THERMAL PERFORMANCE AND EVALUATION OF TWO TYPES LOW COST SOLAR COOKERS

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ABSTRACT

Solar cookers have attracted the attention of many researchers so far. Different types of solar cookers have been developed and tested all over the world. There has been a considerable interest recently in the design, development and testing of various types of solar cookers. In this study the box type of cooker was selected to apply some experimental measurements to evaluate its thermal performance. It is more commonly used than the concentrator type for cooking at noon since it is both cheaper and simpler to construct and operate. The temperature above 100 ◦C can be achieved in such a cooker. This range of temperatures is suitable for cooking by boiling. This study was constructed in faculty of agriculture, Zagazig University (2011). The obtained data showed that, the temperature of the absorber plate reached to 110 ^oC and 95 ^oC at 13:00 pm and 14:00 pm with 0.5 kg of water in the case of using carton and aluminum box types respectively. The standardized cooking power was found to be inversely proportional to temperature difference (T_w-T_{amb}). The values of η_u increased when the load increased for both types of cookers. The cost analysis indicates that using solar cooker is very economically. The hourly operational cost is about 50% of that the gas cooker.

***Keywords**: solar energy, solar cookers, carton boxes, solar thermal devices.*

INTRODUCTION

Solar cooking presents an alternative energy source for cooking. It is simple, safe and convenient way to cook food without consuming fuels, heating up the kitchen and polluting the environment. It is appropriate for millions of people around the world with scarce fuel and financial resource to pay for cooking fuel.

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Solar cookers can also be used for boiling of drinking water, providing access to safe drinking water thus preventing waterborne illnesses. Solar cookers have many advantages, on health, time and income of users and on the environment. Developing countries face a lot of problems in the energy supply. Cooking by the sun is one of the thermal solar applications that use solar radiation as an alternative source of energy instead of using the traditional sources of energy. **Hafner and Schwarzer (2000)** defined different types of solar cookers. The classification of the solar cookers was based on the type of the collector and the place of the cooking. in the case of a direct system with a flat plate collector, the cooking pot was placed directly in the collector but in the indirect system the energy was transported from the collector to the cooking place by a heat transfer medium. **Habib (2002)** presented theoretical heat balance analysis for the glass covers and the study illustrated that the outer top glass cover receives the direct beams from the sun (I_{in}). part of this energy (q_{in}) was absorbed by the top glass cover, another part reflected due to reflectivity of the glass and the rest energy transmitted through top glass cover to bottom glass cover. He also showed that the transmitted energy through double glass cover will distribute to the absorber, the vessel and as losses. Part of this energy of the absorber depends on the thermal capacity and the mass of the absorber material. **Habeebulah *et al*.(1995)** expressed the vessel receives the direct solar radiation transmitted from the glass cover of the cooker and the energy radiated and convicted from both the absorber and the sides. **Mullick *et al.* (1987)** proposed the thermal test procedure for evaluation of double-glazed box type solar cooker. In the test procedure, the need to obtain high ratio of optical efficiency to overall heat loss coefficient as a figure of merit of the solar cooker was emphasized. However, the procedure did not quantify these design parameters separately. The other design parameter, namely the heat capacity of cooker may be estimated by knowing the types of materials used their dimensions and physical properties. Since the reliable and accurate data for these materials are not always available, the use of these values may lead to erroneous results. **Ramadan *et al.*(1988)** designed a simple flat-plate solar cooker with focusing plane mirrors and energy storage capabilities constructed by the locally available materials in Tanta

University. The utilization of sensible heat storage medium such as sand was investigated thoroughly. A jacket of sand (1/2 cm thick) around the cooking pot was improved the cooker performance tremendously. The temperature differences between the heat source and the heat sink during the test time were determined. Six hour per day of cooking time has been recorded. Approximately 3 h/day of indoor cooking has been achieved. Overall energy conversion efficiency up to 28.4% has been obtained which was considered the best among other solar cookers in the literature.

The objectives of this work are: (a) Investigate two designs of solar cookers. (b) Propose a simple test procedure to determine some parameters using the experimentally obtained F_2(the second figure of merit of a box-type solar cooker as the heat exchange efficiency factor and optical efficiency) data for different load of water, (c) Apply the proposed procedure to predict the heating characteristic curves.

