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An Evaluation of Periodic Performance of an Improved Solar Box Cooker

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Abstract— *The study outlined how the solar box cooker is constructed; taking in mind all those conditions that enhances optimum heat gains in the cooker and avoiding those that will bring heat lost into it. Some selected instruments were used in taking major measurements while the cooker is at work. The results found revealed that at about 1400 on the selected day the cooker receives maximum solar insolation. Some other parameters like temperature of the solar plates, the ambient temperature in the cooker seem to be higher at that hour, more importantly, the experimental efficiency recorded higher value at that period, and the result of the experimental value of efficiency is in agreement with the theoretical value calculated.*
Keywords*— *Solar Box Cooker, Thermocouple, Anemometer.

I. INTRODUCTION

Energy has always been an essential input to all aspect of the modern age; moreover, energy is the live wire for industrial production, transportation as well as other conventional power generation. For most developing countries, wood is the most readily available and most important energy source for domestic application. This means that more than two billion people depend largely on various forms of biomass to meet their energy needs mainly for cooking. (Dunn, 1986).. However, the major problem with the use of solar energy is that, it is very dilute and fluctuates with time and weather condition. The economic feasibility of solar energy utilization depends upon efficient collection, conversion and storage. The efficient utilization of solar energy for heating, application requires the use of flat plate or focusing collector system which first captured as much as possible, incoming radiation and then deliver a high fraction of the captured energy to the user. The availability of solar energy depends on the time of the day, the day of the year, and other meteorological parameters, such as clouds, rains and other atmospheric condition. The time variation of solar radiation is generally out of phase with the demand, thus solar energy is viable only when thermal storage is integrated into the system.

II. MATERIALS USED

The data collected in this work was based on the performance of the box cooker when exposed to the solar insolation. Below is the list of equipment/ instruments used in recording measurements made during the experiment with their label of accuracy

S/N	PARAMETER MEASURED	INSTRUMENT	TYPE/MAKE	LEAST COUNT	ACCURACY
1.	Solar insolation	Pyranometer	PSP 24319 F – 3	1.0W/m^2	0.5%
2.	Cooker plate temp.	Thermocouple	Copper-Constantan	0.1^{0}c	0.5%
3.	Ambient and water temp.	Thermometer	Pt-100	0.1^{0}c	0.2%
4.	Wind Speed	Anemometer	CPO Box 1618 Japan	0.1m/s	0.5%
5.	Dim. of the cooker	Measuring tape/ Scale	Kristeel-Shinwa 401E10	0.001m	0.2%

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III. METHOD OF CONSTRUCTION THE COOKER

Most previous cookers (Mohammad et al, 1998; Suharta et al, 2001 and Arouna, 2004) used a single reflector for their cookers; foam as an insulator and larger in sizes. These tend to reduce the cookers efficiency and a bit expensive, hence beyond the reach of most rural people. To overcome these short comings, a double mirror are used as reflectors, sawdust as an insulator and the size of the box cooker reduced.

The box cooker is made up of a thick wood of dimensions 64cm by 41cm by 28cm in a rectangular shape. An aluminum sheet of same rectangular shape, and dimensions 54cm by 31cm by 22cm was used in lining up all the inner surfaces of the cooker. The aluminum plate was painted dull- black, to enhance the heat capacity of the cooker for efficient cooking. It is important to note that since the dimensions of the aluminum is less than that of the cooker, the curved aluminum sheet was slotted into the box allowing some spaces in all the four walls of the box. Another space was left at the bottom of the box. The reasons why spaces were left in all the walls and the bottom of the cooker is to put adequate insulators in all the spaces to curtailed heat losses from the surrounding. Adhesive glue was later used to fill up the top surfaces of the box including any crack created as a result of construction imperfection.

The glass cover is made up of a transparent glass and even plastics may be used. Glass is used here, since according to Aalfs (1992), glass traps radiant heat better than plastics, and glass is difficult to surpass because it is a relatively low-cost material, easy to get and replaced. More so, when a glass gets hot it does not become distorted as many plastics do, more importantly, glass is widely available in developing countries and therefore by far the most common material used. The light energy is absorbed by the dark absorber plate which is converted into longer wavelength heat energy, and radiates from the interior materials. Most wavelengths cannot pass back out through the glass and is therefore trapped within the enclosed space.

The double reflectors used in this construction help bounce additional sunlight through the glass into the solar box. This additional input of solar energy results in higher cooker temperatures. It is however important to note that the choice of double mirror in this project offers the following advantages:

- It generates higher temperature and can efficiently be used for a variety of cooking applications.
- The mirrors need not to be adjusted once they are set, by this all the incident solar radiations impinging on the mirrors are reflected onto the base absorber of the box of the cooker and this will enhanced the heat capacity of a cooker.

