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Design and Construction of a Wooden Solar Box Cooker with Performance and Efficiency Test.

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ABSTRACT

A wooden solar box cooker was successfully constructed with cheap and locally available material with efficiency of 96%.From the various experiments that were carried out, the highest temperature gotten both on the ground floor and at the top of the roof was 72^0C both on the days with air temperature of 38^0C and 35^0C respectively.
Efficiency was found to increase with decreasing temperature difference between collector temperature and ambient temperature. Increase in temperature does not necessarily lead to increase in efficiency. Efficiency decreased with decreasing solar radiation.
KEY WORDS: Solar Cooker, Efficiency, Temperature and Energy.

INTRODUCTION

According to World Bank statistics, 94 % of the African rural population and 73 % of the urban population use fuel wood as their primary energy source (Melanic, 2006). Unfortunately supplies of fuel wood are diminishing throughout the world. As the cost and collection time for fuel wood increases, people seek for alternative sources (Garg, 1994). In many sunny parts of the world, solar cooking is a viable option (Nandwani, 1992, Devadas, 1992, 1997, Olusegun, 2006). The need to to cook food for nourishment is fundamental to every society and this requires the use of energy in some form. The use of solar energy to meet this important need apart from being a viable alternative is also accomplished without the environmental and health problem associated with most other fuels (Shaw, 2003).

Solar cooker technology is not conceptually new. Many efforts have taken place over the years (Lof, 1965, Wary, 1992, Warren, 1994). Different solar cookers have ben tested by researchers at specific geographical locations and under unique climate and physical conditions (Malik et al, 1996, Adegoke, et al, 1998). One of the most common solar cooker types is the box solar cooker in different versions (Daniel, 1990, Amer, 2003, Ekechukwu et al, 2003 Negi et al, 2005). Another solar cooker type is the concentration type where the solar radiation is directed to convey at a point called the focal point where the cooking pot is placed (Kulkarni et al, 1997, Patel et al, 2000, Hussein et al, 2008).

A promising idea for solar cooker was introduced by Bernard of France in 1994 and Barbara Kerr a few years ago (Barbara, 1994). Its development is unique in terms of its simplicity and very light weight. A search through literature revealed that only a limited amount of data existed on quantitative performance evaluation of the panel cooker especially in this country. It is as a result of this the research was carried out by designing and constructing solar cooker using locally available material at Covenant University Ota Nigeria.

In building a solar cooker, the heat principles considered are heat gain, heat storage and heat loss. Solar cooking is simple, safe and it is convenient to cook food without consuming fuel or heating up the kitchen and cooks at moderate temperature and this helps to preserve nutrients.

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Depending on the latitude and weather, food can be cooked either early or later in the day. A solar box cooker is smoke free unlike other forms of cookers which uses smoky cooking fires which results in eye and lung diseases. Solar cooking helps to reduce the demand for wood and to prevent deforestation, saving fossil fuel and lowering utility bills.

In studying the difference in air temperature at high elevations and close to the sea level, it was realized that the earth's atmosphere served as a heat trap for solar energy, causing high temperature at lower elevation instead of the other way round as was first expected. Coincidentally, it was discovered that the wooden "hot boxes" built for that purpose got hot enough to cook (Beth Halacy *et al*, 1992, Felix, *et al*, 2002, Frederick, *et al*, 1997, Duffie *et al,* 1974, Folmer *et al,* 2003, Volker, 2003, 2004).

MATERIALS AND METHODS

Plywood was used since it is very cheap and locally available. It is an opaque substance and does not allow light to pass through it. It contains a natural polymer based on the cellulose molecules. It has strength and stiffness parallel to the grain but is weak across the grain. It is a much weaker material in compression than in tension. The plywood is strong in the two directions and it is easily warped than the single wood with grains in one direction. (Nelkon and Parker, 1995).

