Performance Evaluation of a Double Solar Oven Reflector with Candle Wax As Thermal Storage Material for Domestic Applications

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ABSTRACT

This paper investigated performance of candle wax as thermal storage material for solar oven. The solar oven system uses solar radiation to bake bread. From the experiment carried out it was noticed that the oven with storage material can perform more efficiently than those without storage. The Indian standard method of testing solar thermal was adopted. From the result it was observed that the highest candle wax temperature was 88^0C around 1.00 pmat an ambient temperature of 43^0C while the solar radiation was $1049W/m^2$. Further research should be carried out for more alternative material for thermal storage in order to come up with a material that can give more optimal system performance.

Keywords: *Baking, Candle wax, Solar oven,Temperature and Thermal storage.*

I. INTRODUCTION

In advance search for other alternative ways of baking technology, solar energy becomes a good alternative source of energy for baking in Nigeria. This is because Nigeria is endowed with abundant sunshine of not less than 9 hours per day throughout the year due to its position near the equator (Bald *et al.*, 2000). However, solar oven without a storage cannot be able to replace the other baking technology in Nigeria, but the use of solar energy for baking would save the forest reserves of Nigeria, adequately reduce air pollution from the carbon containing fuels that contribute to global warming and climate change. The need for using solar energy oven with a storage system for baking of bread to supplement the conventional method cannot be over emphasized.

II. METHODOLOGY

General Assembling and Finishing

The wood casing was joined using hinges together with the reflectors and a bating was used in holding the plane glass. Also the oven was painted and the absorber was black in colour. The reflectors (two mirror) of the same size where hugged separately on the box each side. The table and the oven details show the system description is shown in table 1.1 and Figure 1.0below.

Table 1.1: Showing the system description

S/N	Description	Materials
a	Transparent glass	Glass
b	Reflective mirror	Mirror
c	Mirror frame	Wood
d	Absorber plate	Galvanize sheet
e	Opening	
f	Bread container	Galvanize sheet
g	Net	Iron
h	Hinges	Iron
i	Frame	Wood
j	Hanger	Iron
k	Candle wax	
l	Stand	Wood

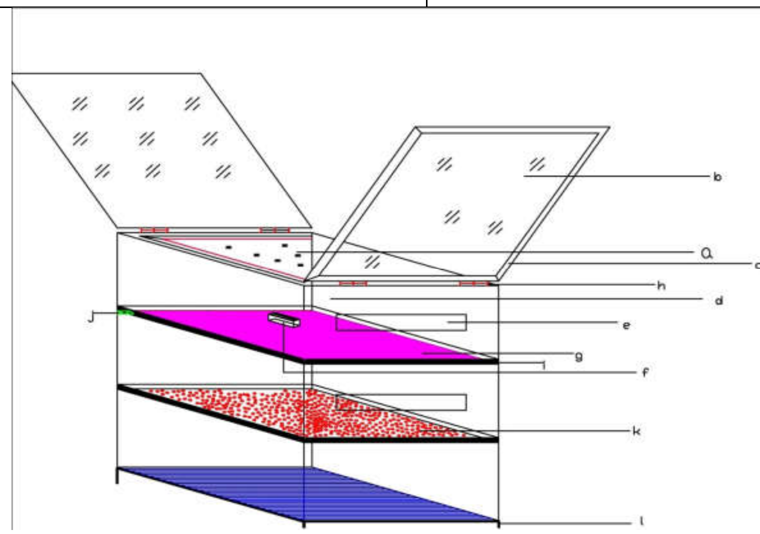

Figure 1.0 Design of the Oven

III. DATA COLLECTION

The India standard provides testing based on thermal test procedures for solar oven. The performance of the reflector based solar oven implemented in this study was done based on India standard, (Ayoola*et al.,* 2014). The method highlighted two tests, the test of stagnation test (test without load) and a load test. The thermometer is used to measure temperatures and pyranometer was used to measure solar radiation and also weighing balance to measure the bread weight, however wind speed was measured by using digital Anemometer and also relative humidity was recorded respectively. The test on solar oven was done on the month of October and it started around 8:00 am to 6:00 pm. Every twenty (20) minutes data was collected and recorded and average hourly data was also computed.

Performance Measures

The performance evaluation of the solar box cooker involve estimation of the following parameters; first figure of merit (F_1), Second figure of merit (F_2) and cooker's efficiency (η).