MATERIALS AND METHODS

This study was conducted in the faculty of agriculture, Zagazig University in August 2011. For fabrication the modification of two solar cookers. Low cost materials have been utilized and selected which are available even in the remote areas of Egypt.

Description of the two solar cookers:

1- The carton cooker in box shape: Two carton boxes - one smaller than the other, the outer is 40*45*20 cm and the inner is 34*39*20 cm. The gap between outer and inner box was filled with glass wool. Inner sides' surface was covered with aluminum foil to reflect incident solar radiation on the base of absorber plate. The glazing material (the upper cover) was commercially available 3 mm thick tempered glass, which satisfies the desirable, cover properties of high optical transmittance, low reflectivity and absorption of solar radiation. A 1.0 mm thickness iron sheet was coated black and used as a solar radiation absorber plate. This sheet has been placed on the inner carton above which the cooking pot placed. Four 65-cm-length legs were connected at the corners of the bottom of the cooker to raise the body of the cooker from the ground. The cooking pot is made of aluminum painted black, cylindrical in shape and has flat base.

It has a diameter of 14 cm and a height of 9 cm. It was placed in the center of the absorber plate inside the cooker. The box of the cooker receives the solar radiation both directly and by reflection from the three aluminum folio reflectors used. The aluminum folio reflectors were suitably fixed on a wood framework in the West, East and North sides of the cooker.

2- The aluminum cooker in cylindrical shape: The cooker made of cylindrical aluminum case 30*30*2 cm. Outer surface was coated black and used as a solar radiation absorber plate. The glazing material (the upper cover) was commercially available 3 mm thick tempered glass, which satisfies the desirable cover properties of high optical transmittance, low reflectivity and absorption of solar radiation. A 1.0 mm thickness iron sheet was coated black and used as a solar radiation absorber surface. This sheet has been placed in the case which the cooking pot placed. Four 65-cm-length legs were connected at the corners of the bottom of the cooker to raise the body of the cooker from the ground. The cooking pot and the three aluminum folio reflectors were the same in the other type. Figs. (1 and 2) show the configurations of the cookers.

The experimental procedures:

The experiments were carried out for testing two types of solar cookers under Egyptian prevailing conditions during the summer of 2011. Two types solar cookers were constructed and their thermal performance was evaluated . For this purpose, a series of experiments were performed with one cooking pot at different quantity of water in the cooking pot .The ambient temperature, absorber plate temperature, pot water temperature, inner air temperature, and the solar radiation intensity were also measured. The cooker was not loaded for the first day, and loaded with 0.5 and 1.0 liter of water for the second and third days respectively. Measurements were taken at intervals of 1.0 hour during the effective sunshine period from 10:00 a.m to 16:00 p.m. Temperature measurements were taken with calibrated thermocouples

