Evaluation Performance of a Solar Box Cooker in Baghdad

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Abstract

In this research, an experimental study was conducted on the solar box cooker manufactured with dimensions of (50*50*47cm). The solar box cooker was tested in Baghdad city from 7/4/2018 to 21/4/2018. Evaluation was carried out to test the performance of the solar cooker in two stages. The first stage included the solar cooker test in four cases through the test of the solar box cooker as fixed tracking and these two cases with and without a reflective mirror as another two cases. The results of the tests show that the best performance of the solar box cooker is when using the tracking and the reflective mirror in which the water temperature reached 109°C at 14:00 and also this test gives average water temperature during test period 81.6°C. The second stage the best case was selected (tracking solar box cooker with reflective mirror) to evaluate its performance according to the American Society of Agricultural Engineers standards. Therefore, the test of the solar box cooker was conducted with tracking and the reflective mirror for three days to reach a more accurate results in which 38 observations from those tests was selected. The results show that standardized cooking power equals to 56.09 W at a temperature difference of 50°C with $r^2 = 0.8318$.

Keywords: Performance of solar cookers, Solar box cooker, Cooking power.

Nomenclature

English symbols	Greek symbols	Subtract
a,b: Constants of the equation	γ: Surface azimuth angle (deg.)	av: Average
C_w: Water heat capacity (J/kg·°C)	ϕ: Latitude angle (deg.)	max: Maximum
I: Solar radiation intensity (W/m^2)	λ: reflective mirror angle (deg.)	i: Initial
m_w: Water mass (kg)		f: Final
P_i: Cooking power (W)		
P_s: Standardized cooking power (W)		
T_a: Ambient temperature (°C)		
T_d: Temperature difference (°C)		
T_p: absorber plate temperature (°C)		
T_w: Water temperature (°C)		

1. **Introduction**

Cooking may be a prime necessity for all folks across the planet. Thanks to fuel insufficiency or extremely big ticket fuel, change of state by renewable energy (Solar) is a very important issue and is mentioned wide within the literature. As well as the process of cooking by fossil fuels or wood affects the safety of the environment. Solar cooking provides a logical solution to this problem, although not available throughout the day [1]. A solar cooker is a device that allows to cook food using the solar energy as fuel. Solar cooker is mainly divided into three types: Box cookers, parabolic cookers and panel cookers. its many distinctions on these basic kinds exist. to boot, many large-scale solar cooking systems are developed to fulfill the wants of establishments worldwide [2]. Solar box cookers are the foremost common and cheap style of Solar cookers. These box cookers have a really easy construction and that they are product of low price materials. The outer box is usually product of wood. The inner box is created of insulation, that is covered with clear glass or with plastic, and infrequently incorporates a reflector of Al or mirror. Solar box cookers cook at moderate temperatures and infrequently will accommodate multiple pots. The solar box cooker needs direct solar radiation to operate [3]. Many researchers have studied these subjects in the past. [4] presented the design solar box cooker with low cost materials and studied the factors which effect the cooking process and the interaction of the sun energy with materials which help to introduce new materials can be chosen to build an effective solar cooking device with low cost such as cardboard, aluminum foil, and glass. This research showed the possibility of using this material to heat the water up to 72°C. Also showed that the mirror the best reflective material for solar radiation. [5] Presented a study on performance and efficiency of solar box cooker. They constructed a wooden solar box cooker with low cost and offered material. The results of this analysis showed that the very best temperature gotten each on the bottom floor and at the highest of the roof within the solar box cooker was 72°C each on the times with close temperature of 38°C and 35°C severally, additionally the results showed the potency increase with decreasing temperature distinction between collector temperature and close temperature which Increase in temperature doesn't essentially cause increase in potency wherever that potency faded with decreasing radiation. [6] Presented describes the performance analysis of a double-glazed box type solar box cooker with reflector fancied victimization domestically offered materials, compressed wood with cowl. He tested performance box-type solar cooker in keeping with the (ASAE) International check procedure and Bureau of Indian Standards (BIS). The results of this research showed that standardized cooking power at a temperature difference of 50 °C equals 23.95 W. [7] presented the experimental investigation of box type solar cooker with Fresnel lens and mirror reflector. He used a box type solar cooker having pyramid shape and mirror reflector for test, for this test are carried out as per BIS standard in two conditions. In first condition box type cooker without application of Fresnel lens and mirror reflector are used and in second condition box type cooker with application of Fresnel lens and mirror reflector. The results showed that the use of Fresnel lens and mirror reflector improves the performance of the box type solar cooker.