Figure below illustrate the optics geometry used for the design of the glass cover. The glass cover is employing two non – tracking plane mirrors fixed in an east-west configuration with the lateral sides of the box of the cooker. The solar concentration is accomplished in such a way that the reflectors positioned on a plane making an angle equal to the latitude of the site with the plane of the solar energy on the absorber plate of the box of the cooker. It could be seen from the figure that, the ray reflected from the mirror placed on the left side will meet the edge R and that reflected from the mirror placed on the right side will meet the edge Q of the absorber. This multiple reflections received by the absorber will enhance accumulation of higher temperature in the cooker.

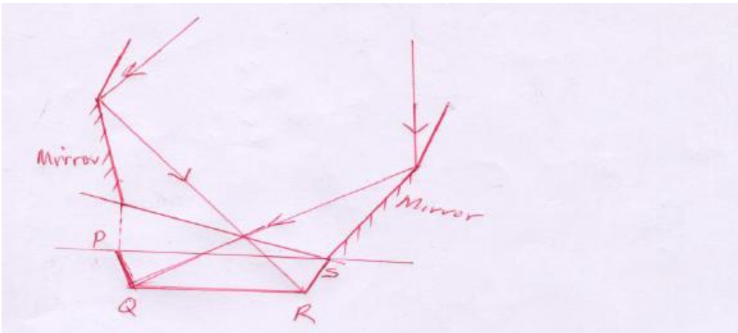

Fig. 1

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ASSEMBLY OF THE SOLAR BOX COOKER

The various components constructed separately were put together and the desired solar cooker was formed. The frame work of the cooker was supported with hinges fixed on the southern wall of the box, the box is also provided with another hinge having an elevation tracking arrangement to set the concentrator for its seasonal tilt arrangement. Based on this, the cooker receives solar radiations on the east-west configuration as shown in the figure below:

Fig. 2

Fig. 3

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DATA COLLECTION PROCEDURE

A completed solar box cooker at work is shown in figure above. The two mirrors were placed in an east-west configuration in order to ensure maximum collection of solar radiations in the cooking chamber. An aluminum pot of mass 0.5kg painted black containing 1kg mass of water was inserted into the cooker. The initial temperature of the water was noted and recorded and the following measurements were subsequently made;

I. solar radiation on the collector plate
II. the collector plate temperature
III. the ambient temperature
IV. water temperature and
V. wind speed

These parameters were measured at an hour interval, from 9:00 am to 6:00 pm on the 20/10/2017. Copper constantan thermocouple positioned inside the cooker was used to record the inside air and the absorber plate temperatures. Solar insolation was recorded using pyranometer, initial and final temperature of water was measured using a sensitive thermometer (pt-100 type).

The measured values were used to calculate the instantaneous efficiency of the collectors.

EVALUATION OF THE DAILY EFFICIENCY USING THE DATA OBTAINED

The measured values can be used to calculate the instantaneous efficiency of the cooker as follows;

Mass of water = 1kg

Specific heat capacity of water = 4200J/kg K

Mass of the vessel and its lid = 0.5kg

Specific heat capacity of aluminum = 800J/kg K

Initial water temperature (T_{wf}) =20ºC =293K

Final water temperature =39ºC =312K at 9:00 am

Therefore,

($T_{wf} - T_{wi}$) = 19K at 9:00 am

A the collector area = 0.1674m^2

I the solar insolation =667.5W/m^2 at 9:00 am

The magnitude of the efficiency at 9:00 am can be found using equation;

$$h = \frac{E_o}{E_i} = \frac{M_w c_w + M_{al} c_{al} \left[T_{wf} - T_{wi}\right]}{AIt}$$

But from the assumptions made,

$$U = u$$

And $u = \frac{1}{R}$ from equation (3.28)

Hence, $u = \frac{conductivity}{thickness}$

Thermal conductivity of wood = 0.1 and its thickness as measured is 0.023m.

So, $u = \frac{0.1}{0.023}$

The theoretical value of the efficiency can be found using the equation,

$$\eta = \frac{M_w c_w + M_v c_v \left(T_{wf} - T_{wi}\right)}{AIt} + \frac{u\left(T - T_a\right)}{I}$$

$$= \frac{(1X4200 + 0.5X800)(312 - 293)}{0.1674X667.5X3600} + \frac{4.35(349 - 303)}{667.5}$$

$$= 0.217 + 0.169$$
$$= 0.386$$
$$\cong 39\%$$

Table.2: Showing data recorded on 20/10/2017

Hours	T_p/ºC	T_a/ºC	T_w/ºC	I/wm^{-2}	v/ms^{-1}	h
8-9	56	30	39	667.5	0.35	0.22
9-10	85.5	34	52	890.0	1.15	0.27
10-11	114.5	37.5	65	1042.5	0.50	0.33
11-12	117.5	38	84	1210.5	0.45	0.40
12-13	126.0	40.7	92	1280.5	1.10	0.43
13-14	142.0	40.5	96	1286.5	0.20	0.45
14-15	136.0	40.3	92.5	1293.3	0.43	0.43
15-16	121.0	40	82.5	1210.3	2.4	0.39
16-17	109	38	70.0	923.3	2.1	0.41
17-18	85.5	36	55.5	477.0	0.35	0.57