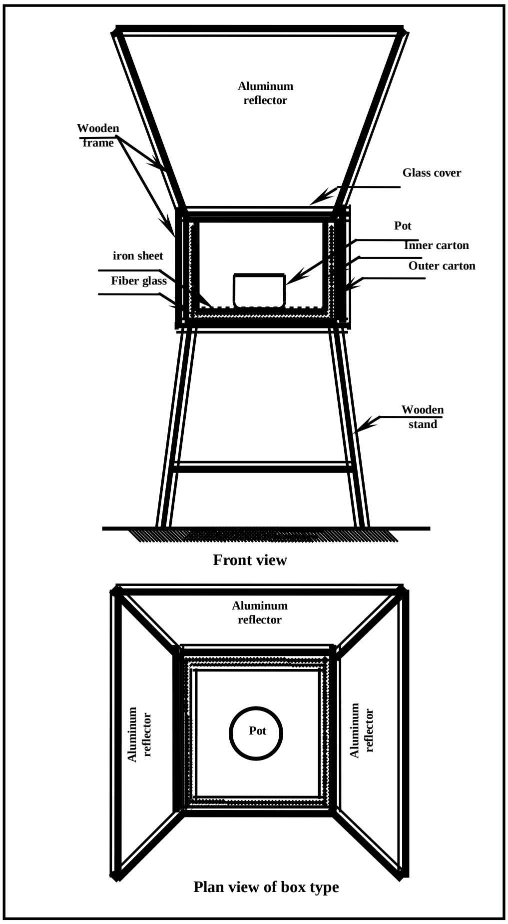


Figure (1) Front and plan view of carton cooker

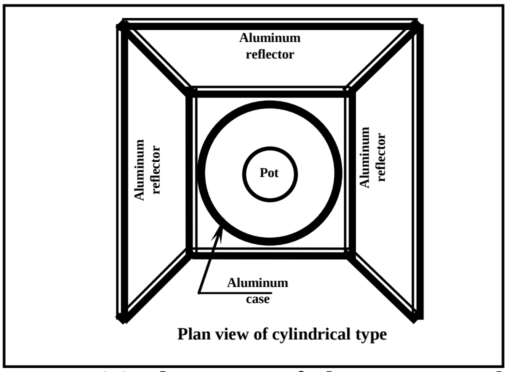


Figure (2) Plan view of aluminum cooker

connected to a multi channel digital display with an accuracy of 0.05 °C. The solar radiation intensity on horizontal surface were measured by

"Watchdog" weather station model 900 ET. The weather station measures wind speed (0-175 mph) ± 5%, wind direction (2° increments) ± 7°, temperature (-30° : 100° c), relative humidity (20-100%) ± 3%, rainfall (0.01-0.25 cm) ± 2% and solar radiation (1- 1250 W/m^2).

Measurements

Power of solar cookers:

In order to compare the two types of solar cookers, characteristic values need to be defined. The first two of these values are expressions of cooking power and efficiency.

cooking power:

The change in water temperature for each ten-minute interval shall be multiplied by the mass and specific heat capacity of the water contained in the cooking vessel. This product shall be divided by the 600 seconds contained in a ten-minute interval as: **ASAE Standards S580(2003)**

$P_i = (T_2 – T_1) m c_v /3600$, Watt

Where: P_i = cooking power (W), T_2 = final water temperature, T_1 = initial water temperature, m = water mass (kg) and c_v = specific heat capacity (4186 J/kg·K)

interval averages:

The average insolation, average ambient temperature, and average cooking vessel contents temperature shall be found for each interval.

Standardizing cooking power:

Cooking power for each interval shall be corrected to a standard insolation of 700 W/m^2 by multiplying the interval observed cooking power by 700 W/m^2 and dividing by the interval average insolation recorded during the corresponding interval.

$P_s = P_i(700/I_i)$

Where: P_s = standardized cooking power (W), P_i = interval cooking power (W) and I_i = interval average solar insolation (W/m^2).

Figures of merit: Kumer (2005) defined the first figure of merit, F_1 of a box-type solar cooker as the ratio of optical efficiency to overall heat loss coefficient which given as:

$$F_1 = \frac{F' \eta_\circ}{F' U_L} = \frac{T_{ps} - T_{as}}{I_s} \quad , m^2\ {}^oC/W$$

Where: $F'\eta_o$ and $F'U_L$: the optical efficiency and overall heat loss coefficient of the cooker, respectively, I_s and T_{as}: respectively, the insolation and ambient air temperature at the time when the plate stagnation temperature T_{ps} is reached.

Buddhi *et al.* (1999) defined the second figure of merit, F_2 of a box-type solar cooker as the heat exchange efficiency factor and optical efficiency:

$$F_2 = \frac{F_1(mc)_w}{A(t_2 - t_1)} In\left[\frac{1 - \frac{1}{F_1}\frac{(T_{w1} - T_a)}{I}}{1 - \frac{1}{F_1}\frac{(T_{w2} - T_a)}{I}}\right] \quad \text{, decimal}$$

Where :m_w : mass of water (kg), c_w: the specific heat capacity of water (J/kg^{o}C), I: average solar insolation over time period (W/m^2), A: aperture area of the cooker (m^2), T_{w1} and T_{w2}: lower and upper values of water temperature (^{o}C), respectively, (t_2-t_1): time taking from heating T_{w1} to T_{w2} (second), and T_a : the ambient air temperature, (^{o}C)

The utilization thermal Efficiency:

El-Sebaii and Ibrahim(2005) defined the utilization thermal efficiency

$$\eta_u = \frac{m_w C_w \Delta T}{I_{avg} A_c \Delta t} \quad \text{as:} \qquad \text{, decimal}$$

Where: mw, Cw are the mass (kg) and specific heat (J/kg^{o}C) of water, respectively. ΔT is the temperature difference between the maximum temperature of water and the mean ambient air temperature during the interval Δt, (^{o}C), I_{avg} is the solar intensity during the time interval (W/m^2) and A_c is the aperture area (m^2) of the cooker.