2. Experimental Work

According to the work requirements, the test device is a solar box cooker with its accessories as shown in figure (1), where consisting of the outer wooden box (47*50*50 cm) with (2 cm) thickness and the inner wooden box (22*39*39 cm) with (2 cm) thickness polystyrene is between them (3 cm) on the sides and (23 cm) on the bottom function as an insulation. The wooden box inside it contains the absorber plate, which is painted in black consisting of aluminum material by dimensions (21*37 cm) and thickness of plate is (1 mm), placed on the four sides of the pot, thus creating a cooking space. The cooking space covers by a glass cover with dimensions (46*46 cm) and thickness (5 mm). The cooking pot is of aluminum material with a height of (9.7cm) and radius of (20cm) and painted black it is placed in the cooking space. Add to the device as well, a panel of the mirror is used to concentrate the solar radiation on the cooking space (44*44 cm). Three thermocouples were used to measure the temperature of the water inside the cooking pot, the absorber plate temperature and the ambient temperature, also determine the wind speed and the intensity of solar radiation.

Test device was installed in Baghdad city with (ϕ = 33.3°) and was tested in four cases: fixed solar box cooker with and without reflective mirror and tracking solar box cooker with and without reflective mirror. Table (1) shows the parameters of experimental test was made in this paper.

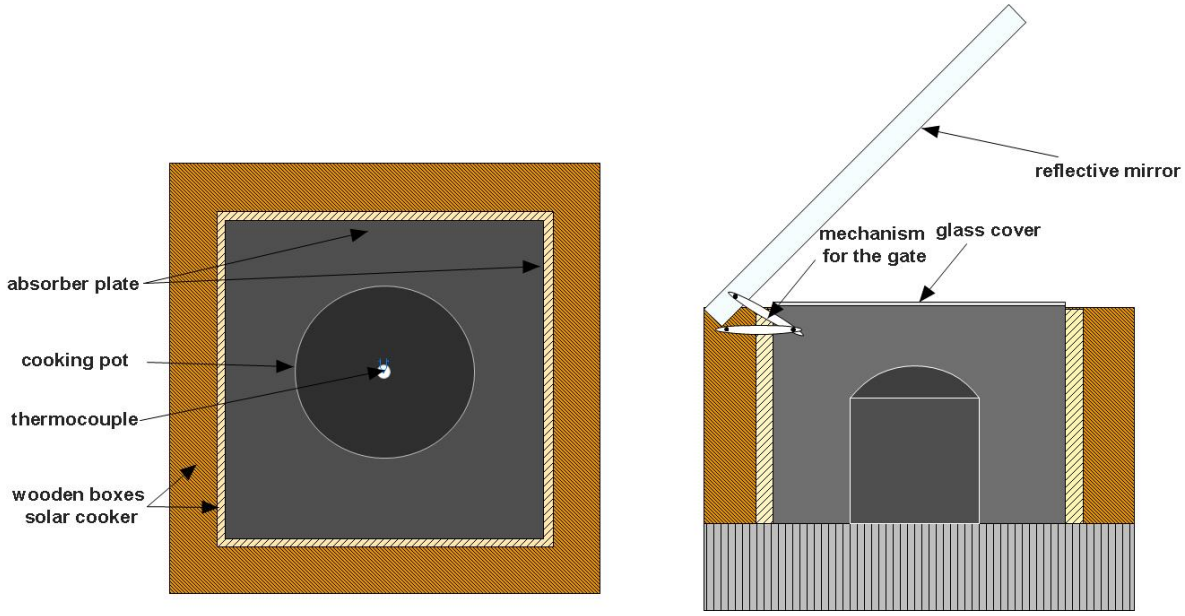

Fig.1 Diagram of the test rig

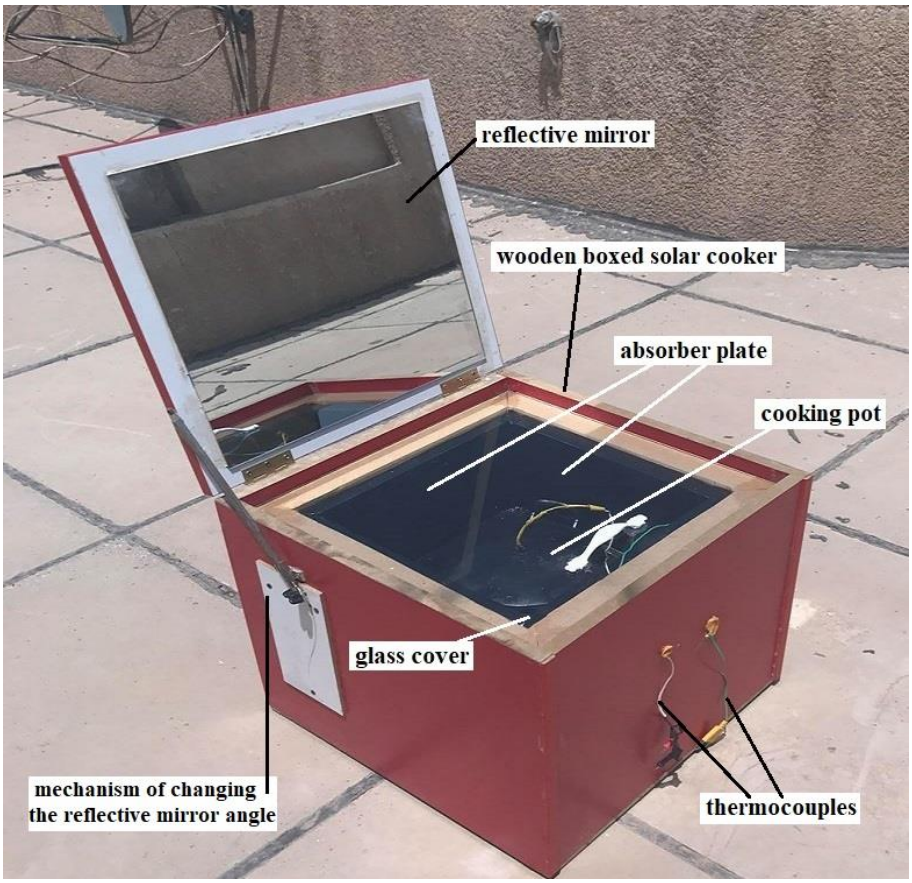

Fig.2 The test rig used in the experiment.

Table (1) the parameters of experimental test

Tests conducted between 10:00 and 14:00 solar time, and observers is recorded every 10 minutes.				
ϕ = 33.3°	**m_w = 3 kg**	**C_w = 4186 J/kg·°C**		
No.	**Test mode**	**Date**	**γ**	**λ**
first test	Fixed without reflective mirror	7.4.2018	0°	-----
