Time of experiment (s)	11:24- 11:48	2:18- 2:44
optical efficiency η_o (%)	67.4	66.7
Energy captured by the reflector Qs (W)	1535.38	1460
thermal losses Q_{loss} (W	112.69	96.576
useful heat from receiver Q$_{useful}$ (W)	922.16	877.244
collector efficiency η_c (%)	60	60
Cooking power (W)	740.25	691.44

5. Experimental results and discussion

Parabolic solar cookers were used as shown in the sample device work diagram in **Fig. 3** were tested in Al-Nasiriyah city, southern Iraq, at a site (31.058 ° N 46.2573 ° E) [25]. Several experiments were conducted for each cooker, and for ease of use, two experiments were chosen for each solar cooker, so that one of the experiments was before noon and the other in the afternoon under a clear sky as shown in **Fig.4**.
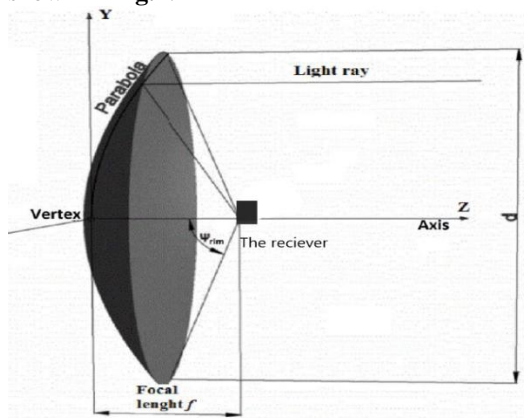
Fig. 3: Diagram of solar concentrator used.

Fig.4 experiments when used a parabolic solar cooker (d=96 cm, 120 cm, and 140 cm) with a 3-liter receiver.

The following outputs were calculated:
The optical efficiency of the solar cooker (η_o), the radiation heat captured by the aperture area of the concentrator (Q$_s$), the amount of heat lost due to the heat radiation convection (Q_{loss}), the amount of useful heat utilized by the receiver (Q$_{useful}$), the solar collector efficiency (η_c), and the cooking power (P). This requires recording the important experimental parameters that we need in computing the important outputs:
These parameters such as solar beam intensity (I_b) falling on the aperture area of the dish A_a, which is measured with a solar meter, and water temperature (T_w), the receiver temperature at the location of the focused ray (T_{abs}), the ambient temperature (T_{amb}), these temperatures are measured by thermocouples, as well as the ambient air

velocity 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 the above parameters (η_{opt}, Q_s, Q_{loss}, Q_{useful}, η_c and p) are calculated. And then draw curves that show the change of these variables during the time for heating water from its initial temperature until reaching the boiling point, as shown in **Fig. (5-10)**. Two experiments were selected for each solar cooker, one before midday n and the other after midday under a clear sky to measure the experimental data to analyze the performance of the parabolic solar cooker. Data were measured as shown in Figures (4-9, namely T_w, I_b , T_{amb}, T_{abs} and V_{air}.

The figures show that T_w and T_{abs} increase with the increase in the intensity of the solar beam radiation (I_b), as well as the time for boiling water decreases with the increase in the intensity of the solar beam radiation and the accuracy of directing the parabolic dish towards the sun, and the increase in the velocity of the movement of ambient air surrounding the solar cooker, which leads to an increase in the heat losses by convection, especially at high surface temperatures of the receiver.