Cost analysis:

Soliman (1997) evaluated the hourly cost of the solar cooker as following equations:

1. The yearly cost: $T_c = F_c + M_c$, L.E
2. The hourly cost: $H_{o.c} = T_c/t_h$, L.E/h
3. The yearly fixed cost: $F_c = C_c/L_E$, L.E
4. The yearly maintenance cost: can be expected for the following items: glass changing and repainting.

Where: M_c: the yearly maintenance cost, (L.E), $\mathbf{t_h}$: maximum operating time, (h), C_c: constructed cost, (L.E) and L_E: expected life, (year)

RESULTS AND DISCUSSION

The obtained results of this study will be discussed under the following heading:

1- Effect of Solar Radiation and Daily Time on the Solar Cooker Temperatures Without Load:

Figure (3)and (4) show that the highest values all over the day of the solar radiation recorded from 12:00 pm to 3:00 pm were with about (800 W/m^2) .The highest temperatures in both types of the used cookers were in this period. This fact led to that the perfect period to cook using the solar cookers is from 12:00 pm to 3:00 pm.

2- Effect the Type of Cooker on the Cooker Temperatures:

The obtained results showed that in the carton type ,the absorber plate reached to 110 ^oC at 13:00 with 0.5 kg of water while in the aluminum type the absorber plate reached to 99 ^oC at 14:00 with the same load. The maximum water temperature was 100 ^oC at 13:00 with the carton type and reached to 95 ^oC at 14:00 with the other type. Figure (5) and Figure (6) showed the variations in the cookers temperatures.

3- Effect of Load on the Cooker Temperatures:

Figure (7) shows the effect of load on the cooker temperatures in the box type. It was noticed that in the carton type the maximum water temperature of 100 ^oC was obtained at 13:00 pm with 0.5 kg load and reached to 100 ^oC at 14:00 pm with 1.0 kg load, when the load increased.

4- First Figure of Merit (Stagnation Temperature Test):

The results showed that the value of F_1 was 0.086 and 0.073 ^oC m^2/W with carton and aluminum types respectively at stagnation plate temperature of 110 and 99 ^oC ,ambient air temperature of 36.6 and 36.5 ^oC and insolation on a horizontal surface of 847.1 and 845W/m^2 for carton and aluminum types respectively.

5- Second Figure of Merit (Heat Up Condition Test) and the Utilization Thermal Efficiency:

The data given in Table (1) shows the variation of F_2 and the values of η_u at different load. The results indicated that the value of F_2 and η_u increased when the load increased.

Table (1) sensible heating tests with different load of water and results of F_2 and η_u

Parameter	Quantity of water (kg)			
	Carton Type		Aluminum Type	
	0.5	1.0	0.5	1.0
Insolation (W/m^2)	894	841	894	800
Ambient temperature (°C)	37.5	37	36.2	37
F_2	0.22	0.23	0.24	0.32
η_u	9.04	13.57	6.86	10.59

6- The Cooking Power:

The results presented in Figures (8), (9), (10) and (11) show A linear regression relationship between (P_s) and (T_w – T_{amb}). In the carton type, the linear regression equation for 0.5 kg of water is $p_s = 2.1298(T_W – T_{amb})-9.6868$ and the value of the coefficient of determination (R^2) of the equation is (0.8396) and linear regression equation for 1 kg of water is $p_s = 1.2527(T_W – T_{amb}) -18.886$ and the value of the coefficient of determination (R^2) of the equation is (0.8576). In the Aluminum type, the linear regression equation for 0.5 kg of water is $p_s = 1.7772(T_W – T_{amb})-4.2764$ and the value of the coefficient of determination (R^2) of the equation is (0. 0.809) and linear regression equation for 1 kg of water is $p_s = 0.9196(T_W – T_{amb}) -3.8792$ and the value of the coefficient of determination (R^2) of the equation is (0.858). The standardized cooking power was found to be inversely proportional to temperature difference (T_w-T_{amb}).From the previous data, it can be referred that, there were a highly positive relation with high (R^2) under using the two types.

