Assessment of the Impacts of Solar Radiation and Wind Speed on the Performance of Solar Thermal Oven

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Abstract
A solar baking oven was successfully constructed with cheap and locally available materials and was tested. Data was collected during the experiment and was also recorded. The effect of wind speed to the system have become a major concern, due to this limitation, this paper present the effects of solar radiation and wind speed on the performance evaluation of a solar thermal oven. The performance evaluation of the oven in terms of figures of merits and oven efficiency was evaluated based on Indian Standard (IS 13429:2000). The results obtained reveals that the highest temperature of the bread was 78^0C around 1:20pm at an ambient temperature 40^0C at about 2:00pm when the solar radiation was 988.3w/m^2 and also the wind speed was 4.8m/s respectively. It actually shows that the wind speed has effect to the system because the values obtained were high. Further research on this study more alternative material for thermal storage should be investigated to come up with one that can give the most optimal system performance.

Keywords: *Solar radiation, Thermal storage, temperature, efficiency and phase change material.*

Introduction

The continuous process of using firewood in the rural area for baking, cooking and heating had also resulted to deforestation, health hazard, desert encroachment, soil erosion and the reduction or shortage of firewood. The recent research for alternative ways of baking technology in which solar energy becomes a good energy source for baking and other processes in Nigeria. This reason is because our great nation is endowed with abundant sunshine at least 9 hours per day for the whole year depending were the position near the equator. Further, more, solar energy can also be use as water pump for farm and in our various house for water heater, this process of using solar energy can save the forest reserves in the Nigeria. (Bald *et al.,* 2000).

Methodology

Materials/Apparatus Use

The following are the instrument and apparatus use in construction of solar oven;

(1) Plywood
(2) Plank
(3) Reflectors made of mirror (two pieces)
(4) Plane glass
(5) Sand paper
(6) Black paint
(7) Nail
(8) Galvanize sheet
(9) Top gum/silicate gum
(10) Thermometer
(11) Bread container
(12) Pyrometer
(13) Anemometer

General Assembling and Finishing

The wood casing was joint using a 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, therefore all necessary movement is possible to reflect as much as solar radiation that can be attained into the oven chamber, these reflectors help to increases the intensity of solar radiation falling into the baking chamber.

