Design, Fabrication and Performance Evaluation of Solar Brick Oven

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***Abstract*-Bread baking in Maiduguri and environs (north eastern Nigeria) is mainly done in ovens that are fuelled by charcoal sourced from fuel-wood; this process releases harmful greenhouse gasses to the atmosphere with known negative effects on the environment. The demand for fuel-wood as energy source by bakeries and household users is increasing while the resource is becoming scarce and costly when available. These require immediate attention by providing alternative sources that are environmentally safe, less costly and accessible locally, so that overdependence on fuel-wood is greatly reduced. A potentially cost effective alternative energy source that is locally available is the solar energy. Three materials (glass, Perspex and aluminum) were used as window/screen materials for the oven, onto which a parabolic solar collector was focused. All the three materials achieved baking bread at different temperatures and time, Glass oven baked at 90ºC screen temperature and 120ºC oven temperature in 3hours, Perspex oven baked at 150ºC screen temperature and 130ºC oven temperature in 3 ½ hours and aluminum oven baked at 130ºC screen temperature and 150ºC oven temperature in 2hours thirty minutes with solar insolation of 850 w/m^2 on the test day. Glass and Perspex sustained defect at different temperatures and exposure time. It was observed that aluminum screened solar oven produced bread with oven performance efficiency of 16% while glass screened oven produced bread at 63% efficiency and Perspex screened oven produced bread at 51% efficiency. Temperature profiles within and outside the oven were analyzed (with and without load). Analysis of the experimental results showed that solar radiation, ambient temperature and wind velocity with respect to the screening materials were the most influential factors.**

Keywords; Fuel-wood, Solar Energy, Brick, Oven

1.0 INTRODUCTION

Bread baking in Maiduguri and environs (north eastern Nigeria) is mainly done in ovens that are fuelled by charcoal sourced from fuel-wood; this process releases harmful greenhouse gasses to the atmosphere with known negative effects on the environment. The demand for fuel-wood as energy source by bakeries and household users is increasing while the resource is becoming scarce (due to the prevailing insurgency within the sub-region) and costly when available. These require immediate attention by providing alternative sources that are environmentally safe, less costly and accessible locally, so that overdependence on fuel-wood is greatly reduced.

For example in Australia, the cost of cooking meal with gas or electricity is only a few tenths of a dollar, so financial savings attributable to solar cooking are low [1]. In South Africa, however, many people in rural areas do not have access to electricity. Additionally, other fuels such as gas, kerosene, paraffin etc can be difficult to obtain (inaccessibility), inadequate road networks and cost. This justifies the deployment of solar cookers and necessitates research into their operation.

Concentrated solar cookers work on the principles of concentrating the direct solar rays to raise food or water temperatures to cooking level. Cooking temperatures begin at about 65º C, although temperatures of 120ºC to200ºC are preferred [4]. Various designs of the solar cookers were studied in order to optimize their performance. They vary by their geometrical form and the place of the cooking (position). It is reported that an effective solar cooker generally forms part of two categories; one is of box type and the other is with reflectors (parabolic) focusing [4]. Open reflector type solar cookers focus the sun's ray on open cooking pots or pan while solar oven trap the sun's heat inside insulated boxes with transparent lids. Most solar ovens are variations of the bread box type developed by two Arizona women, Barbara Ker and Sherry Cole [1].

The Effect of Geographical Location and the Climatic Condition:

The latitude of the location could significantly affect the design of solar system as reported by [11]. For locations near the equator, a simple parabolic concentrator is desirable. The sunshine hours available and seasonal variations are also very important and can significantly affect the performance of the cooker [1]. On clear days, the performance of solar energy equipment is higher [3]. The monthly average sunshine hours, monthly average solar radiation and monthly average maximum temperature for the location under study (1998-2007) has established that a well designed solar system shall perform effectively [9], see figures 4, 5 and 6.

2.0 MATERIALS AND METHOD

Materials used in construction of concentrator and absorber units:

The concentrator or the paraboloid mirror consists of mild steel rods, sheet metal and segments of back silvered mirror used to form the reflecting surface. The frame was made of square pipe and the absorber which is the oven, is made of common bricks as described in 3 below; the entire oven structure can be moved around with the help of four wheels on the oven frame, two drivers and two followers. A screw knot is used as the paraboloid concentrator adjuster and a mild steel square pipe is used to hold it on the frame.