7-The Cooker Cost Analysis:

Figure (14) illustrates the hourly operational cost for the two types of cookers in comparing with the gas cooker. The cost analysis indicates that using solar cooker was very economically. The hourly operational cost was about 50% of that the gas cooker. The hourly operational costs were (0.055, 0.051 and 0.14 L.E) for carton, aluminum solar cookers and gas cooker respectively.

CONCLUSION

This research investigated two designs of solar cookers to propose a simple test procedure for determining some parameters using the experimentally obtained F_2 data for two different load of water and to apply the proposed procedure for predicting the heating characteristic curves. The concluded results from this study were:

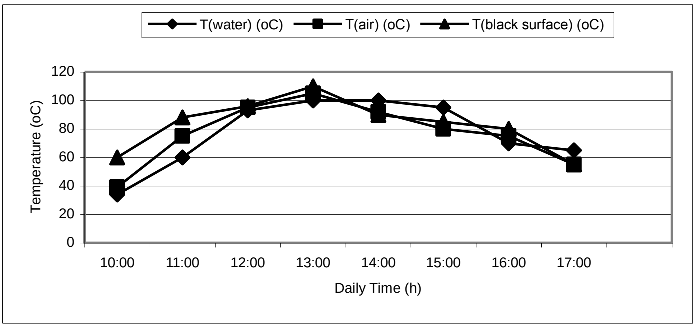
1- The perfect period to cook using the solar cookers was from 12:00 pm to 3:00 pm.

2- In the carton type the maximum water temperature was 100 ^oC at 13:00 with 0.5 kg load and reached to 100 ^oC at 14:00 with 1.0 kg load. When the load increased, it needs more time to reach the boiling point.

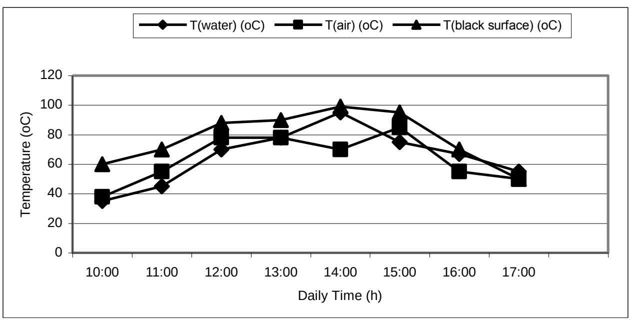
3- The standardized cooking power was found to be inversely proportional to temperature difference (T_w-T_{amb}).

4- The values of F_2 and η_u increased when the load increased with the two cookers.

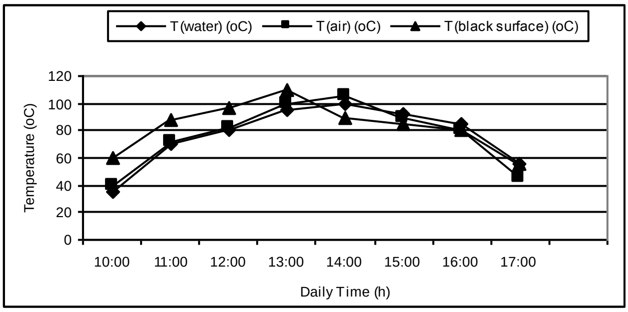
5- The cost analysis indicated that using solar cooker was very economically. The hourly operational cost was about 50% as compared with gas cooker. The hourly operational cost were (0.055, 0.051 and 0.14 L.E) for carton, aluminum solar cookers and gas cooker respectively.