second test	Fixed with reflective mirror	13.4.2018		102.8°
third test	Tracking without reflective mirror	10.4.2018	Rotate 7.5° every half hour starting from 26.25° SE and ending to 26.25° SW	-----
fourth test	Tracking with reflective mirror	19.4.2018		Variable with rotation
		20.4.2018		
		21.4.2018		

3. Experimental Procedure

3.1 The following parameters were Recorded every (10 minutes), the water temperature (°C), solar radiation (W/m^2), ambient temperature (°C), wind speed (m/s) and plate temperature (°C).

3.2 Calculating cooking power [8]: The change in water temperature for every ten-minute interval shall be product by the mass and heat capability of the water contained within the cooking pot. This product shall be divided by the 600 seconds contained during a ten-minute interval, as in equation (1):

$$P_i = m_w * C_w * \frac{T_{w)f} - T_{w)i}}{600} \dots\dots\dots\dots\dots\dots\dots\dots (1)[8, \text{eq. (1)}]$$

3.3 Standardizing cooking power [8]: Cooking power for every interval shall be corrected to a standard solar radiation of 700 W/m^2 by product the interval determined cooking power by 700 W/m^2 and dividing by the interval average radiation recorded during the corresponding interval, as in equation (2):

$$P_s = P_i * \left(\frac{700}{I_{)max)av}}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2)[8, \text{eq. (2)}]$$

3.4 Temperature difference [8]: average ambient temperature for every interval is to be subtracted from the average water temperature for every corresponding interval, as in equation (3):

$$T_d = T_{w)av} - T_{a)av} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3)[8, \text{eq. (3)}]$$

4. Results and Discussion

After recording the temperatures for the four tests were shown the behavior of each of the ambient temperature, the water temperature and the absorber plate temperature during period of the test that showing in figures (1), (2), (3) and (4).