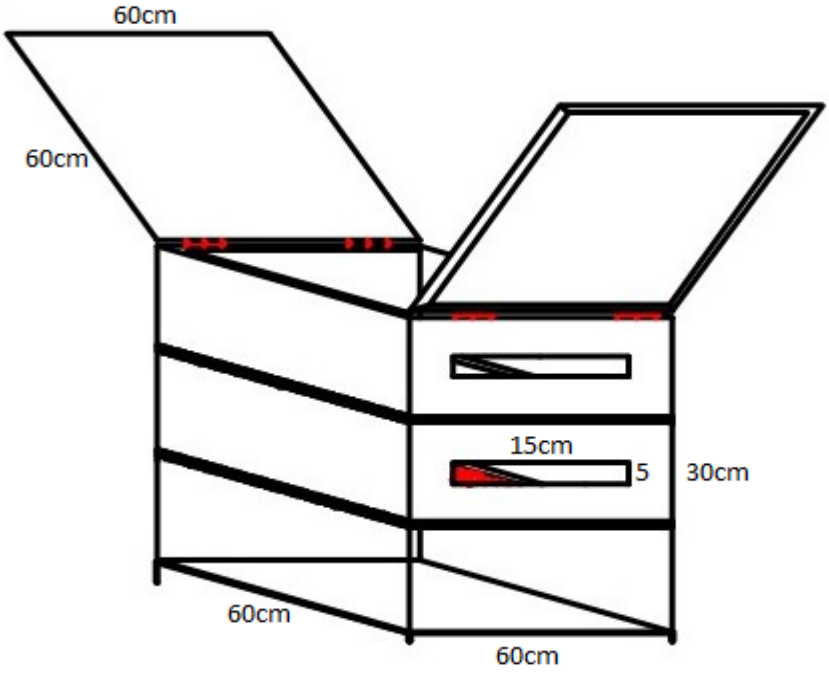

Figure 1.1 The General Assembling

Properties of Materials

Table 1.1 Properties of Materials

S/N	MATERIAL DESCRIPTION	QUALITY/PROPERTIES
A	**REFLECTOR (MIRROR)**	
	Number	Two (2)
	Thickness	4mm
	Emittance	0.92-0.94
	Length and breath	60cm by 60cm
B	**WOOD**	
	Plywood	One and Half sheet
	Plank	six pieces of 2 by 2
C	**ABSORBER PLATE**	
	Inner plate	Galvanized sheet
	Thickness	0.9mm
	Color	Ash in color
	Thermal conductivity	19w/mk
D	**PAN FOR BREAD**	
	Number	One
	Material	Aluminum
	Height of the pan	2m
	Specific heat	0.996kj/kg ^{0}c

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, (IS 13429: 2000 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 pyrometer 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.

Data Evaluation

The performance evaluation of the solar oven involve estimation of the following parameters; first figure of merit (F_1), Second figure of merit (F_2) and oven's efficiency (η). The first figure of merit (F_1) has an equation which is given below

$$F_1 = \frac{T_{ps} - T_{as}}{Hs} \quad (1)$$

Where T_{ps}, T_{as} and H_s are stagnation plate temperature, average ambient temperature and intensity of solar radiation respectively Purohit and Purohit, (2009). Therefore, the second figure of merit (F_2) is given below

$$F_2 = \frac{F_1(M_b\, C_b)}{At\ \ln\left\{\dfrac{1 - \frac{1}{F_1}\frac{(T_{b1}-T_a)}{H}}{1 - \frac{1}{F_1}\frac{(T_{b2}-T_a)}{H}}\right\}} \quad (2)$$

Where F_1 is first figure of merit (Km^2w^{-1}), M_b is the mass of the bread as load (kg), C_b is the specific heat capacity of the 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) Mohod and Powar, (2011).

Finally, the overall efficiency of the system is given below

$$\eta = \frac{M_b\, C_b\, \Delta T}{I_{av}\, A_C\, \Delta t} \quad (3)$$

Where η_u represents overall thermal efficiency of the solar cooker; M_b mass of the bread (kg); C_b, Specific heat of the bread (J/kg/^{o}C); ΔT, temperature difference between the maximum temperature of the bread and the ambient air temperature; Ac, the aperture area (m^2) of the oven; Δt, time required to achieve the maximum temperature of the bread; I_{av}, the average solar intensity (W/m^2) during time interval Δt khalifa *et al*, (2005) and reported by El-Sebail and Aboul, (2005).

Performance Evaluation

The experiments were performed in October using the solar oven in order to test the performance of the oven for baking. The experiment was set up and started around 8:00 am and end around 6:00pm. The first figure of merit (F_1) was calculated by using equation (1) above. Where $T_{ps}=90^0$C, T_{as}, $= 37^0$C and $H_s= 961.3$. Hence $F_1=0.05$. The second figure of merit (F_2) was also calculated by using equation (2) above. Where $F_1 = 0.05$, $M_b = 1$kg, $C_b = 251$ kj/kg^{0}C, At$= 43.2m^2$/s, $T_{b1} = 20^0$C, $T_{b2} = 40^0$C, $T_{as} = 37^0$C and H = 654.4 W/m^2 Therefore $F_2=1.54$. and the overall efficiency (η_u) of the system was calculated by using equation (3) above. Where $M_b = 1$kg, $C_b = 251$ kj/kg^{0}C, $\Delta T = 50^0$C, $\Delta t = 360$s, $A_c = 0.36m^2$ and $I_{av} = 654.4W/m^2$ Therefore $\eta_u=14\%$.

