# Experimental Study of the performance of a Box Solar Cooker

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**Abstract** – The purpose of this study is to present an investigation for the thermal performance of a box solar cooker in Jordan climate conditions, by studying the effect of adding three highly reflective aluminum sheet reflectors, that are fixed with the calculated slopes. Also changing the number of the glass plates covering the top of the box cooker in order to specify the conditions in which the cooker has its maximum thermal performance. By controlling the degree of the reflector slope and noticing the changes in water temperature, box temperature, ambient temperature, solar radiation and wind speed. A digital thermocouple, day star meter and an anemometer were used to collect the data.

The cooking power and the cooker efficiency were calculated. The system was tested under four modes of operation, single glass cover without adding reflective surfaces, single glass cover with reflective surfaces, double glass cover without reflective surfaces, and double glass cover with reflective surfaces. The results showed that using reflective surface or double glass cover is useful when high difference, between water and ambient temperatures, is expected, while the combined effect is useful almost over the entire range of temperature difference. It is found that adding reflective surfaces made double positive effects on cooker efficiency; by making the efficiency more stable and by making a considerable improvement in the efficiency along the hours of the day.

**Keywords** –Box solar cooker, Cooking power, cooking efficiency.



## 1. INTRODUCTION

Solar energy technology is becoming increasingly efficient as fossil fuel prices have risen globally in the last few years. In addition to many advantages using solar energy for food cooking, e.g. clean energy, low cost, health and safety benefits and infinite energy source, solar cooking is a new approach to cooking in many parts of the world. These cookers, usually, take longer time to cook food compared to standard ovens.

The solar box cooker typically reaches a temperature up to 150 °C (300 °F). This is not as hot as a standard oven, but still hot enough to cook food over a somewhat longer period of time. Food containing a lot of moisture cannot get much hotter than 100 °C (212 °F) in any case, so it is not always necessary to cook at the high temperatures indicated in standard cookbooks. Because the food does not reach too high temperature, it can be safely left in the cooker all day without burning [1].

M. Hönes of Germany has established solar cooking in Lesotho, enabling small groups of women to build up community bakeries using solar ovens. There is a welfare society deep in the mountain kingdom of Lesotho that helps Aids orphans and their foster mothers in a rather novel way. Known as Tin-Can Villages (TCV), the organization builds structures out of tin cans. The benefits of the cans, according to project head Michael Hones is that they are cheap - currently sourced and they are strong when stacked vertically, and provide good insulation [2] . An Austrian non-governmental organization, sponsored the provision of powerful "Sk-14" parabolic solar cookers in 2004, resulting in an entire village that uses only solar cooking [3] . To improve the performances of box solar cookers some researchers brought solutions to enhance the heat capacity by increasing the solar irradiation in the box with the help of reflective surfaces.

The performance of a box solar cooker with outer-inner reflectors was evaluated by El-Sebaii; the calculations indicated that good improvement in cooker performance was attainable [4].

The thermal analysis of a double reflector box solar cooker with transparent insulation material was investigated experimentally by Nahar [5].

Amer [6] developed a double exposure box cooker; the absorber is exposed to solar radiation from the bottom sides. An experimental study of a box solar cooker was done by Negi and Purohit [7], He made a theoretical and experimental assessment of the cooker performance aimed at development of a box type solar cooker utilizing non-tracking concentrator optics to enhance the solar energy availability in the box of the cooker for efficient cooking. A laboratory model of a box type solar cooker employing a non-tracking concentrator has been designed and fabricated, and its thermal performance has been investigated experimentally.

Design analysis was accomplished by Mirdha and Dhariwal [8] where various possible designs of tilted cookers

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with various positions of booster mirrors to optimize the cooker performance.

Many works have been done on the reduction of the cooking time. Using modified cooking vessels as did Grupp et al [9]. Who proposed an improved version of the box solar cooker with a fixed cooking vessel in good thermal contact with a conductive plate. Gaur et al. [10] analyzed the performance of the box solar cooker with modified utensils with a concave shaped lid. Narasimha Rao and Subramanyam [11,12] have studied the effect of keeping the cooking vessel on lugs and using a cylindrical cooking vessel with central annular cavity; the results indicated that the cooking vessel with central cavity improves effective heat transfer surface towards the water which reduces the cooking time.

Using Solar Box cookers, a simple, effective, low cost, clean and practical method for cooking is provided The objective of this work is to experimentally investigate the thermal performance of a box- type solar cooker in Jordan climate conditions. Considering first the effect of reflective surface and redesign the top of the box cooker using single and double glass plates. The tests were conducted considering the single effect of each parameter and the combined effect of both.