First Figure of Merit

The figure of merit (F_1) of a solar box cooker is defined as the ratio of optical efficiency (η_o) and the overall heat loss coefficient (U_L) (Purohit and Purohit, 2009).

$$F_1 = \frac{\eta_o}{U_L} \quad \text{....... Equation (1)}$$

Experimentally,

$$F_1 = \frac{T_p - T_a}{H_s} \quad \text{.......... Equation (2)}$$

Where T_p, $T_a$and $H_s$are stagnation plate temperature, average ambient temperature and intensity of solar radiation respectively.

Second Figure of Merit

The second figure of merit (F_2) is evaluated under full load condition and can be expressed by the expression given by (Mohod and Powar, 2011) as follows:

$$F_2 = \frac{F_1(M_b C_b)}{At} \ln\left(\frac{1 - \frac{1}{F_1}\left(\frac{T_{b1} - T_a}{H}\right)}{1 - \frac{1}{F_1}\left(\frac{T_{b2} - T_a}{H}\right)}\right) \quad \text{.......... Equation (3)}$$

Where F_1 is first figure of merit (Km_2w^{-1}), M_b is the mass of bread as load (kg), C_b is the specific heat capacity of bread (J/kg°C), T_a is the average ambient temperature (°C), H is the average solar radiation incident on the aperture of the oven (W/m^2), T_{b1} is the initial bread temperature (°C), T_{b2} is the final bread temperature (°C), ***A*** is the aperture area (m^2) and ***t***is the time difference between T_{b1} and T_{b2} (s).

Cooker Efficiency

The overall thermal efficiency of the solar box cooker is expressed mathematically by (Khalifa*et al*, 2005) and reported by (El-sebail and Aboul, 2005) as follows:

$$\eta_u = \frac{M_b C_b \Delta T}{I_{av} A_c \Delta t} \quad \text{.......... Equation (4)}$$

Where η_u represents overall thermal efficiency of the solar oven; $M_b$mass of bread (kg); C_b, Specific heat of bread *(*J/kg/^{o}C); ΔT*,* temperature difference between the maximum temperature of the baking chamber and the ambient air temperature; Ac, the aperture area (m^2) of the oven; Δt*,* time required to achieve the maximum temperature of the baking chamber; I_{av}, the average solar intensity (W/m^2) during time interval Δt.

IV. RESULT

The results of the variation of the solar radiation, ambient temperature and candle wax temperature with time as shown in Figure 1.1 while the primary vertical axis shows the hourly average values of the temperatures and the secondary vertical axis shows similar result but for solar radiation. The figure reveals that the solar radiation begin to increase from 8.00 am, reaching a peak value of about 1049 W/m^2 around 11.00 am, after which it began to decrease. During this period the candle wax temperature and ambient temperature increase and a peak value was recorded to be 88^{o}C and 43^{o}C respectively. Further observation from the Figure shows that the decrease in solar radiation from 11.00am -6.00 pm was consistent with time and candle wax temperature decrease around 2.00pm. The graph of solar radiation is shown in Figure 1.1 below.