Absorber Unit; the oven in this case is the absorber, it is made of common bricks with alternative screens (glass, Perspex and aluminum sheets) used to determine the efficiency, temperature and baking time for the ovens. Aluminum sheet is painted with black paint to enhance absorption of the solar radiation; this enhances heat generation due to black body radiation and glass/Perspex heat-up due to green house effect. The baking tins used were also painted black and the oven's interior was packed with few materials to help conserve heat generated.

3. METHODOLOGY AND DESCRIPTION OF THE SYSTEM

Description of the Solar Brick Oven System: Pictures of the solar brick oven system are shown in Figures 1, 2 and 3 made of the following components: A Parabolic Concentrator with reflecting Mirrors, Common-brick (burnt brick) of 70mm thickness and a width of 90mm was used to build the oven, it was arranged on a 5mm x 2" mild steel Angle iron (plate 1). A 10mm thick transparent glass was used at an adequate position to receive solar radiation into the oven; it also allows visualization of the oven activities such as heat build-up, by noting the stages of bread baking, the glass was later replaced with 5mm Perspex and 5mm aluminum sheet as different window screen material, these were later assessed and the best in terms of heat transmission was determined.

Plate1. Brick oven model

Collector design: The principal focal point of the system for solar collection is the parabolic mirror. This optical surface forms a point image on the optical axis and provides a maximum possible brightness of the solar image. The aperture of the solar concentrator is obtained to be (2.25m) as reported by [12];

$$D=\left[\frac{4H}{\pi H_a}\right]^{\frac{1}{2}} \text{---1}$$

Where; H= Solar intensity within the suns image at the focus, H_a = Amount of solar radiation of the area under study (W/m^2).

Determination of the Maximum Concentration Ratio of the Solar Cooker: Concentration ratio is defined as the ratio of the area of the collector to that of the receiver (brick oven screen), or the intensity of the solar radiation to that of the incident solar radiation (53.43) [8]. This is obtained from the following relation;

$$C_m = \frac{4\gamma}{\alpha^2}\left\{1-\left[\frac{16-n^2}{16+n^2}\right]^2\right\} \text{--------------------------2}$$

Where; γ = reflectivity of the applied system The equation used to determine the focal length (0.64m) is given by sayigh [12].

$$f = \frac{D}{n} \text{--3}$$

Where' D = aperture diameter

n= aperture ratio.

The parabola surface area ($3.972m^2$) is given by [6][10] in the following relation:

$$A=\frac{8\pi f^2}{3}\left[\left(\left(\frac{d}{4f}\right)^2+1\right)^{\frac{3}{2}}-1\right] \text{------------------------ 4}$$

Efficiencies of the Solar Ovens were obtained using the following relations, [5];

$$\eta=\eta_o-a_1\,(T_C-T_a)/1000-a_2\,(T_c-T_a)^2/1000 \text{------------------- 5}$$

Where $\eta_o = \alpha \tau F'$

Denotes collector efficiency at 0^oc difference between absorber and ambient temperature.

α.....absorption factor of absorber plate (0.93) i.e Aluminum Bread Tin

Ƭ.....transmission factor of cover (0.895 glasses, 0.92 Perspex, 0.74 aluminum)

F' ....absorber efficiency factor (0.945)

a_1....linear heat transfer coefficient 2.6 w/m^2k

a_2....quadratic heat transfer coefficient 0.01 w/m^2k

E_e....solar irradiance 1000 w/m^2

T_c....temperature of absorber (oven temperature)

T_a....temperature (ambient).

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Fig 1. Glass Screened Solar Brick Oven

Fig 2. Perspex Screened Solar Brick Oven

Fig 3. Aluminium Screened Solar Brick oven

Table 1 Bill of engineering measurements and evaluation

S/No.	Item description	Quantity	Rate (₦)	Amount(₦)
1	Mild steel angle iron 2"x 5mm	3 length	5500	16500
2	Castor wheels	4 pieces	500	2000
3	(18x7x5)cm Common Brick	115	50	5750
4	Electrode	½ packet	750	750
5	Glass screen (18"x18")	1 piece	1200	1200
6	Bonding agent(POP)	2 bags	2500	5000
7	Hinges	1 pair	1000	1000
8	Parabolic Dish Collector	1	15,000	15,000
9	Labour	--------------	-------------	20,000
10	Total	-------------	--------------	67,150
11	Contingency	-------------	10%	6715
12	Grand Total	-----------	-------------	73,865

NB. Item 5 changes for the cost of Perspex and aluminum screens at ₦2500 and ₦3500 respectively.

