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Studying & Evaluating the Performance of Solar Box Cookers (Untracked)

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Abstract

The primary aim of this study was to conduct the performance evaluation on solar cooker design. The secondary aim was to build and developing of a new and efficient solar cooker design. A direct solar box cooker (Untracked type) was tested in this study with low cost feature and low technology. The testing for the solar box cooker was conducted at the top roof of Material Engineering Department building. In this test, three water quantities (1.5, 1 and 0.5 kg) were used in order to find the effect of the mass quantity of cooking food on the temperature rise inside the solar cooker. The results showed that the attainable temperature reached a maximum cooking temperature of (81.6 ^{o}C) for water mass quantity of (1000 grams) with temperature difference between the cooking temperature and the ambient temperature of (61.5 ^{o}C). But a lower maximum temperature (81.7 ^{o}C) for (500 grams) the reason for that is due the lower solar intensity during the test of partially cloudy day. As a conclusion, it was found that as the solar intensity increases the cooking temperature increases too. The other factor which influences the cooking temperature is the cooking mass as the cooking mass increases the cooking temperature decreases. Although the cooking temperature increases but the standardized Power decreases, this is because the increasing in cooking temperature is not equalizing or go in parallel with the decreasing in cooking mass, thus it is preferable to use solar cooker for adequate cooking mass quantity to get a high merit or advantage solar cookers.

I. Introduction

The increasing demand of electricity, the exhaustion of wood/charcoal consumption and the rapid inflating of fuel price, the environmental degradation, have lead countries to encourage the use of renewable energy [1], one of this renewable energy is the solar energy. There is a long history for humans to use solar energy. They used steel mirror to concentrate the sunlight for inflaming a fire, and they used solar energy for drying agriculture crop. In recent times, the use of solar energy is widely spread; including solar thermal usage, solar photovoltaic employment and solar photochemical application etc., solar power is simply can be said as the of sunlight conversion into electricity [2]. In many developing countries especially in rural area, they can play a major role in developing good living situations among low-income families by lowering and reducing fuel resources. However, many rural areas do not have an electricity grid net, in order that people can access to and use electricity as a fuel source. Additionally, other fuels such as gas net can be difficult to connect between the towns and rural area due to the large distances and inadequate road networks. These reasons give the people to justify their using and deployment of solar cookers and necessitate research into their operation [3].

Solar cooking presents an alternative energy source for cooking. It is a simple, safe and convenient way to cook food without consuming fuels, heating up the kitchen and polluting the environment. It is appropriate for hundreds of millions of people around the world with scarce fuel and financial resource to pay for cooking fuel. Solar cookers can also be used for boiling of drinking water, providing access to safe drinking water to millions of people thus preventing waterborne illnesses. Solar cookers have many advantages, on the health, time and income of the users and on the environment. In tropical countries, the solar energy is plenty and therefore it becomes a reliable and sustainable source of energy [4].

This paper presents a model of untracked solar box cooker with four side reflectors using solar energy for cooking has been designed, fabricated and experimentally studied to produce heat from solar energy which is used to reduce the consumption of electricity or conventional fuel where it is difficult to supply to rural and desert areas.

II. The Research Goal

The goal of this paper is to carry out a design, fabrication, investigation and testing the model of an untracked solar box cooker prepared for this study to obtain the thermal performance for such type and taking into account all the points to gain heat and reducing the heat losses.

III. Experimental Rig Description

The solar cooker model is made mainly of plywood with an overall dimensions (40 cm X 40 cm X 40 cm), it consist of the following parts [figure (1)]:

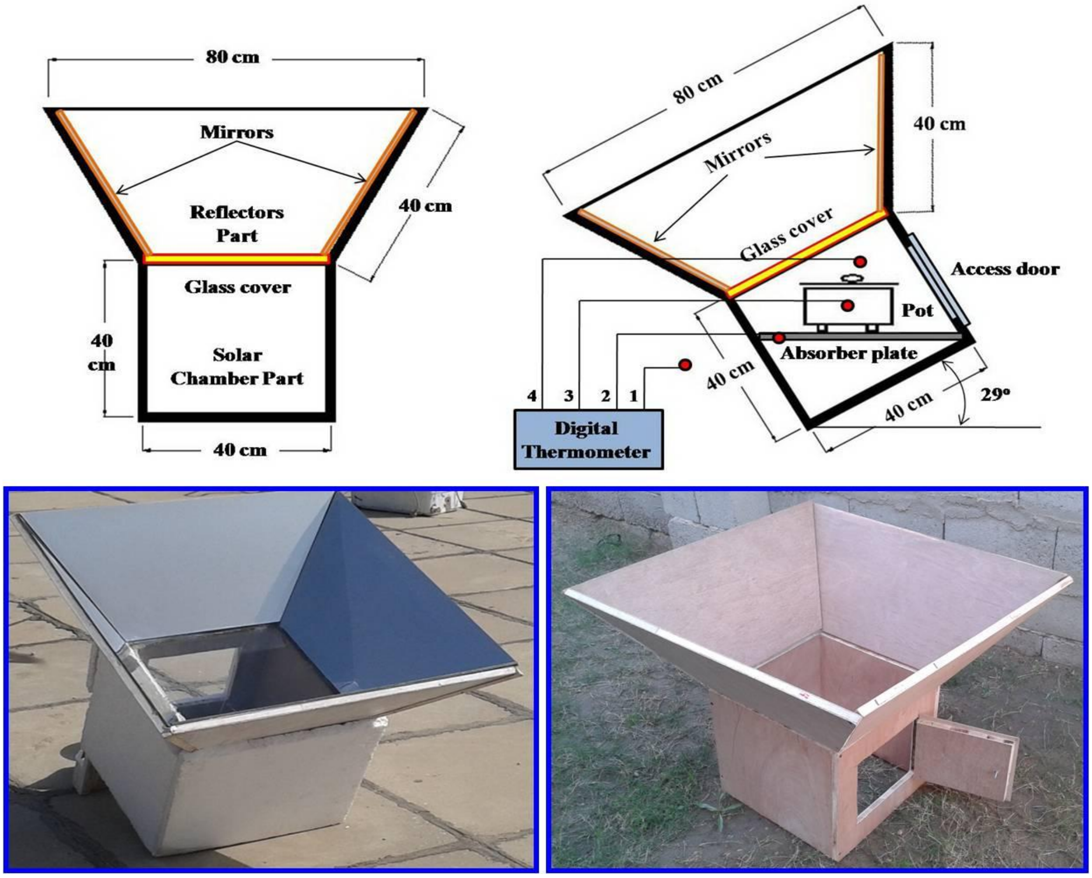

Figure (1): the solar box cooker with four sides reflectors prototype.

1. The aperture window of [40 cm X 40 cm] made of glass cover (6 mm thickness) which is supported by cooker sides' structure, the purpose of the glass cover is to close the solar box and help to capture and trap the solar heat inside the solar box.
2. A dark absorber plate exposed to solar radiation aligned horizontally inside the cooker chamber is made of a thick aluminum plate of (3 mm) thickness, to highly absorbing the solar heat incident on it.
3. The four reflectors [trapezoidal shape of lower base of (40 cm), upper base of (80cm) and height of (40 cm)] were covered with mirrors which are well stuck to reflectors using special glue. The reflector angles for the solar cooker were tilted with (30^0) with the vertical showing the best amount of admitted sunlight can captured into solar cooker [5]. The mirrors were used to reflect and direct the solar rays into the solar oven through the glass cover.
4. The cooker sides and its bottom were insulated with a Polystyrene board of (50 mm) thickness. This will help to reduce the heat dissipated outside the cooker and to improve its performance, the only side to loss heat form the solar cooker is from the glass cover which is exposed to the sky.
5. The solar cooker was oriented according to Baghdad latitude which is (33.4^o degree) in the northern sector of earth. The tilt angle was calculated for Baghdad city to be found equal to (29^o degree) by using the following formula [6] for latitude between (25^o to 50^o):

$$tilte\ angle = (latitude * 0.76) + 3.1^o$$

6. A pot with cover made of aluminum is used to warm (cooking) water inside it. The pot is painted with black color in order to highly absorbing the solar heat incident on it, it will get warm faster.
7. The measuring instruments used in this experiment include the digital thermometer instrument and digital solar intensity instrument:

- Two digital thermometers model (TM – 924C) each of two channels thermocouple are connected in order to measure temperature in four positions:
  T_1 : is the ambient temperature outside the solar cooker (°C) .
  T_2 : is the temperature of the absorber plate (°C).
  T_3 : is the temperature of the cooking water inside the pot (°C).
  T_4 : is the temperature inside solar cooker chamber (°C).