The thickness of the wood used in constructing the sides of the box is 1.91 cm and a thickness of 1.27 cm for the base. These thicknesses are used so that the box will not be too heavy. Each side of the box is lagged using a baton and saw dust to prevent heat loss due to convection. When the wood is lagged, heat escaping from its sides is negligible and the flow per second is now constant along the length of the wood. The dimension of the box used was 50 cm x 35 cm x 40 cm, while the dimension of the absorber plate was 31 cm by 23 cm. as shown in figures 1, 2, and 3 there are grooves made around the top of the box to serve as a slot for the mirrors. The inner part of the box is painted black to absorb the heat and trap the heat needed for cooking. A black surface is a good emitter and absorber of radiation. A black surface absorbs all the radiation that falls on it, but reflects, and transmits none. The radiation that was refracted by the glass is absorbed by the black plate and converted to heat. Food cooks best in dark, shallow, light-weight, thin metal pots with tight fitting to hold heat and moisture which works best in solar cooker. For this project, a shallow pot that is slightly larger than the food to be cooked is used. The mirrors serve as reflectors. Inside the box is a mechanism which makes the mirror slant at an angle as soon as it is slotted into the groove made for it. When radiation from the sun is incident on the mirror, it is reflected in the opposite direction in such a way that it is absorbed by the glass on top of the box which serves as the lid. For this project, a mirror with thickness of 3mm was used. The dimension of the mirror used for the sides of the box was 46 cm by 30.5 cm. Glass provides about 10% better performance than plastic. And there is reason to believe that under windy conditions, glass is preferred since it doesn't flap in the wind and pump heat out of the cooker. For this project, the thickness of the glass used is 4mm. The glass dimension was 33cm x 26 cm. The box cooker was placed on the third floor of the college building at a high altitude for the box cooker to be heated faster since there are no obstructions at that height.

A thermometer was used to measure the temperatures of the absorber plate in the box cooker and the ambient at different time intervals. The cooking experiment started at 3:50 pm. The air temperature Ta at that time was 400C and the collector temperature was 50 0C. 200ml of water was put in the pot and the water was left there for about 20 minutes there after 75 grams Pack of indomie was put in the pot containing the water. After 25 minutes, the indomie had cooked and ready to be eaten. The air temperature reduced to 380C with the collector temperature remaining at 500C.

Figure 1: Picture showing the side view of the box.

Figure 2: Picture showing the inner part of the box painted black to absorb heat.

Figure 3: A picture showing the sliding glass cover with the box slightly open.

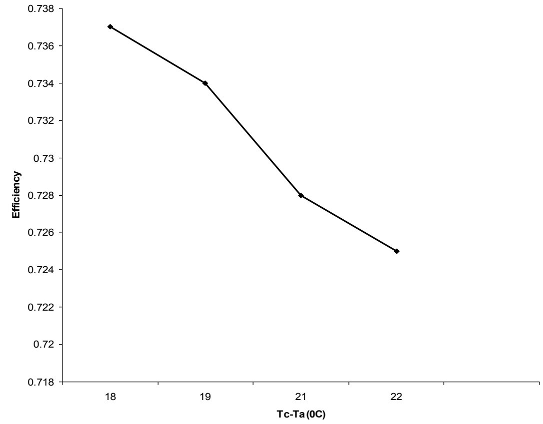

Figure 6: Graph of Efficiency against (Tc-Ta) 0C.

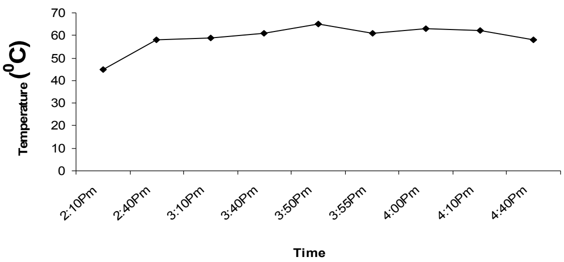

Figure 4: Graph of Temperature against Time.