From figures (1), (2), (3) and (4), note that gradually increase in water temperature with the increase period of the test the reason of that is the continuous incidence of the solar radiation on the box solar cooker (the cooking pot) and also because of the increase of the ambient temperature during period of the test which leads to increase in thermal storage in a cumulative way.

Also note from figures (1), (2), (3) and (4) that the increase in water temperature before 12:00 (from 10:00 to 12:00) more than the increase after 12:00 (from 12:00 to 14:00) and the reason is the decrease the solar radiation intensity afternoon and as shown in figure (5).

It's worth mentioning whenever the water temperature curve was close to the absorber plate temperature curve the utilization of solar energy is greater and the thermal losses is lower. This is manifested when the ambient temperature is relatively high and the wind speed is low.

The four tests results can be summarized in table (2), which shows the results of the four tests while figure (6) which shows the behavior of the water temperature for the four tests during period of the test and figure (7) shows the behavior of the difference between the water temperature and the ambient temperature for the four tests during period of the test. It is evident from table (2) and figures (6) and (7) that the best results are from using the reflective mirror and the sun tracking (the fourth test) in which gives higher water temperatures from the other tests. To obtain a more accurate comparison, figure (7) is

used to avoid the difference in the ambient temperature between the four tests and as noted that the use of the reflective mirror and the sun tracking is the optimum method in using solar box cooker to cooking. Also from figures (6) and (7) show the effect of using the reflective mirror is greater than the effect of the sun tracking. Noting that the black curve shows the effect of using the reflective mirror gives a higher water temperature in most of the test period than the green curve which shows the effect of the sun tracking only. After knowing the best condition and is the fourth test (using the reflective mirror and the sun tracking) it has been used in the evaluation of the performance of the solar box cooker according to ASAE standard [8] by finding the slope between the standardized cooking power (Y-axis) and the difference between average water temperature and average ambient temperature (X-axis) and extraction the equation of slop (Ps=a+b*Td) to obtain the standardized cooking power at 50 °C and also finding the coefficient of determination r2. And to obtain more accurate results the test has been done in two more days in the same method in the fourth test in which the first additional test has carried on 20/4/2018 the wind speed ranged (from 8 to 14 km/hr) and the ambient temperature ranged from 30 °C to 34 °C and the second additional test carried out on 21/4/2018 the wind speed ranged (from 12 to 15 km/hr) and the ambient temperature ranged from 27 °C to 32 °C.

In figure (8) a relation has been drawn between the unified cooking power (Y-axis) and the difference between the temperature (X-axis) and taking 12 observations from the first day and 15 observations from the second day and 11 observations from the third day to reach the sum of 38 observations (30 observations are acceptable) and as shown in table (3).

From figure (8) find that the equation of the cooking power at each temperature difference is (Ps=149.52-1.8686*Td) with r2 = 0.8318 and that is in the acceptable range (r2 above 0.75) and accordingly the Ps (50 ºC) = 56.09 W. this results illustrate that the cooker has a good reliability for cooking food and boiling water.

Table (2) Summarize results of the four tests

Type of test	Date of test	Wind speed (km/h)	T_a (ºC)	$T_{w)max}$ (ºC)	$T_{w)av}$ (ºC)
Fixed solar box cooker without reflective mirror	7-4-2018	5-10	26.1-34.5	72	55.16
Tracking solar box cooker without reflective mirror	10-4-2018	7-13	26-31	77	55.81
Fixed solar box cooker with reflective mirror	13-4-2018	6-10	29-31.5	81	59.08
Tracking solar box cooker with reflective mirror	19-4-2018	5-13	30-35	109	77.56