For measuring these four temperatures, it was used a special thermocouple type (K) in which it is connected to the dual thermometer instrument.

- The digital solar radiation instrument is used to measure the horizontal solar intensity [model solar power measuring instrument type (SPM – 1116 SD), which is applicable to measure the solar radiation and solar power.
- The wind speed (V) was determined using the digital Thermo – Anemometer (model: AM-4210E).

IV. Theoretical Analysis

In this paragraph, and in order to determine the performance of the solar cooker prototype, the standard which was originally developed by Dr. Paul Funk as an international testing standard for solar cookers was used. This standard was recognized at the Third World Conference on Solar Cooking, in January of 1997 (Funk, 2000). The goal of this standard was to produce a simple, yet meaningful and objective measure of cooker performance that was not so complicated as to make testing in less developed areas prohibitive.

Temperature measurements are made of the water and averaged over 10 minute intervals. Ambient temperature and normal irradiance (solar energy flux per area) are also measured and recorded. This is calculated through the following procedure [7]:

$$P = \left(\frac{T_2 - T_1}{600}\right) * m * C_p \qquad \dots (1)$$

Where:

P = cooking power (W)
T_2 = final water temperature (^oC)
T_1 = initial water temperature (^oC)
m = mass of water (kg)
C_p = heat capacity (4168 J/kg. K)

Equation (1) was divided by (600 sec.) of each (10 minute) to get the power produced by the solar cooker in each (10 minute).

To determine the standardized cooking power (P_s), (P) is multiplied by the standard and normalized solar irradiance figure of (700 W/m^2) and divided by the average global irradiance of that interval through the following equation:

$$P_s = P\left(\frac{700}{I}\right) \qquad \dots (2)$$

Where:

P = cooking power (W)
P_s = the standardized cooking power (W)
I = interval average insolation (W/m^2)

Tests were performed to study and evaluate the performance for Solar Cookers (Un-Tracked) and Reporting Performance according to (Funk, 1997), with and under the following conditions [8]:

- Testing was carried out between 9:00 and 14:00 solar time.
- Ambient temperature and wind speed were recorded (it is less than 2.5 m/s).
- The test began with water at ambient temperature. Cooking temperature was recorded.
- The horizontal irradiance were recorded and averaged for a 10- minute interval.
- Wind speeds greater than (2.5 m/s) and ambient temperatures below (20 ºC) were disregarded.

V. Results and Discussion

In this paragraph, the analysis for this research shows the possibility to evaluate the solar cooker performance by using three different quantities of water as a cooking food. Those quantities are (1.5 kg, 1 kg and 0.5 kg); in this way the standardized cooking power (P_s) can be predicted and used as a factor of merit to show the solar cooker performance.

The testing was carried out at three successive days from (19 to 21April). The measured temperatures for the water mass for (1.5 kg), the absorber plate, the solar cooker chamber temperature and the ambient temperature,

Figure (2) showing the temperatures variation with solar time conducted between (9:00 morning and 14:00 afternoon).