When observing **Fig.5** where a parabolic solar cooker was used (d = 96 cm), where the beam solar intensity (I_b) ranged between (911 – 940 W/m^2) in the time of heating the water (10: 15 am-10: 50 am), and the concentration temperature of the receiver (T_{abs}) between (384 – 254 ℃), and the low concentration temperature indicates that the solar cooker was not accurately tracking the sun, and there was a gradual increase in the temperature of the water T_w, which rose from (11℃) at the beginning of the experiment until it reached the boiling point at (10: 55 am), as for the ambient air temperature (T_{amb}), there was a slight change as it was (20 ℃) at the beginning of the experiment and reached (22.6 ℃) at boiling, which is a small change that did not affect the boiling period and appeared in the drawing in the form of a horizontal line very close to the horizontal, as for the ambient air velocity, it was an oscillation between (0.1-0.2 m/s), which is a small change that did not affect the course of the experiment.
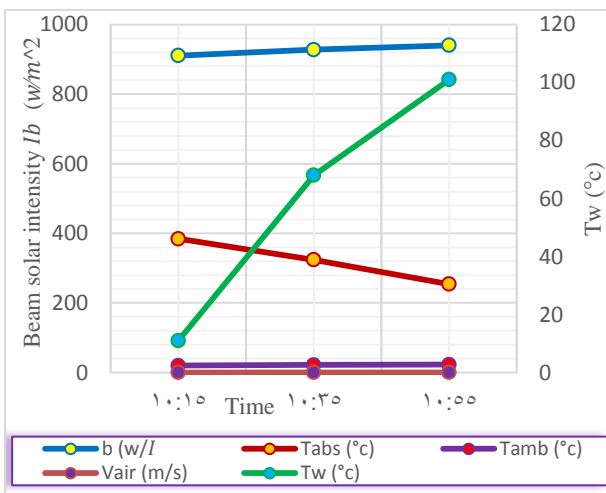
According to **Fig.6**, where a parabolic solar cooker (d = 96 cm) was used too, where the beam solar intensity (I_b) ranged between (787 – 663 W/m^2) in the time for heating the water (3: 40 pm - 4: 40 pm), and the concentration temperature of the receiver (T_{abs}) between (225 – 206 ℃), and the reduction of the concentration temperature due to the decrease in the beam solar intensity due to that the sun was not vertical at this time, and there was a gradual rise in the temperature of the water T_w, which rose from (23 ℃) at (3:40 pm) until it reached the boiling point at (4:40 pm), as for the ambient air temperature, there was a slight change as it was (29.2 ℃) at the beginning of the experiment and began to decreased slightly until it reached (28.2 ℃) at boiling, which is a small change that did not affect the boiling period and appeared in the graph as a horizontal line very close to the horizontal axis, as for the ambient air velocity, it was oscillating between (0.2-0.3 m/s), which is a small change that appeared in the form of a horizontal line almost identical on the horizontal axis.
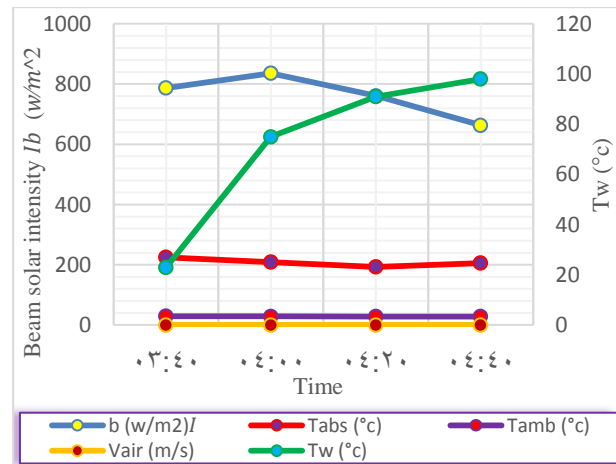
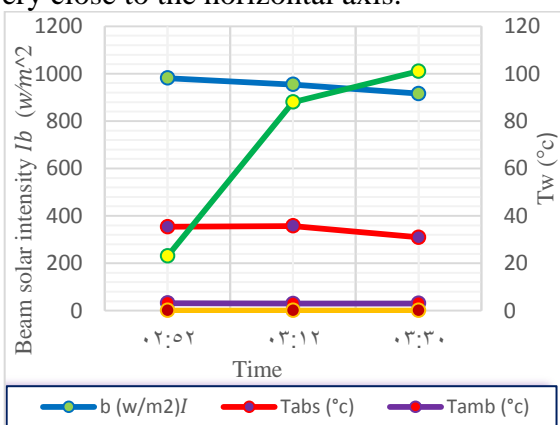**Fig.6** The experiment using a parabolic solar cooker (d=96 cm) for the period (3:40 pm- 4:40 pm).