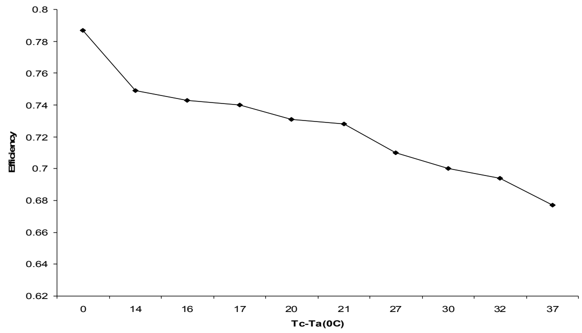

Figure 7: Graph of Efficiency against (Tc-Ta)0C.

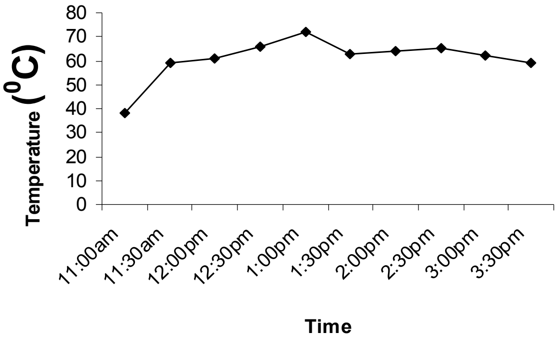

Figure 5: Graph of Temperature against Time.

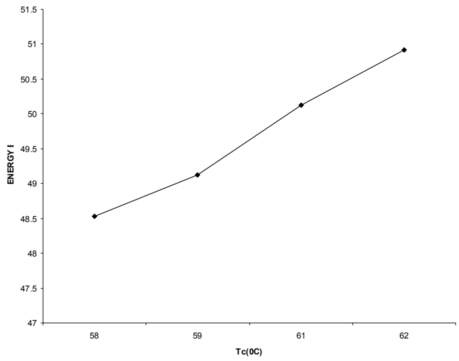

Figure 8: Graph of Energy against collector temperature Tc 0C.

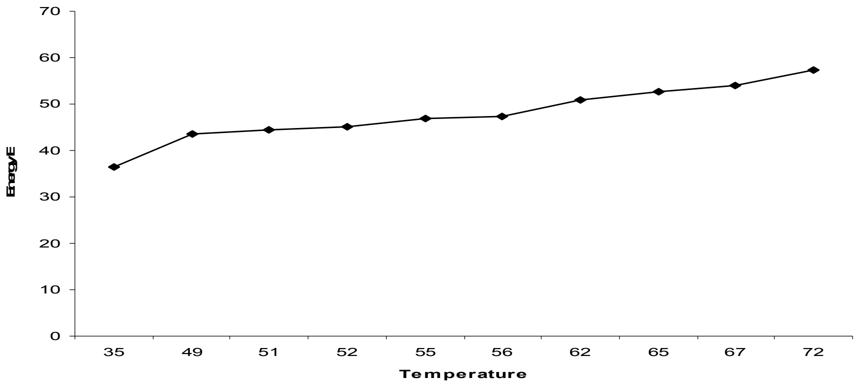

Figure 9: Graph of Energy against Tc 0C.

RESULTS AND DISCUSSION

Experiments carried out show that the highest temperature gotten both on the ground floor and at the top of the roof was 720C both on the days with air temperature of 38 0C and 35 0C respectively. It means that temperature gotten at the top of the roof is same with that at the ground floor. The total cost of the wooden solar box cooker with the mirror, glass, absorber plate and cooking pot was #4500.

Efficiency (n) is not a function of temperature of the collector but a function of the temperature difference between the collector temperature and the ambient temperature (Tc-Ta) 0C. Efficiency of the solar cooker calculated was 96 %. Efficiency increased with decreasing temperature difference between collector temperature and ambient temperature. Increase in temperature does not necessarily mean an increase in efficiency. Efficiency decreased with decreasing solar radiation.

Energy (E) per second radiated by the absorber plate is dependent on the Collector Temperature Tc (0C). Energy increased as collector temperature increased. For the cooking experiment that was carried out, 70 grams pack of indomie which takes about 15 minutes to cook using a conventional cooker was cooked in 25 minutes. This shows that a solar cooking might not be as fast as a conventional cooker but solar cooking is simple, safe and it is a very convenient way of cooking and it works.