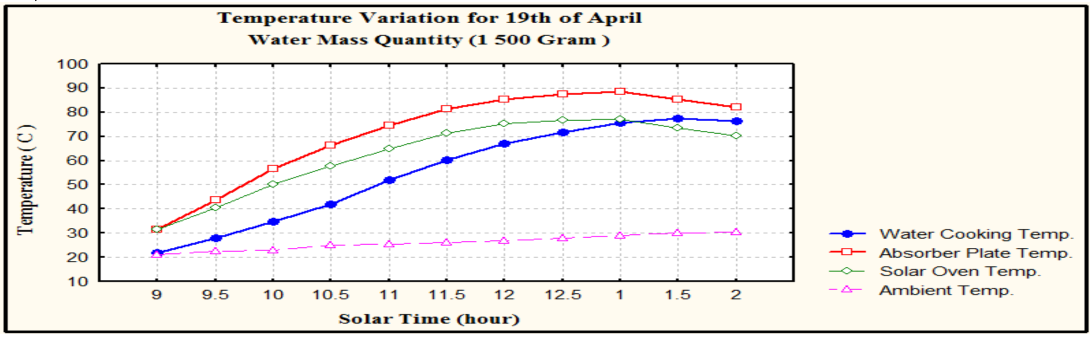

Figure (2): The temperatures variation for (1.5 kg) water mass.

The water cooking temperature is risen at the beginning of heating to a maximum temperature of (76.6 ^{o}C) at solar time of (1:30 afternoon) and start to fall down, while the absorber plate temperature reaches its maximum temperature of (88.6 ^{o}C) at (1:00 afternoon) and the solar cooker's chamber temperature has its maximum temperature of (77.2 ^{o}C) at (1:00 afternoon). The maximum temperature difference between the water cooking temperature and the initial water temperature is at (1:30 afternoon) is (56.7 ^{o}C).

In the same manner, **figure (3)** showing the temperatures variation with solar time conducted between (9:00 morning and 14:00 afternoon) for water mass of (1 kg). The maximum water cooking temperature of (82.3^{o}C) at solar time of (1:30 afternoon) was obtained, while the absorber plate temperature reaches its maximum temperature of (96.1^{o}C) at (12:00 afternoon) and the solar cooker's ambient temperature has its maximum temperature of (84 ^{o}C) at (12:00 afternoon). The maximum temperature difference between the water cooking temperature and ambient temperature is at (1:30 afternoon) is (62.2 ^{o}C).

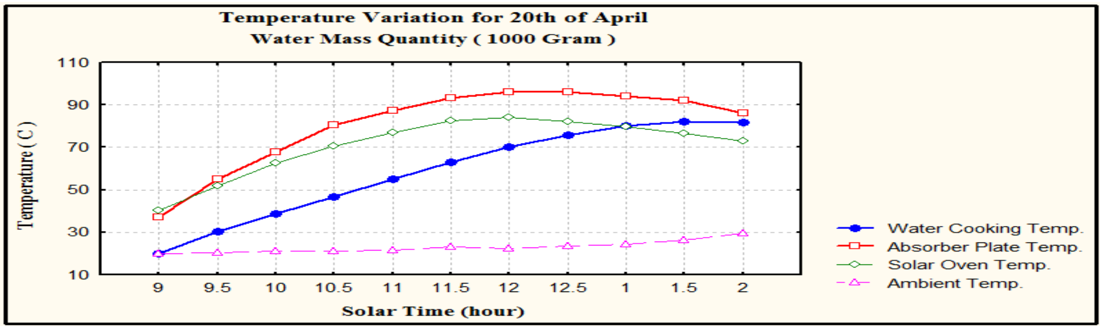

Figure (3): The temperatures variation for (1 kg) water mass.

In the same manner, **figure (4)** showing the temperatures variation with solar time conducted between (9:00 morning and 14:00 afternoon) for water mass of (0.5 kg). The maximum water cooking temperature of (83 ^{o}C) at solar time of (1:30 afternoon) was obtained, while the absorber plate temperature reaches its maximum temperature of (93.2 ^{o}C) at (12:30 afternoon) and the solar cooker's ambient temperature has its maximum temperature of (82.3 ^{o}C) at (12:30 afternoon).