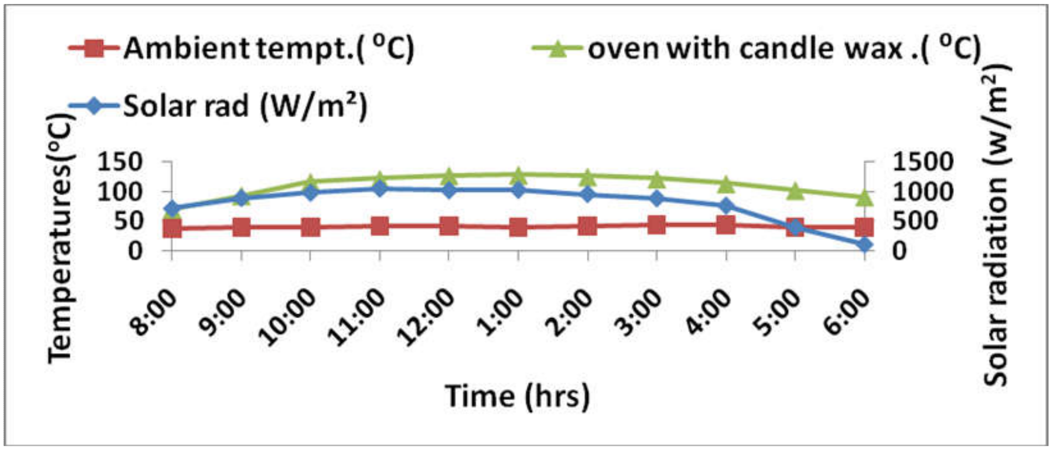

Figure 1.1 Graph of Solar Radiation And Temperatures

The results of the variation of the solar radiation and candle wax temperature with respect to time as shown in Figure 1.2 while the primary vertical axis shows the hourly average value of temperature of candle wax and the secondary vertical axis shows similar result but for solar radiation. The Figure reveals that the solar radiation begins to increase from 8.00 am, reaching a peak value of about 1049W/m^2 around 11.00 am, after which it began to decrease. During this period the candle wax temperature keep increase until a peak value 88°C was obtained around 1.00 pm. Further observation from the Figure shows that the decrease in solar radiation from 11.00 am -6.00 pm was consistent with time.The graph of solar radiation and temperature are shown in Figure 1.2 below.

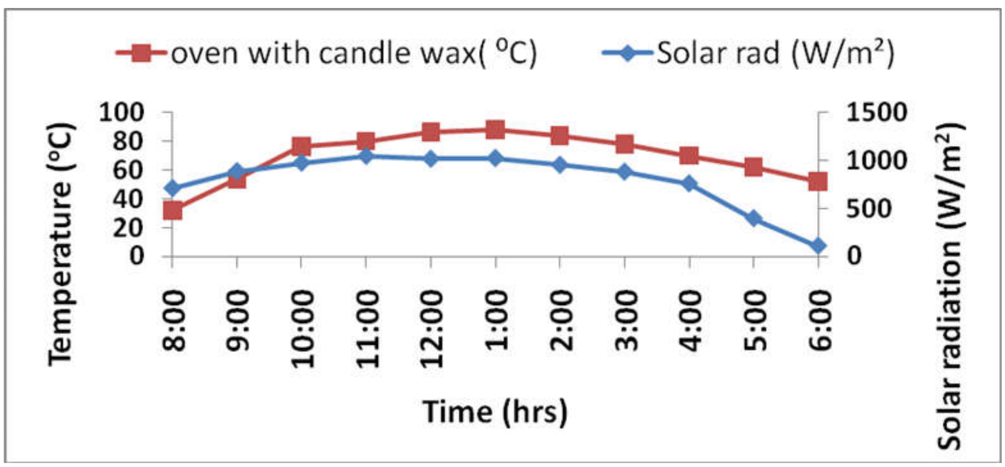

Figure 1.2 Graph of Solar Radiation and Temperature

The results of the variation of the solar radiation and ambient temperature with respect to time as shown in Figure 1.3 while the primary vertical axis shows the hourly average value of temperature and the secondary vertical axis shows similar result but for solar radiation. The Figure reveals that the solar radiation begins to increase from 8.00 am, reaching a peak value of about 1049W/m^2 around 11.00 am, after which it began to decrease. During this period the temperature keep increase until a peak value 43°C was obtained around 3.00

pm. Further observation from the Figure shows that the decrease in solar radiation from 11.00 am -6.00 pm was consistent with time. The graph of temperature and solar radiation are shown in Figure 1.3 below.