Noting **Fig.7** here, a parabolic solar cooker was used (d = 120 cm), where the beam solar intensity (I_b) ranged between (983 – 1030 W/m^2) in the period of heating the water (10: 22 am - 11:08 am), and the concentration temperature of the receiver (T_{abs}) between (341-322 ℃), and the concentration temperature was reduced due to the decrease in the beam solar intensity due to the inaccuracy of tracking the sun, and there was a gradual rise in the water temperature T_w, as it rose from (11 ℃) at (10:22 am) until it reached (101 ℃) at (11:08 am), as for the ambient air temperature, there was a slight change as it was (22.1 ℃) at the beginning of the experiment and rose to (23 ℃) at boiling, which is a small change that did not affect the boiling period and appeared in the graph in the form of a horizontal line very close to the horizontal axis, as for the ambient air velocity, it was almost constant at (0.2), and the air velocity line appeared in the form of a horizontal line also very close to the horizontal axis.

Fig.5 The experiment using a parabolic solar cooker (d=96 cm for the period (10:15 am- 10:50 am).
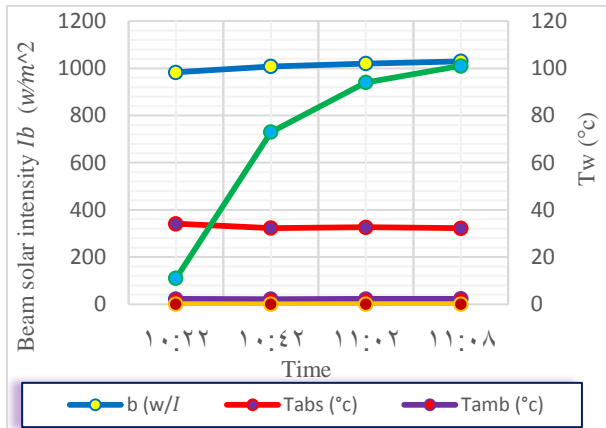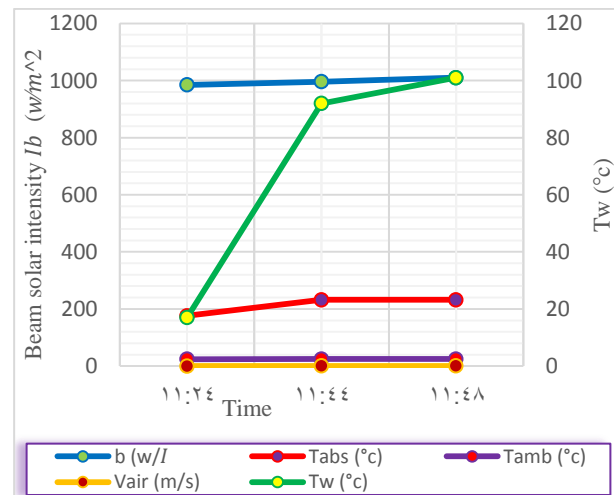
Fig.7 The experiment using parabolic solar cooker (d=120 cm) for the period (10:22 am- 11:08 am).

As for **Fig.8**, where an equivalent solar cooker (d = 120 cm) was used too, and the beam solar intensity (I_b) was between (981 – 916 W/m²) in the period of heating the water (2: 52 pm - 3:30 pm), and the concentration temperature of the receiver (T_{abs}) between (354-309 ℃), and the concentration temperature was reduced due to the decrease in the beam solar intensity due to the movement of the sun towards the horizon, and there was a gradual rise in the temperature of the water T_w, as it rose from (23 ℃) at (2:52 pm) until it reached (101 ℃) at (3:30 pm), as for the ambient air temperature, it fluctuated between (31.7 ℃) at the beginning of the experiment and decreased to (29.8 ℃) at (3:12 pm), then it rose to (30.1 ℃) at boiling, which was a small change due to the movement of air was didn't affect on the boiling period and appeared in the graph as a horizontal line very close to the horizontal axis, as for the air velocity, it fluctuated between (0.3- 0.6 m/s) and because the speed was low, the air velocity line appeared as a horizontal line also very close to the horizontal axis.

Fig.8 The experiment using a parabolic solar cooker (d=120 cm) for the period (2:52 pm- 3:30 pm).