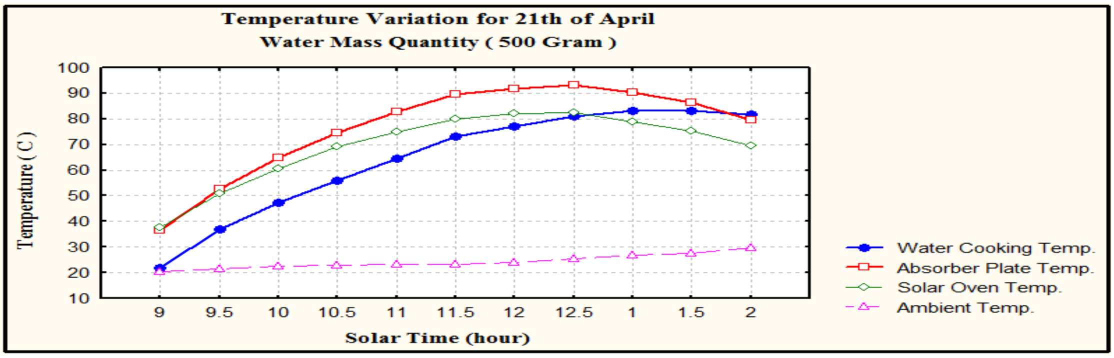

Figure (4): The temperatures variation for (0.5 kg) water mass.

The maximum temperature difference between the water cooking temperature and ambient temperature is at (1:30 afternoon) is (62.5 ^{o}C).

Figures (5, 6 and 7) showing the water cooking temperatures and solar intensity falling on the solar cooker against solar time. It was noticed that at the beginning the water cooking temperature increases due the solar heat accumulated inside the solar oven and trapped inside the solar oven, then it will begin to fall down as the solar radiation intensity decreases at solar time of (12:00 noon).
The highest water cooking temperature that is being obtained is (83.2 ^{o}C) for water mass quantity of (0.5 kg) on (21st of April) which a dusty day (not clear and shine), it could be reached to higher temperature but it can be concluded from the figure (7) that the solar intensity less than the other measuring days (19th and 20th of April) as a result less average total solar radiation incident on the solar oven and thus a lower maximum water cooking temperature was obtained.

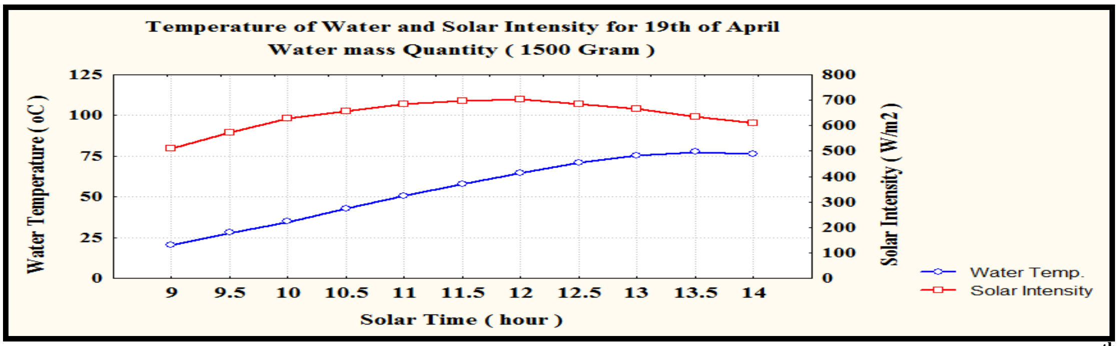

Figure (5): The cooking temperature for (1.5 kg) water mass versus solar radiation intensity for (19th of April).

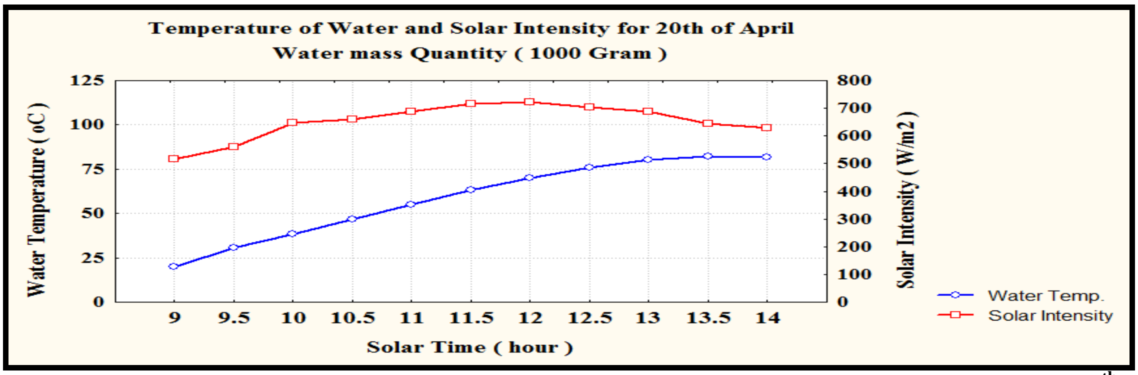

Figure (6): The cooking temperature for (1 kg) water mass versus solar radiation intensity for (20th of April).