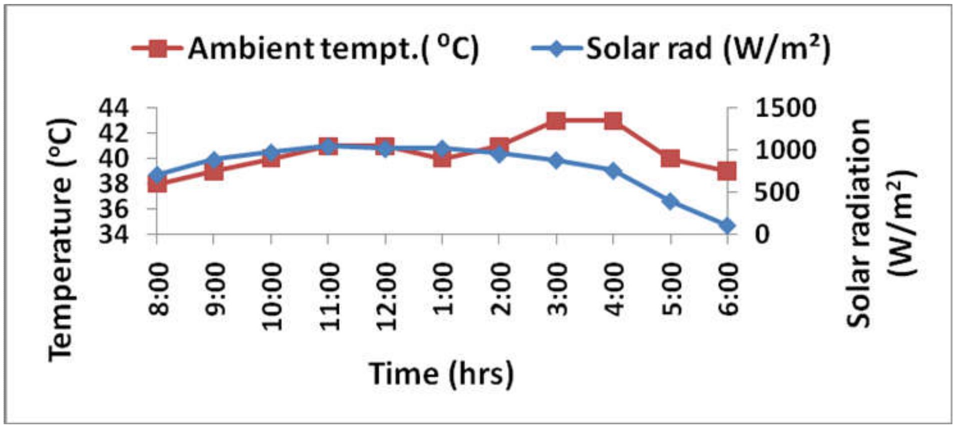

Figure 1.3 Graph of Temperature and Solar Radiation

The results of the variation of the ambient temperature and candle wax temperature with respect to time as shown in Figure 1.4 while the primary vertical axis shows the hourly average value of ambient temperature and the secondary vertical axis shows similar result but for candle wax temperature. The Figure reveals that the candle wax temperature begins to increase from 8.00 am, reaching a peak value of about 88^0C around 1.00 pm, after which it began to decrease. During this period the ambient temperature keep increase until a peak value 43^oC was obtained around 3.00 pm. Further observation from the Figure shows that the decrease in candle wax temperature from 1.00 pm -6.00 pm was consistent with time. The graph of ambient temperature and oven temperature are shown in Figure 1.4 below.

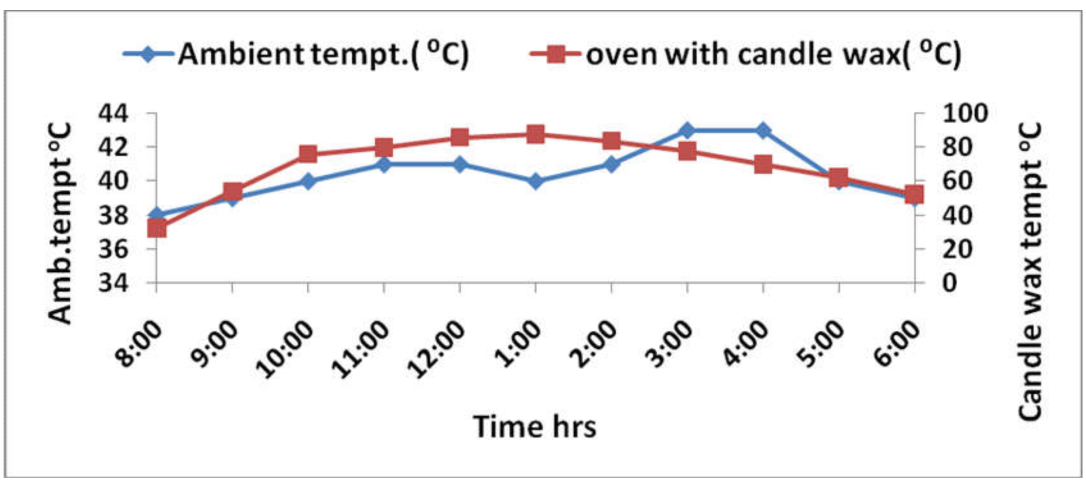

Figure 1.4 Graph of Temperatures

Discussion

The performance evaluation of solar thermal oven was tested based on the relationship between the solar radiation, candle wax temperature and ambient temperature. The result from this study reveals that solar radiation, candle wax and ambient temperature increased with time from 8.00 am to 11.00 am because of the sky is clear while the candle wax temperature keep increasing because of the thermal storage material. Furthermore, the solar radiation and candle wax temperature decreased because of cloud cover this discussion was from Figure 1.1 to 1.4.

V. CONCLUSION

The solar oven work efficiently in the baking of bread using galvanized sheet as absorber plate and also the use of candle wax as thermal storage material has proven to be productive in retaining heat capacity in the oven. We should disregard sole dependency on petroleum products with its abundant green house gas emission into the air due to fossil fuel combustion.Although some limitations were encountered during the execution of this research but it gives room for further research. Therefore we hereby recommended that:

1. Aluminum sheet should be used in construction of solar oven instead of galvanized sheet to compare the oven efficiency ofthe two materials.
2. Further tests should also be carried out during more sunny days or periods of the year and in different climates.
3. The size of the reflectors can also be increased for additional solar radiation.
4. More alternative material for thermal storage should be investigated to come up with one that can give the mostoptimal system performance

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