Noting **Fig.9**, where a parabolic solar cooker (d = 140 cm) was used, and the beam solar intensity (I_b) was between (985 – 1010 W/m^2) in the time for heating the water (11: 24 am - 11:48 am), and the concentration temperature of the receiver (T_{abs}) between (176 – 232 ℃), where an increase in the concentration temperature was observed due to the high beam solar intensity, and there was a sharp rise in the water temperature (T_w), as it rose from (17 ℃) at (11:24 am) until it reached (101 ℃) at (11:48 am) due to the amount of concentrated heat applied to the receiver for a large focus area, as for the ambient air temperature, it was (23.9 ℃) at (11:24 am) at the beginning of the experiment, then it rose to (24.6 ℃) at boiling, which was a small change as a result of ambient air movement that did not affect on the boiling period and appeared in the graph as a horizontal line very close to the horizontal axis, as for the ambient air velocity it was between (0.2-0.3 m/s) and because it was low, the ambient air velocity line appeared as a horizontal line also very close to the horizontal axis.

Fig.9 The experiment using parabolic solar cooker (d=140 cm) for the period (11:24 am- 11:48 am).

Noting **Fig.10**, where a parabolic solar cooker (d = 140 cm) was used too, and the beam solar intensity (I_b) was between (950 – 946 W/m²) in the time for heating the water (2: 18 pm - 2:44 pm), and the concentration temperature of the receiver (T_{abs}) between (223 – 171 ℃), where the decrease in the concentration temperature due to the inaccuracy of tracking the sun, and there was a sharp rise in the water temperature (T_w), which rose from (16 ℃) at (2:18 pm) until it reached (101 ℃) at (2:44 pm) due to the amount of concentrated heat applied to the receiver for the large focus area of concentration, as for the ambient air temperature it was almost stable, as it was (27.1 ℃) at (2:18 pm) at the beginning of the experiment, then it became (27.2 ℃) at boiling, it was a very simple change that didn't affect on the boiling period and appeared in the graph as a horizontal line very close to the horizontal axis, as for the ambient air velocity it was between (0.1-0.2 m/s) and because it was low, the ambient air velocity line appeared as a horizontal line also very close to the horizontal axis.
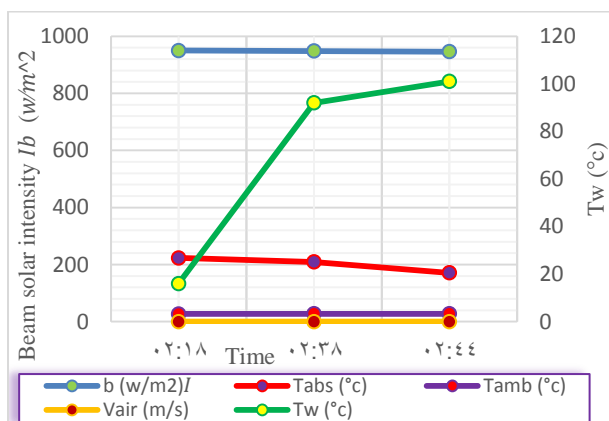
Fig.10 The experiment using parabolic solar cooker (d=140 cm) for the period (2:18 pm- 2:44 pm).

By discussing the parameters obtained from the six experiments and included in **table 4** for the parameters of the first model (the two experiments that were conducted using a solar cooker d=96 cm), and table (7) for the parameters of the second model (the two experiments that were conducted using a solar cooker d= 120 cm), and table (10) for the parameters of the third model (the two experiments that were conducted using a solar cooker with d= 140 cm). The following results can be reached:

1- The optical efficiency (η_o) in the two experiments conducted using the first model was at (69-66%). The reason for the decrease in the optical efficiency in the second experiment due to the receiver shade reflected on the concentration dish was greater. The optical efficiency in the two experiments that were conducted using the second model was (66.5-66.35%) because the receiver shade reflected on the concentration dish was approximately equal in the two experiments, and the optical efficiency in the two experiments conducted using the third model was (67.4-66.7%), the optical efficiency decreased in the second case due to the area of the receiver shade reflected on the concentration dish. This indicated that the optical efficiency is controlled by the quality of the reflector, the quality, and coating of the absorbent surface of the receiver, and the shaded area reflected on the surface of the concentrating dish.