Results

The results of the variation of the solar radiation, ambient temperature and oven temperature with time as shown in Figure 1.2 while the primary vertical axis shows the values of the temperature on the 17th October, 2017, 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 $1095w/m^2$ around 2:20 pm, after which it began to decrease. During this period the oven temperature and ambient temperature increase and a peak value was recorded to be 83^0C and 37^0C. Further observations from the Figure shows that the decrease in solar radiation from 2:20 pm -6:00 pm was consistent with time and oven temperature decrease around 1:00 pm. Similar observation was also made around 1:00 pm when the ambient temperature maintained it steady peak value until around 4:00 pm it decrease. This indicates an inverse relationship between the two parameters at particular intervals.

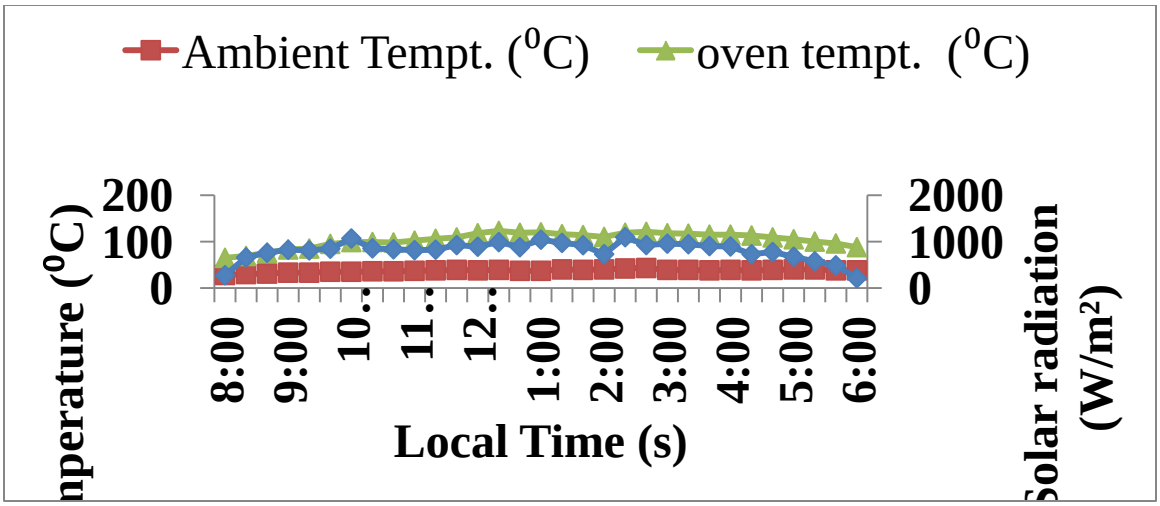

Figure 1.1 The stagnation test

The results of the variation of the solar radiation, ambient temperature and oven temperature with time as shown in Figure 1.2 while the primary vertical axis shows values of the temperatures on the 18th October, 2017, 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 988.3W/m^2 around 11:40 am, after which it began to decrease. During this period the oven temperature and ambient temperature increase and a peak value was recorded to be 79^{0}C and 40^{0}C. Further observations from the Figure shows that the decrease in solar radiation from 12:00 pm -6:00 pm was consistent with time and oven temperature decrease around 1:20 pm. Similar observation was also made around 1:00 pm when the ambient temperature maintained it steady peak value until around 4:00 pm it decrease. This indicates an inverse relationship between the two parameters at particular intervals.