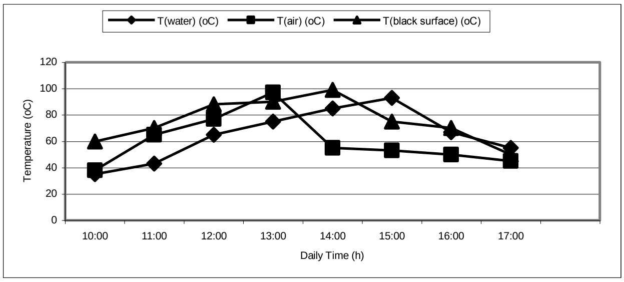
Figures (3): Effect of the Solar Radiation and the Daily Time on the Cooker Temperatures without load for carton box cooker in the 2nd of August 2011



Figures (4): Effect of the Solar Radiation and the Daily Time on the Cooker Temperatures without load for aluminum box cooker in the 2nd of August 2011



Figures (5): Effect of Cooker Type on the Cooker Temperatures for carton box with 1.0 kg of water



Figures (6): Effect of Cooker Type on the Cooker Temperatures for aluminum box with 1.0 kg of water

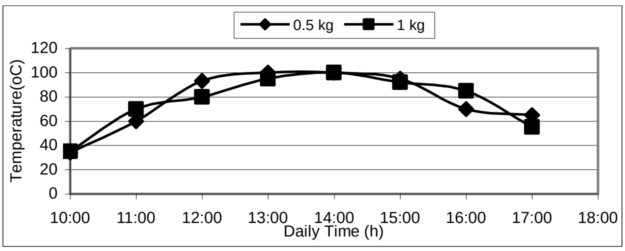
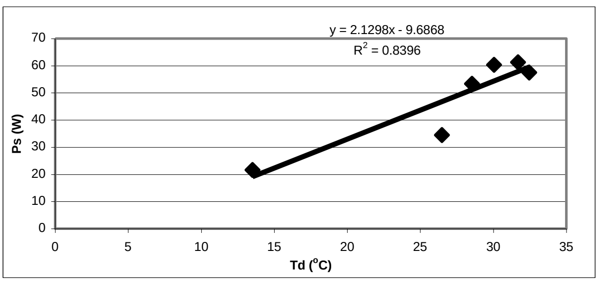
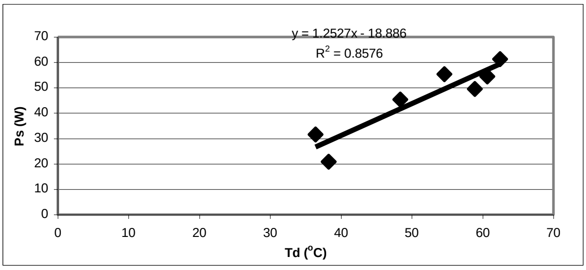


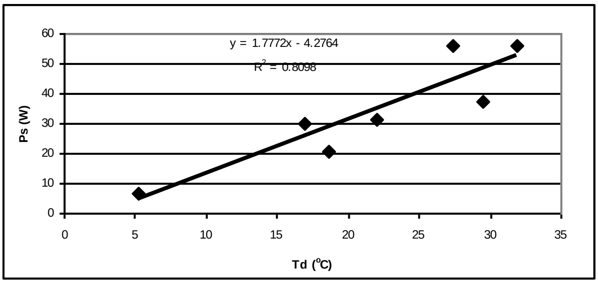
Figure (7): Effect of Load on the Cooker Temperatures for carton box



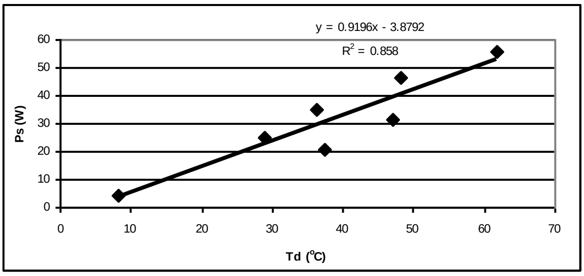
Figures (8): The standardized cooking power as a function of temperature difference (T_w-T_{amb}) for carton box type with 0.5 of water.



Figures (9): The standardized cooking power as a function of temperature difference (T_w-T_{amb}) for carton box with 1 kg of water.



Figures (10): The standardized cooking power as a function of temperature difference (T_w-T_{amb}) for aluminum box with 0.5 kg of water.



Figures (11): The standardized cooking power as a function of temperature difference (Tw-Tamb) for aluminum box with 1 kg of water.