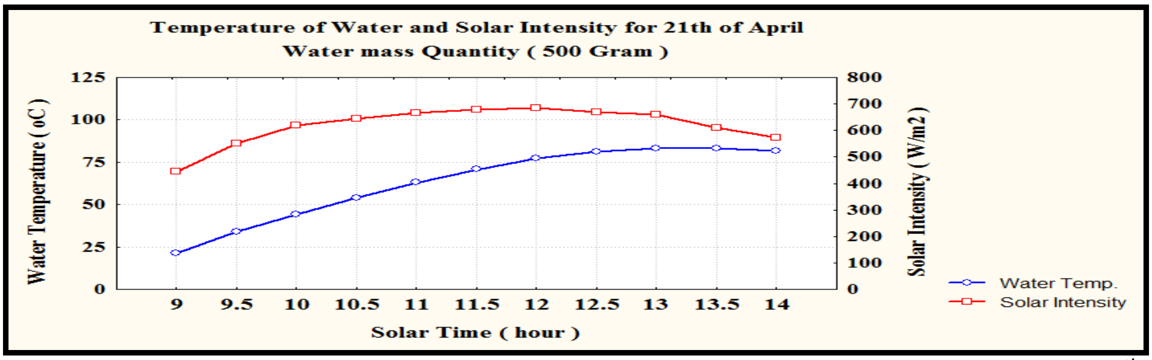

Figure (7): The cooking temperature for (0.5 kg) water mass versus solar radiation intensity for (21stof April).

As a conclusion, the cooking temperature increases as the average solar radiation intensity increases and vice versa during the conducted solar time interval that will be used for cooking.
Another point that affects the temperature rise of cooking water is the mass quantity which is used in cooking, and as the mass quantity which is used in cooking increases yielding to a lower cooking temperature.
Figures (8, 9 and 10) showing the performance of the solar box cooker (Standardized Cooking Power) which has been established versus the temperature differences. It was noticed that the performance for solar box cooker increases as the temperature difference increases too, but the most important point is as the water quantity increases the performance for solar box cooker increases too.

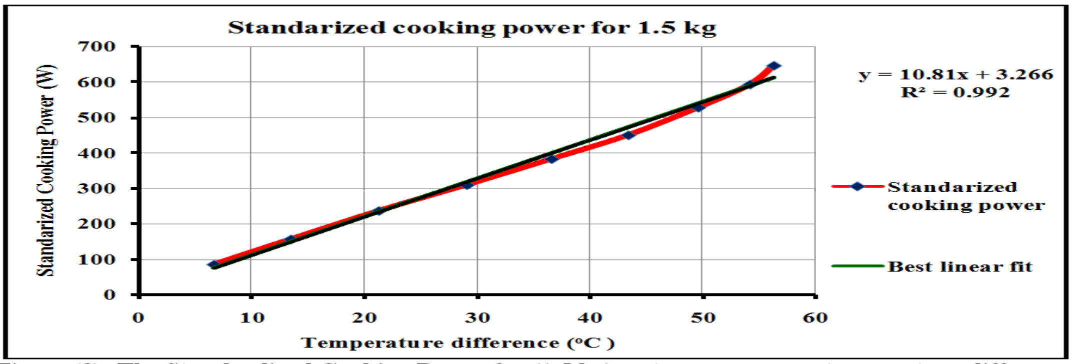

Figure (8): The Standardized Cooking Power for (1.5 kg) water mass versus temperature difference between Pot content at initial and final temperature.