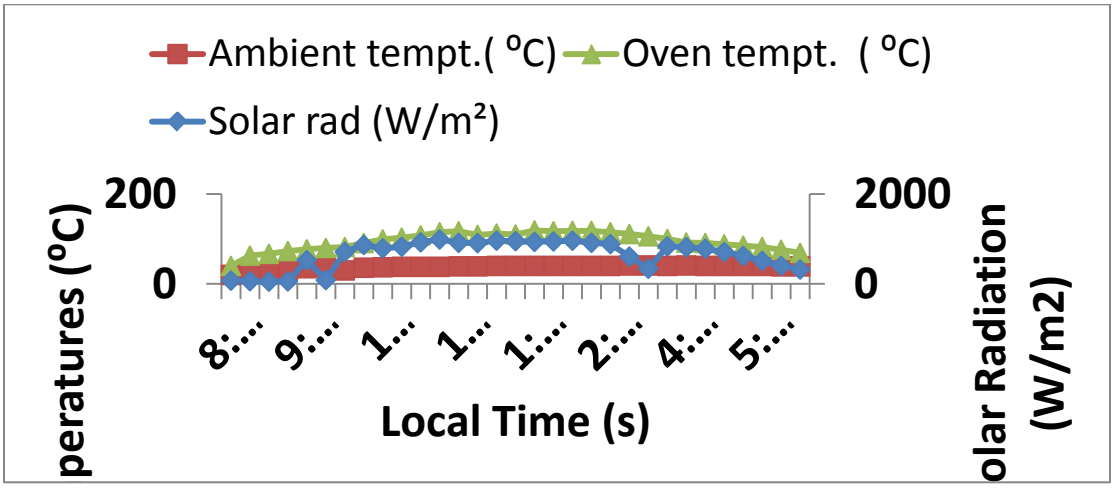

Figure 1.2 The Result of the Oven

The results of the variation of oven temperature with time as shown in Figure 1.3 while the primary vertical axis shows the values of the temperature on the 18th October, 2017, the secondary vertical axis shows similar result but for wind speed. The Figure reveals that the temperature begins to increase from 8:00 am, reaching a peak value of about 79^{0}C around 1:20 pm, after which it began to decrease. During this period the wind speed increase and a peak value was recorded to be 4.8m/s. Further observations from the Figure shows that the decrease in temperature from 1:40 pm -6:00 pm was consistent with time and wind speed decrease and started fluctuating around 12:00 noon which was the exact time solar radiation was high.

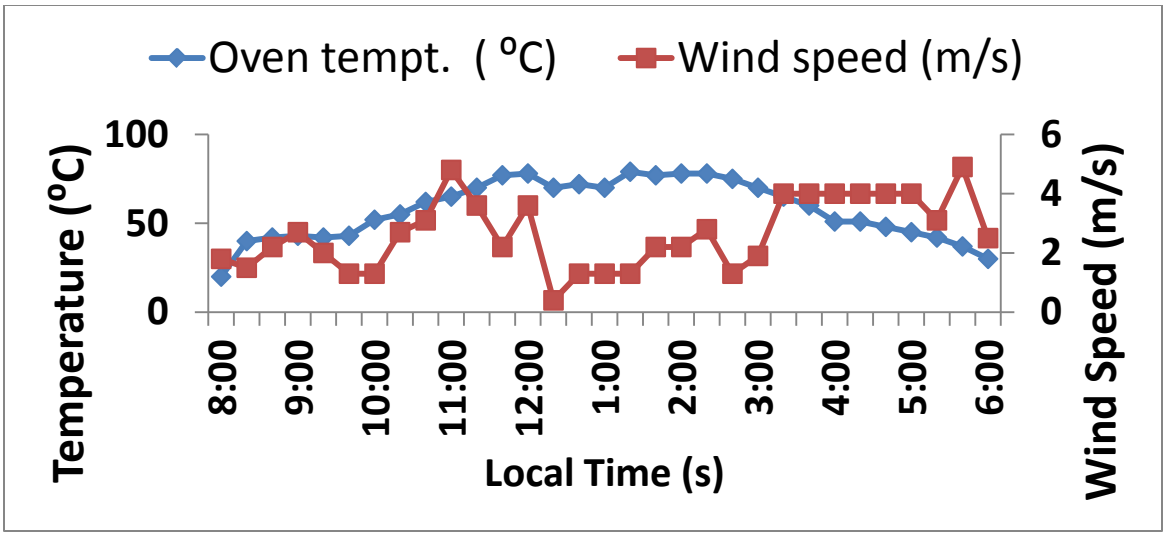

Figure 1.3 Result of Oven Test

The results of the variation of the solar radiation and wind speed with time as shown in Figure 1.4 while the primary vertical axis shows the values of the solar radiation on the 18th October, 2017, the secondary vertical axis shows similar result but for wind speed. The Figure reveals that the solar radiation begins to increase from 8:00 am, reaching a peak value of about 988.3W/m^2 around 11:40 am, after which it began to decrease. During this period the wind speed increase and a peak value was recorded to be 4.8m/s. Further observations from the Figure shows that the decrease in solar radiation from 12:00 pm -6:00 pm was consistent with time and wind speed decrease and started fluctuating around 12:00 noon which was the exact time solar radiation was high.