## 2. MATHEMATICAL MODEL

### *2.1. Cooking Power*

In order to facilitate the comparison and study of the results, the cooking power for each interval shall be corrected to a standard insulation of 700 W/m$^2$[6] by multiplying the interval observed cooking power by 700 W/m$^2$ and dividing by the interval average insulation recorded during the corresponding interval.

$$P_s = P_i \,( 700/I_i ) \qquad (1)$$

where:

$P_s$ = standardized cooking power (W)

$P_i$ = interval cooking power (W)

$I_i$ = interval average solar insulation (W/m$^2$)

The observed cooking power is firstly calculated by multiplying the change in water temperature for each 15-minute interval by the mass and specific heat capacity of the water contained in the cooking vessel. This product shall be divided by the 900 seconds contained in a fifteen-minute interval;

$$P_i = M\, C_p\, \Delta T \,/\, 900 \qquad (2)$$

where:

$P_i$ = cooking power (W)

$\Delta T$ = the difference between the final and initial water temperature for each interval.

M = water mass (kg)

$C_p$ = specific heat of water (4186 J/[kg•K])

### *2.2. Temperature Difference*

Ambient temperature for each interval is to be subtracted from the average water temperature:

$$T_d = T_w - T_a \qquad (3)$$

Where:

$T_d$ = the temperature difference (C)

$T_w$ = the water temperature (C)

$T_a$ = the ambient temperature (C)

A linear regression of the obtained results is used to find the relationship between the temperature difference and the standardized cooking power in terms of intercept A (W) and slope B (W/C) [13] or $P_s$=A + B $T_d$ .

The performance equations are plotted using MATLAB codes.

### *2.3. Cooker Efficiency*

The interval cooker efficiency is calculated using the following formula. [14]:

$$\eta = (M\, C_p \Delta T\,)/(900\, A_c\, I_i)\ 100\% \qquad (4)$$

Where $A_c$ is the cooker intercept area.

### *2.4. Reflector Angle*

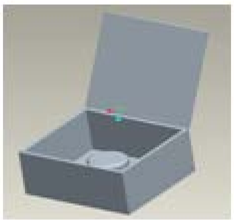

Figure 1. The Box Cooker

The reflector angle θ shown in Figure 1, was calculated using the equation:

$$\theta = 90° + [sin - 1\, x \,\{-(b \div 4a) + (0.25\, x \sqrt{((b^2 \div a^2) + 8)})\}] \qquad (5)$$

a: is the glass width

b: is the reflector length.

By substituting the corresponding values , the slope angle is found to be ( 116.7° ).

## 3. EXPERIMENTAL SETUP

Figure 2. Reflectors in the Box Cooker

A Box of aluminum material was constructed in the dimensions of 60x56x30 ( length, width and height respectively ) , and the top of the box is covered by a glass plate 59 x 55 this cover is designed to be a single or a double glass plate each time of the test.

This box is surrounded by three highly reflective aluminum sheet reflectors of 60x60 in dimension, that are fixed with manually changed slopes, as shown in Figure 2. At the center of the box cooker a black cylindrical kitchen pot filled of three liters of water is placed.

This pot was tested in four modes:

1. Single glass cover without reflecting sheets.
2. Single glass cover with reflecting sheets.
3. Double glass cover without reflecting sheets.
4. Double glass cover with reflecting sheets.

All temperature measurements were recorded using digital thermocouples fixed inside the pot (to measure the water and box temperatures), and outside the cooker to measure the ambient temperature.

A day star meter was used to measure the solar radiation

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intensity. Wind speed was recorded using the anemometer to be sure that it will not exceed the upper acceptable limit specified by 3 m/s. Experiments were performed on the roof of the Mechanical Engineering Department at Philadelphia University, Amman, (32°N, 36°E) during different periods of Winter and Summer.

## 4. Results and Discussion

To study the performance of the solar box cooker with the designs done in this experimental research, cooker performance parameters have been calculated from the collected data as shown in the described mathematical model.

### *4.1. Effect of adding a single or a double glass cover Effect of adding a single or a double glass cover*

A comparative study was carried out between the solar cooker gained standard power with a single glass cover and the cooker with a double glass cover as shown in Figure 3.

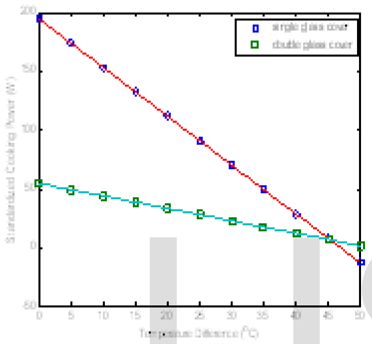

Figure 3. Effect of adding a single or a double glass cover.

It is obvious that for small temperature differences the standard power is much higher using a single glass cover, while for higher temperature differences the double glass cover is better to use for gaining more standard power.

This means that in conditions in which the food can be cooked at low temperature difference, it will be better to use a single glass cover.

Also analysis shows that the power decreases faster in a single glass model, with temperature difference, then in a double glass model. This is due to the fact that at large temperature difference the heat loss rate is more with single glass model.

### *4.2. The effect of using reflective surfaces*

The standard cooking power was plotted against the temperature difference for the design where the single glass cover is tested with and without addition of reflective surfaces. The results are shown in Figure 4.