Table (3) The standardized cooking power and temperature difference

19.4.2018		20.4.2018		21.4.2018	
T_d (ºC)	**P_s (W)**	**T_d (ºC)**	**P_s (W)**	**T_d (ºC)**	**P_s (W)**
11	144.8893	9.5	144.9826	4.5	144.9826
17.25	112.2265	16.25	96.25769	8	143.8632
24.25	127.7922	22.75	143.8632	43	47.32511
44.5	47.21566	38	63.10015	46.5	31.59077
48	62.99426	42	63.03976	50	47.46354
52	31.5682	45.5	47.24985	53	31.70534
54.5	47.42988	48.5	47.23494	56.5	47.6705
57.5	47.52459	51.5	47.23494	61	15.93405
61	63.51651	54.5	47.32511	64	31.96959
68	31.94806	57	31.59077	66	48.12885
70.5	48.09709	59.5	47.46354	68	16.10918
73	32.19762	62	31.70534		
		64.5	47.6705		
		66.5	15.93405		
		72.5	16.10918		

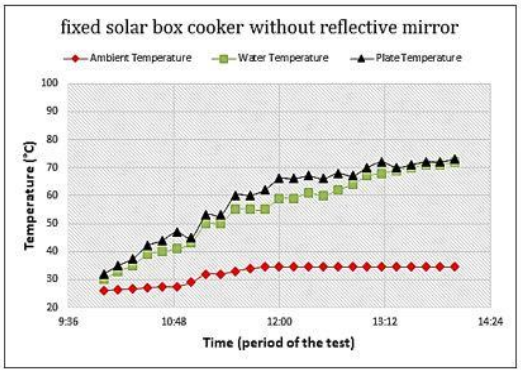

Fig.1 behavior of temp. during period of the first test.

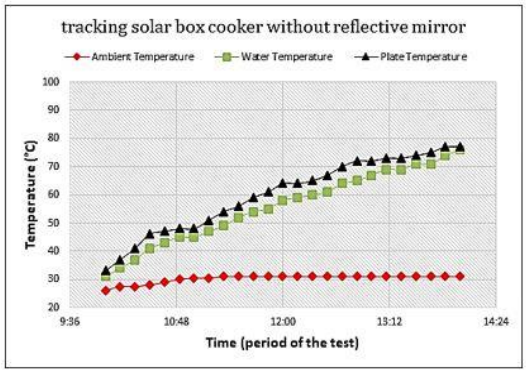

Fig.2 behavior of temp. during period of the second test.

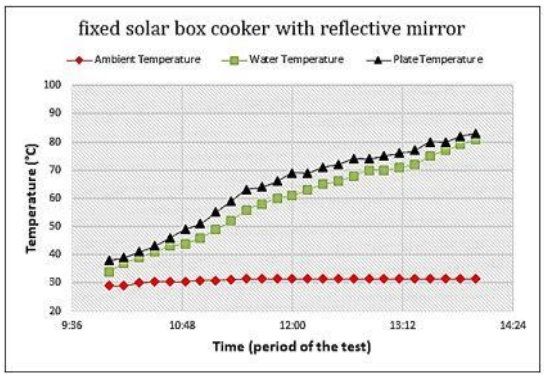

Fig.3 behavior of temp. During period of the third test.

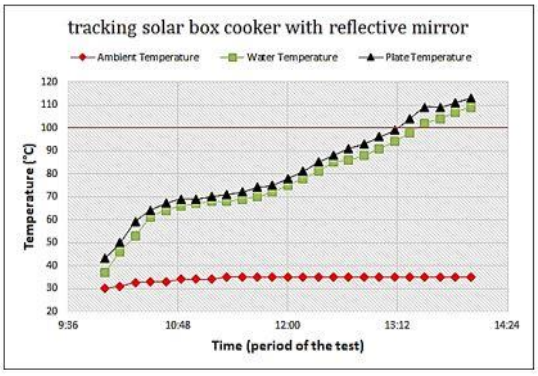

Fig.4 behavior of temp. during period of the fourth test.