In this case the reflectors increased the amount of solar radiations getting into the box.

The maximum temperature of the absorber plate was 72 0C. The reflectors helped to concentrate more sunlight thereby increase the temperature of the absorber plate as shown figs. 4 and 5

In figures 8 and 9, energy increased as temperature increased. Efficiency increased with decreased difference between collector temperature and ambient temperature (Tc -Ta) 0C as shown in figures 6 and 7. Increase in temperature does not necessarily mean an increase in efficiency. Efficiency decreased with decreasing solar radiation. The efficiency and the energy were computed using the relationship given in equations 1 and 3

Efficiency $$n = n_0 - a_1 \frac{(T_c - T_a)}{E_e} - a_2 \frac{(T_c - T_a)^2}{E_e} \qquad 1$$

(Felix A. et al. 2002)

n_0 = efficiency of the collector at zero temperature difference between absorber temperature and ambient temperature.

$$n_0 = \alpha\tau F' \qquad 2$$

α = Absorption factor of absorber plate = 0.93

τ = Transmission factor of cover = 0.895

F' = Absorber efficiency factor = 0.945

$n_0 = \alpha\tau F' = 0.93 \times 0.895 \times 0.945 = 0.787$

a_1= Linear heat transfer coefficient = 2.6 (W/m^2k)

a_2= Quadratic heat transfer coefficient = 0.01 (W/m^2k^2)

E_e= Solar Irradiance = 1000 (W/m^2)

T_c = Temperature of the collector (absorber plate)

T_a= ambient air temperature

For the first experiment, $T_a = 40^0C$

When $T_c = 58^0C$

$$n = 0.787 - 2.6\frac{(58-40)}{1000} - 0.01\frac{(58-40)^2}{1000} \quad n = 0.787 - 2.6\frac{(18)}{1000} - 0.01\frac{(18)^2}{1000}$$

$$= 0.787 - 0.0468 - 0.00324 = 0.737$$

Percentage efficiency.

$$\frac{\textit{Output Efficiency}}{\textit{Input Efficiency}} \times 100$$

$\textit{Output Efficiency}\ (n) =$

$$\text{Efficiency} \quad n = n_0 - a_1\frac{(T_c - T_a)}{E_e} - a_2\frac{(T_c - T_a)^2}{E_e}$$

$$n = 0.787 - 2.6\frac{(12)}{1000} - 0.01\frac{(12)^2}{1000}, \quad n = 0.787 - 0.0312 - 0.00144 = 0.754$$

$\textit{Input Efficiency}(n) =$

$$0.787 - 2.6\frac{(40-40)}{1000} - 0.01\frac{(40-40)^2}{1000} = 0.787, \quad \frac{0.754}{0.787} \times 100 = 96\%$$

Energy Calculation.

Energy (E) per second radiated by the absorber plate is given as:

$E = e\, A\, \sigma\, T_c^{\,4}$ 3

A = Surface area of the absorber plate = L×B 4

L = 0.31m, B = 0.23m, A = 0.31×0.23 = 0.0713m^2, e =1,

σ= Stefan's constant= $5.67\times10^{-8}\ Wm^{-2}K^{-4}$.$T_c$= Temperature of the collector (absorber plate)

When $T_c = 58^0C$ T_c in Kelvin = 331, E= e A σ T_c = 1× 0.0713×5.67 × 10^{-8} × $(331)^4$ = 48.53

Conclusion

A wooden solar box cooker was successfully constructed with cheap and locally available material with efficiency of 96%.From the various experiments that were carried out, the highest temperature gotten both on the ground floor and at the top of the roof was 72^0C both on the days with air temperature of 38^0C and 35^0C respectively.

Efficiency was found to increase with decreasing temperature difference between collector temperature and ambient temperature. Increase in temperature does not necessarily lead to increase in efficiency. Efficiency decreased with decreasing solar radiation.

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