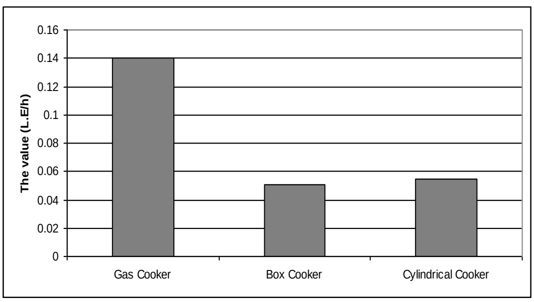


Figure (12): The hourly operational cost (L.E/h)

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الملخص العربي

تقييم الأداء الحراري لنوعين من الطباخات الشمسية ذات التكلفة البسيطة

منى محمود عبد العزيز حسن*

يهدف هذا البحث إلى تقييم الأداء الحراري لنوعين من الطباخات الشمسية ذات التكلفة البسيطة. تم تصنيع كلا الطباخين من مواد خام متاحة ومتوفرة بحيث يتم استخدامهما بديلا عن أنظمة الطبخ التقليدية ويتكون الطباخ الأول وهو من النوع الصندوقى من صندوقين متداخلين من الكرتون ابعادهما: (٤٥*٤٠*٢٠سم)،(٣٩*٣٤*٢٠سم) توضع الصغرى بداخل الكبرى و يوضع بينهما عازل من الصوف الزجاجي بسمك (٣سم) وبداخل الصغرى توضع شريحة من الصاج المطلى باللون الأسود ويعمل كسطح ماص للحرارة بسمك (١مم) وتغطى جوانب الكرتون من الداخل بورق الالومنيوم لعكس الأشعة الشمسية و يغطى الكرتون بلوح زجاجي بسمك (٣مم)٠

تم عمل إطار من الخشب يوضع بداخله الطباخ ويثبت عليه اللوح الزجاجي مع تزويد الإطار الخارجي بثلاث عواكس مصنوعة من ورق الالومنيوم ولها إطار خاص من الخشب.

أما الطباخ الثاني فتم صنعه من إناء اسطواني الشكل من الالومنيوم بأبعاد (٣٠*٣٠*٢) وتم دهانه من الخارج باللون الأسود ليعمل على امتصاص الأشعة و وضع بداخله شريحة من الصاج كسطح ماص أيضا مع وضع الإناء الاسطواني بداخل نفس الإطار الخشبي و عليه العواكس الثلاث ٠تم استخدام إناء للطبخ من الالومنيوم أبعاده (١٤*٩سم) وتجريبه في ثلاث حالات هي (بدون حمل ،٠.٥ ، ١ كجم من الماء)٠

وتم دراسة بعض العوامل المؤثرة على أداء الطباخ وأوضحت النتائج ما يلى:

١- أفضل فترة يتم فيها الطبخ بالطاقة الشمسية يكون من الساعة الثانية عشرة ظهرا إلى الثالثة بعد الظهر عندما يكون الإشعاع الشمسي في أعلى معدلاته اليومية٠

٢- وصل السطح الماص لأعلى درجاته بعد (٤,٣) ساعات تشغيل مع الطباخ المصنوع من الكارتون والمصنوع من الألومونيوم على التوالي عند تحميلهما بنصف كجم ماء٠

٣- مع النوع الكارتوني وصلت درجة حرارة الماء إلى ١٠٠ درجة مئوية بعد (٤.٣) ساعات تشغيل مع (٠.٥ ،١) كجم من الماء على التوالي٠

٤- زادت قدرة الطبخ مع زيادة الحمل ووجدت علاقة عكسية مع درجتي حرارة الماء والهواء الخارجي مع قدرة الطبخ٠

٥- كفاءة الاستخدام زادت مع زيادة الحمل في النوعين٠

٦- بحساب تكلفة التشغيل بالساعة و الصيانة السنوية للطباخين الشمسيين وجد أنها بسيطة جدا بالمقارنة بالأنواع الأخرى قد لوحظ أن تكلفة التشغيل لكل ساعةّ كانت(٠.٠٥١) مع الطباخ الكارتون و(٠.٠٥٥) مع الطباخ الألومونيوم في حين كانت قيمتها مع الأنواع التقليدية (٠.٠١٤) جنيهاً مصرياً.

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