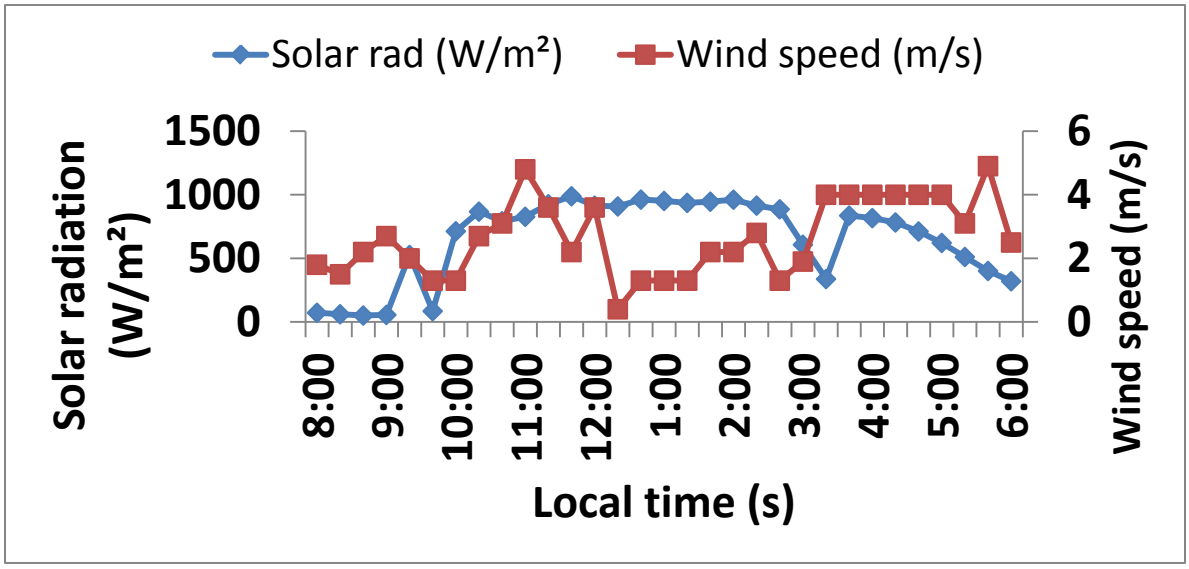

Figure 1.4 Results of Oven Test

Discussion

In this study, a solar oven was constructed and used to bake bread. The performance of the oven was tested based on the relationship between the solar radiation, oven temperature, ambient temperature and wind speed of the oven was also computed. The result from this study reveals that solar radiation, oven temperature, ambient temperature and wind speed increased with time from 8:00 am to 2:00 pm because of the sky is clear while the wind speed fluctuate because of the solar radiation reduced and started fluctuating from the system, however, the oven temperature decrease as solar radiation decreased because of cloud cover when the ambient temperature maintained a peak value because the effect of wind speed to the system. This discussion was from Figure 1.2 to 1.4.

Conclusion

From the experiment that was carried out it was observed that the system worked perfectly well and attained the highest temperature 78^{0}C around 1:00pm that will be able to bake bread. So therefore if solar oven is adopted it will provide a cheap simple and

alternative way for cooking, baking and it will go a long way to reduce the cutting down of trees for fire wood as the solar energy will serves as an alternative energy source to the firewood used by our local people as source of energy for domestic use.

Recommendation

Although limitation was encountered during the execution of this research but it gives room for further research. Therefore the following recommendations are given for further researcher.

(1) To use aluminum sheet in constructions of solar oven instead of galvanized sheet to compare the oven efficiency of the two materials.

(2) Further tests should also be carried out during more sunny days or periods of the year.

(3) More alternative material for thermal storage should be investigated to come up with one that can give the most optimal system performance.

(4) The size of the reflectors can also be increased for additional solar radiation.

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