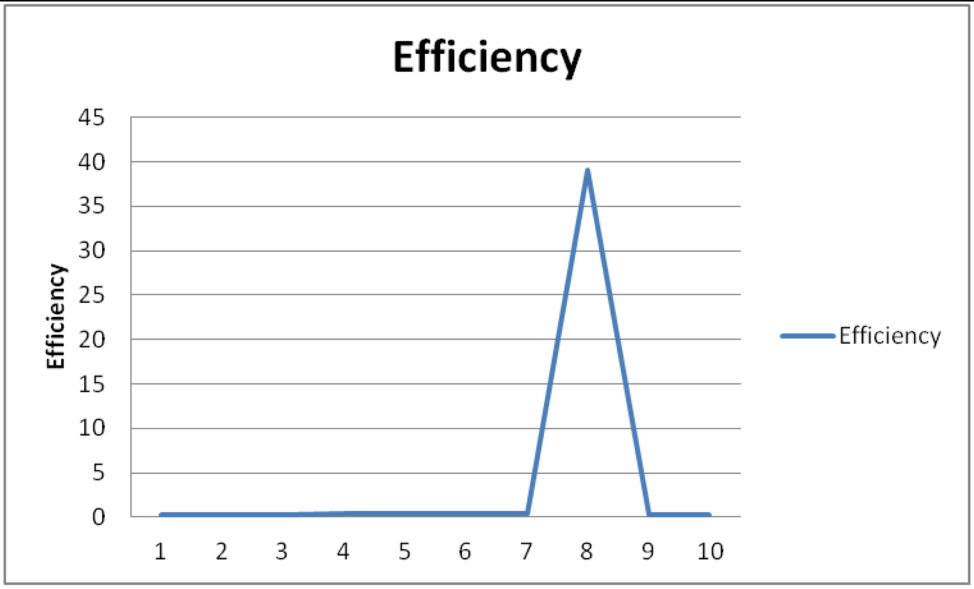

Fig 4

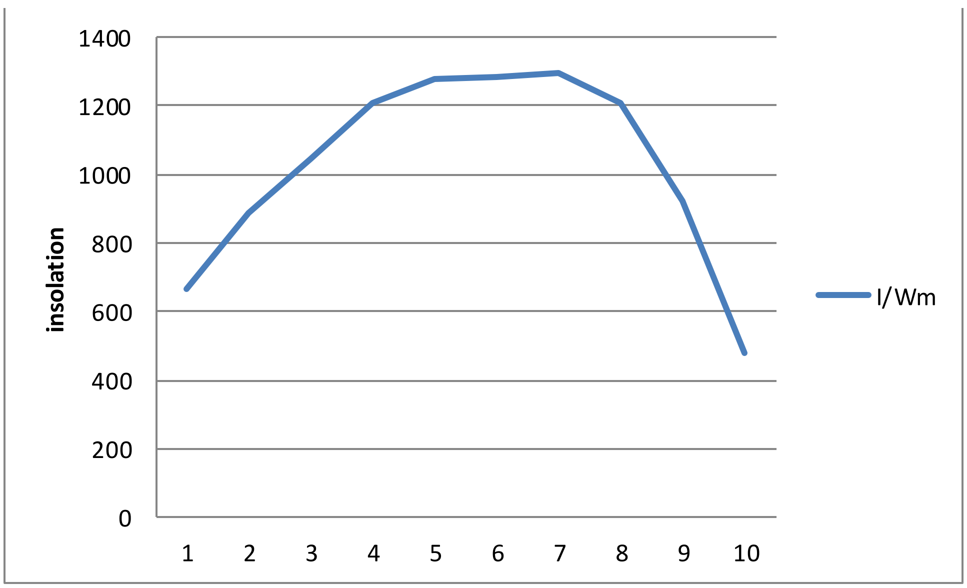

Fig.5

VI. DISCUSSION

Figs 4 above show the variation of the cooker efficiency at different time. It is clear from the figure that the efficiency of the cooker is high at 14.00. Moreover the experimental value is iin good agreement with the theoretical value which s approximately 40%.

Fig 5 above shows the variation of solar insolation on the selected day. It is clear from the figure that the cooker receives enough solar radiation at around 14.00. Hence, the thermal performance of the cooker is better at that period.

CONCLUSION

We have been able to construct a cooker that is used to determine at what period of the day is its efficiency maximum. More so, the experimental efficiency found is in good agreement with the theoretical value as calculated in the work.

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