2- As for the radiation heat captured by aperture area of the concentrator (Q_s) in the two experiments using the first model, it was (670.665 - 556.394 W), as the beam solar intensity was larger in the first case, and the heat (Q_s) in the two experiments that were conducted using the second model was (1142.6 - 1074.83 W), and the heat(Q_s) in the two experiments that were conducted using the third model (1535.38-1460 W), and the reason for the decrease in the radiation heat captured by aperture area of the concentrator in the afternoon experiments was the decrease of the beam solar intensity.

3- The heat losses from the receiver (Q_{loss}) were for the first model experiments (68.6-70.53 W), the second model experiments (118.16-140.385 W), and the third model experiments (112.69- 96.576 W). This indicates the thermal losses in the experiments of the second model were greater than in the first and third models, due to the high concentration temperature on the surface of the receiver, as well as the relative increase in the velocity of the ambient air in the experiments of the second model.

4- As for the useful heat (Q_{useful}) that the receiver was used for the two experiments using the first model was (394.16 - 246.69 W), the useful heat in the two experiments that were conducted using the second model was (641.67 - 572.765 W), and the useful heat in the two experiments that were conducted using the third model (922.16). - 877.244 W), and the reason for the reduction of the useful heat in the afternoon experiments was the decrease in the beam solar intensity and the increase in heat losses.

5- The solar collector efficiency (η_c) in the first model of experiments was (58.77 - 53.32 %), and in the second model it was (56.16 - 53.3 %), and in the third model (60 %). The difference in collector efficiency was the result of the difference in heat losses.

6- The cooking power in the first model of experiments was (475.875- 264.375 W), and it was (413.8-434.13 W) for the second model of experiments, and (740.25- 691.44 W) for the third model experiments. This difference in the cooking power was caused by the boiling time, as the shorter boiling time leads to an increase in the cooking power.

7- The boiling period of water in the two experiments in which a solar cooker with a diameter of 96 cm was used took (40-60 minutes), respectively, and the two experiments in which a cooker with a diameter of 120 cm was taken (46-42 minutes), while the two experiments in which a solar cooker with a diameter of 140 cm taken (24-26 minutes), this indicates that the diameter of the aperture of the solar cooker greatly affects the period for boiling, as the boiling time decreases as the diameter increases.

11. Conclusions:

This research paper presented a practical study of three models of the solar cooker in diameters (96 cm, 120 cm, and 140 cm), where the models of these cookers were designed using simple and cheap materials that are 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 the city of Nasiriyah, southern Iraq. This study was distinguished by the following points:

1- Working on solar cookers of diameters (96 cm, 120 cm, and 140 cm) manufactured using satellite dishes of the same diameters.

2- Using aluminum foil as a cheap reflective material available in the local market.

3- Tracking the sun was done manually by moving the concentrator dish and changing the height every 20 minutes with small distances.

4- Using a receiver with a volume capacity (3 liters).

Based on these results, it was found that:

1- The optical efficiency (η_o) of a parabolic solar cooker can be improved by using a reflective material with high reflectivity, and by using a thermal receiver with high absorptivity and low reflectivity by painted with dark, non-reflective black paint that absorbed heat, and reduced the reflection of the receiver shade on the solar concentrator.

2- The amount of the radiation heat captured by the aperture area of the concentrator (Q_s) can be increased when the diameter of the concentration dish increased and the beam solar intensity increases, and this was by using the cooking time close to midday for cooking.

3- To reduce thermal losses (Q_{loss}), the focus area should be reduced on the surface of the receiver, and this is done by using a large diameter solar cooker free of manufacturing defects, tracking the sun accurately, and insulating the thermal receiver (cooking pot) with heat-resistant glass.

4- Increasing the amount of useful heat (Q_{useful})) from which the thermal receiver used was by increasing the diameter of the concentration dish, increasing the optical efficiency, and reducing thermal losses.

5- Increasing the collector efficiency was done by increasing the useful heat, increasing the optical efficiency, and reducing the thermal losses.

6- To increase the cooking power, it was preferable to use a large solar cooker, isolate the cooking pot and carefully track the sun to reduce the cooking time.

7- In terms of economic cost and ease of transportation and movement, it was best to use a solar cooker with a diameter of less than 140 cm.

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