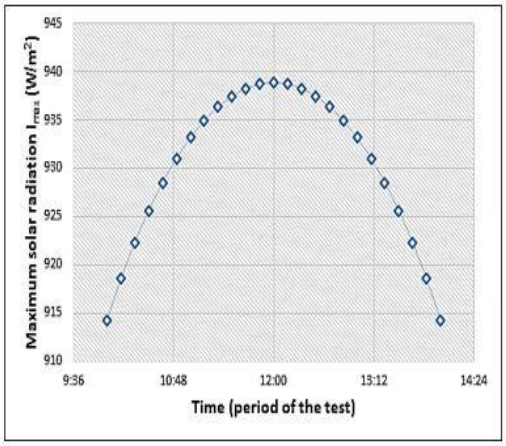

Fig.5 behavior of solar radiation during period of the first test.

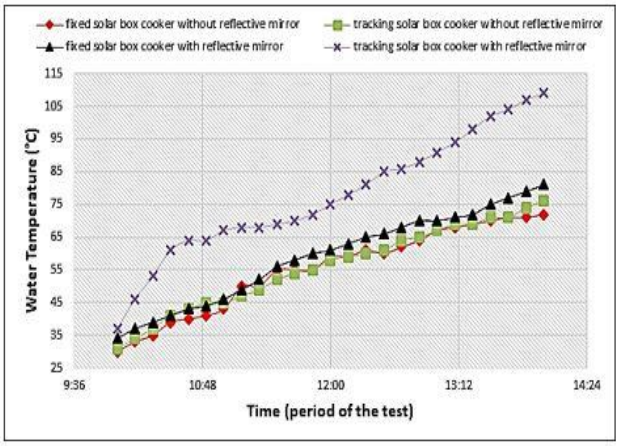

Fig.6 behavior of water temperatures during period of the test for the four tests.

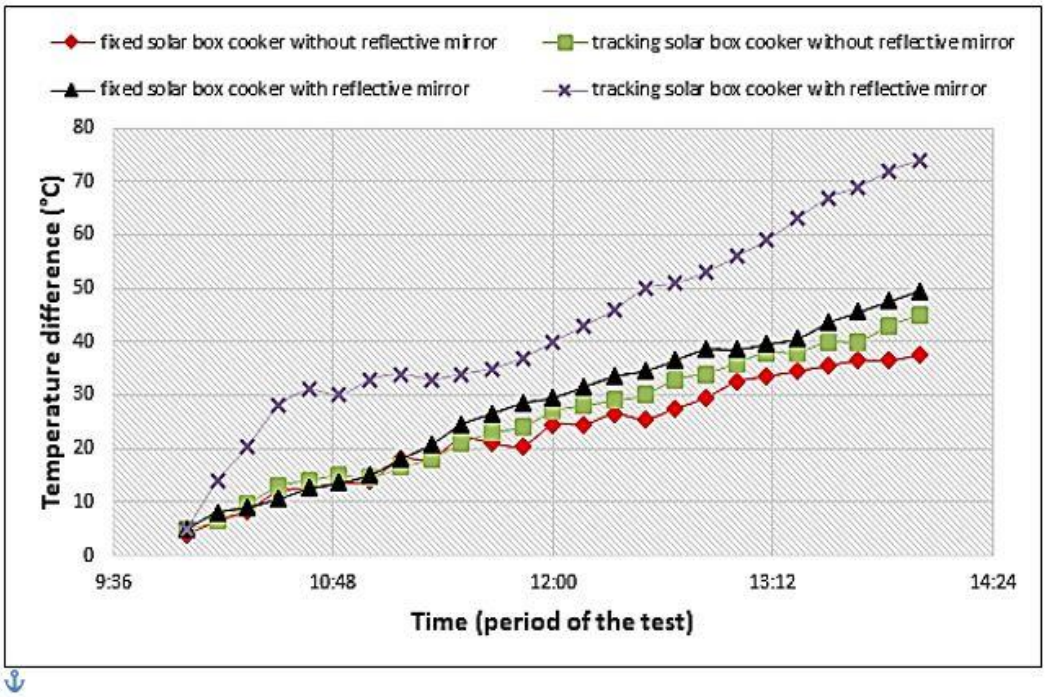

Fig.7 behavior of temperature difference during period of the test for the four tests.