Testing; After constructing the solar brick oven system, it is put to test by baking three tins (₦100 size, 24x14x9 cm^3) of 0.5kg weight dough at different periods in the respective Ovens. The test was conducted at the Centre for Entrepreneurships University of Maiduguri; this test was conducted in the months of March to June 2015. Results of the test are shown in table 2.

4.0 RESULTS AND DICUSSION

The glass screened oven was able to bake bread at 90^{o}C screen temperature and 120^{O}C oven temperature after three hours period of baking time with average solar radiation of 850 W/m^2 while Perspex screened oven baked bread at 150^{o}C screen temperature and 130^{O}C oven temperature after three and half (3 ½) hours period of baking time with 850W/m^2 solar radiation on the test day fig 7. The aluminium screened oven baked bread at 130^{o}C screen temperature and 150^{O}C oven temperature after two hours thirty minutes (2½) with average solar radiation of 850W/m^2 fig 8 in the month of May with highest ambient temperature records of (54^{o}c) during the investigation period.

Table2. Test results of solar brick ovens.

Oven	(Baking temp. (°C)) Screen	oven	Baking time (hrs)	Solar Rad.(W/m^2)
Glass screen	90	120	3	850
Perspex screen	150	130	3 ½	850
Aluminium screen	130	150	2 ½	850

5. CONCLUSSION

The performance of the solar brick oven System has directly or indirectly contributed in curbing the numerous environmental/social problems highlighted earlier with efficient performance and a sustainable energy source (abundant Solar energy), spanning to several sunshine hours as shown in fig 5. The success of this System is also exciting for Entrepreneurs as it can be adopted for either small or large scale Bread production or house-hold uses.

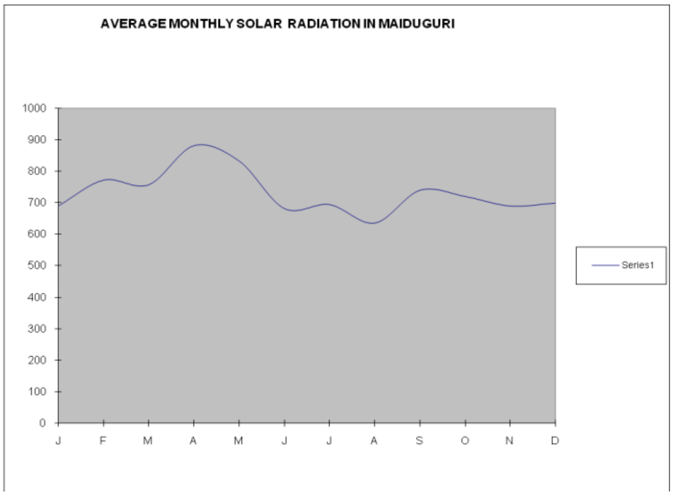

Fig 4. Sources; department of metrological services, Federal ministry of Aviation.

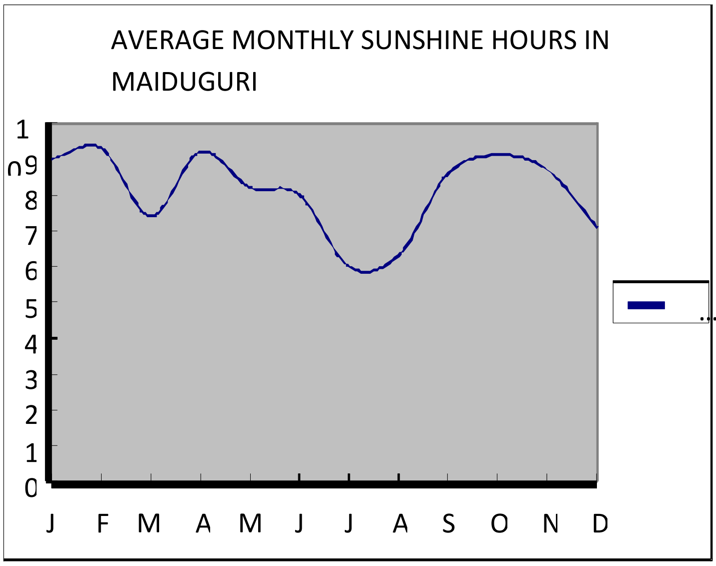

Fig 5. Sources; department of metrological services, Federal ministry of Aviation.

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