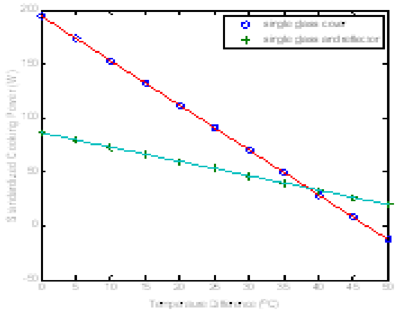

Figure 4. Effect of adding reflective surfaces.

It is clear that the effect of adding the reflective surfaces made the drop rate of cooking power much less. The improvement in cooking power due to the addition of reflective surfaces is more than that due to the effect of adding double glazed cover. So to maintain a stable high power over a wide range of temperature difference, it will be essential the addition of reflective surfaces to the cooker.

### *4.3. The combined effect of using double glazed cover and reflective surface.*

From Figure 5, it can be shown that using the reflectors with double glass cover involves a significant improvement in the gained power. It is clear that the gained power is high enough along the whole range of temperature difference, although the rate of drop is relatively high.

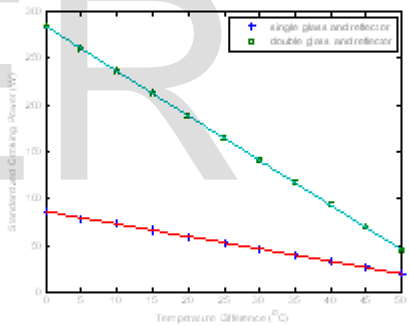

Figure 5. The combined effect of using double glazed cover and reflective surfaces.

This can be explained by noting that the benefits of the two modifications are acquired together. The addition of two glass cover reduced the losses at high temperature difference, while the addition of reflective surfaces enhanced the rate of solar energy gained.

### ***4.4.** Effect of using reflected surfaces and double glass cover on the efficiency of the cooker.*

As shown in Figure 6.a the addition of a double glass cover made the efficiency more stable with time. It can be noted that the efficiency is higher at the early morning hours with single cover. This may give rise to the suggestion of starting cooking with single glass cover and adding the second cover after solar noon.

The effect of adding reflective surfaces is shown in Figure 6.b. It can be seen that this modification made a double positive effects; one is making the efficiency more stable and the second is making a considerable improvement in the efficiency along the hours of the day.

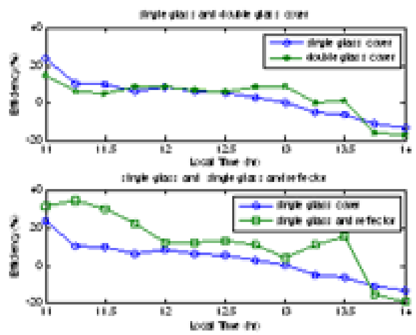

Figure 6.a.b Effect of using reflected surfaces and double glass cover on the efficiency of the cooker.

A sudden drop in the efficiency is noted in the late afternoon. This can be explained by noting that at certain time, the reflective surfaces start to have a shading effect. From the above results, it can be concluded that using either reflective surfaces or double glass cover are useful when high temperature difference is expected, while the combined effect is useful over the entire range of temperature difference.

*4.5. Effect of the different four modes of operation on the increase rate of cooker temperature.*

Figure 7. shows that the addition of reflective surfaces made the rate of temperature increase very high, while the double glass cover made the temperature more stable.

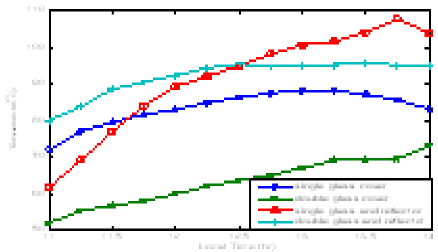

Figure 7. Temperature distribution of water with the four different modes of operation.

From this we can understand easily the combined effect of using reflective surfaces and double glass together that appears in the Figure, by achieving high and stable temperature during the day.

*4.6. The rate of change of box and water temperatures.*

From Figure 8 It can be seen that initially at early morning the box (air) temperature increases faster than the pot (water) temperature. After that, the water temperature exceeds the air temperature along the rest of the day.



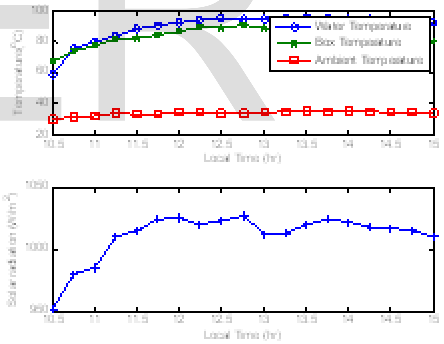


Figure 8. Rate of changes of temperature and solar radiation

This can be explained by noting that the thermal capacity of air is less than that of water, which makes the initial rate of temperature change of air faster.

After that, when the energy stored in water becomes high enough, the water temperature increases and exceeded the air temperature.

The intensity of solar radiation in typical day in Jordan looks to be more than adequate for the use of the solar cooker. In fact it exceeds 1000 $W/m^2$ a little bit after 11:00 am and continues on that most of the afternoon.

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