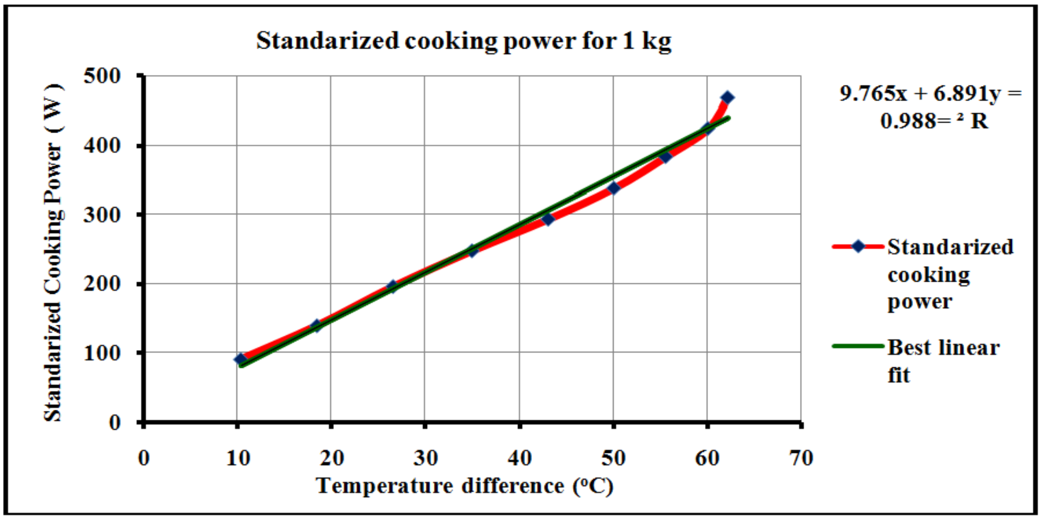

Figure (9): The Standardized Cooking Power for (1 kg) water mass versus temperature difference between Pot content at initial and final temperature.

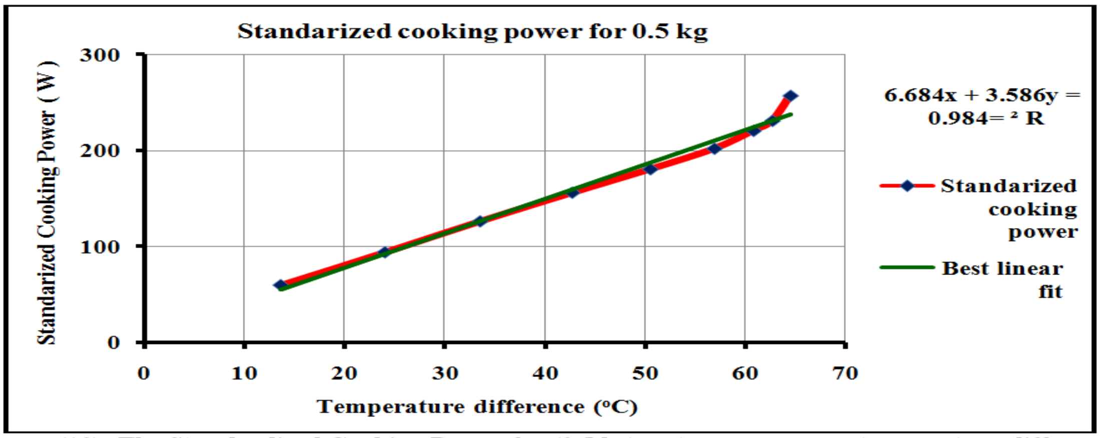

Figure (10): The Standardized Cooking Power for (0.5 kg) water mass versus temperature difference between Pot content at initial and final temperature.

The highest standardized cooking power was obtained for water quantity of (1.5 kg) which was reached to about (650 W), while the lowest was obtained for (0.5 kg) which was reached to about (270 W).
This is because the increasing in cooking temperature is not equalizing or go in parallel with the decreasing in cooking mass, thus it is preferable to use solar cooker for adequate cooking mass quantity to get a high merit or advantage solar cookers.
Figures (8, 9 and 10) showing too, the best linear fitting curve equations for the different water quantities and its coefficient of fitness (R^2). The coefficients of fitness for them is not less than (0.98)

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