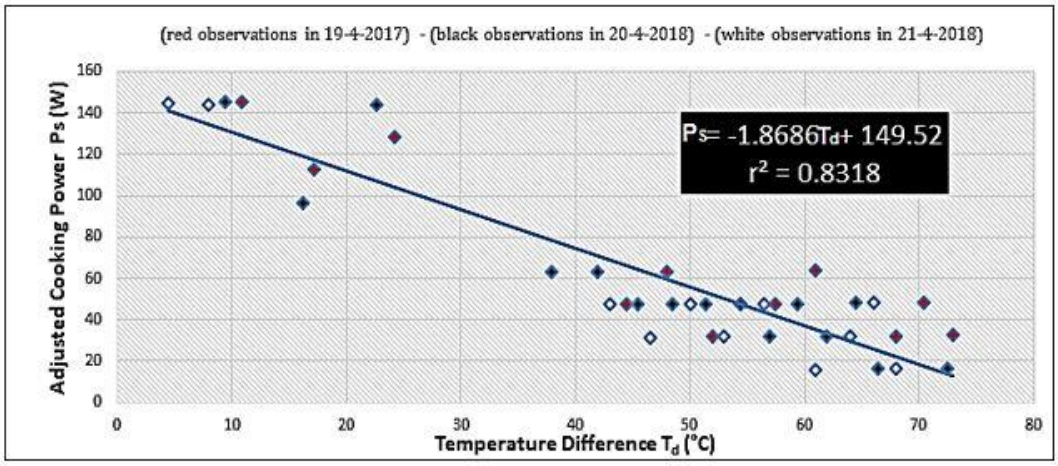

Fig.8 relationship between the standardized cooking power and temperature difference.

5. Conclusion

The wind speed, the ambient temperature, the solar radiation intensity, dust and clouds are all effecting the performance of the solar box cooker. The tracking improves the performance of the solar box cooker and whenever the tracking is more accurate (surface azimuth angle equal hour angle) the performance will increase. The reflective mirror improves the performance of the solar box cooker. The correct selection of the mirrors angle improves the performance of the solar box cooker. In the relation between (T_d & P_s) whenever r^2 is near one, the accuracy of the results will increase in ASAE standard.

CONFLICT OF INTERESTS.

- There are no conflicts of interest.

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تقييم اداء طباخ شمسي صندوقي في مدينة بغداد

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الخلاصة

في هذا البحث اجريت دراسة عملية على طباخ شمسي صندوقي تم تصنيعه بأبعاد (50x50x47 سم). وتم اختباره في مدينة بغداد في الفترة ما بين 2018/4/7 و 2018/4/21. تم اجراء تقييم اداء الطباخ الشمسي الصندوقي على مرحلتين. المرحلة الاولى تضمنت اختبار الطباخ الشمسي الصندوقي بأربع حالات من خلال اختبار الطباخ الشمسي الصندوقي بشكل ثابت ومتعقب ومع وبدون المرآة العاكسة. نتائج الاختبارات بينت ان أفضل اداء للطباخ الشمسي عند استخدام التعقب والمرآة العاكسة حيث وصلت درجة حرارة الماء الى 109 درجة مئوية عند الساعة 14:00 وبفارق 37 درجة مئوية في حالة عدم استخدام التعقب والمرآة العاكسة، وكذلك اعطى هذا الاختبار معدل درجة حرارة الماء خلال فترة الاختبار 81.6 درجة مئوية وبفارق 22.4 درجة مئوية عن معدل درجة حرارة الماء خلال فترة الاختبار في حالة عدم استخدام التعقب والمرآة العاكسة. المرحلة الثانية تم اختيار الاختبار الافضل (طباخ شمسي صندوقي متعقب مع مرآة عاكسة) لتقييم اداءه وفق المعايير المتبعة من قبل الجمعية الأمريكية للمهندسين الزراعيين. لذا تم اختبار الطباخ الشمسي بوضع متعقب مع مرآة عاكسة على مدار ثلاث ايام للوصول الى نتائج أكثر دقة حيث تم اختيار 38 قراءة من تلك الاختبارات. النتائج بينت ان قدرة الطهي الموحدة تساوي 56.09 واط عند فرق درجة حرارة 50 درجة مئوية مع معامل تحديد وصل الى 0.8318.

الكلمات الداله: – اداء الطباخ الشمسي، الطباخ الشمسي، قدرة الطهي.