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CHARACTERIZATION OF A FIBRE REINFORCED PLASTIC CONCENTRATING SOLAR COOKER

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ABSTRACT: Materials remain the most vital input in engineering construction. Many materials exist for solar cooker fabrication. But much is not known of fibre reinforced plastic (FRP) material in solar cooker fabrication more especially in Nigeria. A concentrating solar energy cooker was designed, constructed and characterized at the National Centre for Energy Research and Development, University of Nigeria, Nsukka, lat 6.8°N and long.7.29°E Nigeria. The study involved construction of mold and a scraper for the construction of the parabolic concentrating solar cooker. The solar cooker has an aperture area of 1.56 m^2 and a focal length of 0.5m with a stand support. The cooker has a manually adjustable thistle for pot positioning and tracking of the sun over the sky. The characterization of the cooker involved both temperature measurements and performance evaluation of the solar cooker using local food stuff. Performance results of the cooker was compared with three other solar cookers - a Japanese made concentrating solar cooker, an NCERD made concentrating solar cooker and a box type solar cooker simultaneously. Indication showed that the fibre reinforced plastic solar cooker was able to maintain maximum and minimum temperature range of 270 and 60°C, and 80 and 33°C under clear sky and cloudy weather while the imported Japanese, NCERD and box type solar cookers maintained temperature range of 350 and 40°C, 250 and 33°C, and 78°C respectively. The cooking test showed that the fibre reinforced plastic concentrating solar cooker performed better than the NCERD and the box type solar cookers, but performed lower when compared to the Japanese solar cooker. Observation showed that the concentrating solar cookers performed poorly under very poor weather showing that the solar concentrator cookers could only be a supplement to other cooking systems rather than being a substitute. The choice of fibre reinforced plastic was basically on the ease of molding, the non-corrosive and longer life expectancy, high strength to weight ratio and high flexural strength which makes it very attractive as a light weight material.

KEYWORDS: characterization, fibre, plastic, solar, cooker.

1 INTRODUCTION

Cooking is an act of preparation of food through the application of heat energy. It is a worldwide phenomenon, which cut across the globe irrespective of race or religion. According to Okonkwo et al (1999) cooking could be achieved by the application of heat through the use of conventional cooking fuels identified as wood fuel, kerosene, liquidified petroleum gas (LPG) and electricity or the use of solar energy for domestic and commercial purposes.

Energy for cooking accounts for about 90 percent of all household energy consumption in the developing countries (GTZ, 2002 and Burgos, 2008). Fuel wood alone accounts for over 50% of the overall energy consumption in Nigeria (Iwu, 1998). About 80% of this is consumed as firewood mainly in the rural areas. The average daily consumption is between 0.5 – 1.0kg of dry wood person. According to Sambo (1994) this is equivalent to 10 to 20MJ per day. A survey of heating technologies by United Nations Industrial Development Organization (UNIDO) in 2005 at Okposi and Uburu communities, Ebonyi State, Nigeria revealed that about 26,000 tons of fuel woods costing about US$1.5 million are used in the communities for salt extraction. The current rate of fuel wood consumption in Nigeria far exceeds the replenishing rate. This results to deforestation, soil erosion, desertification and air pollution with the attendant global warming.

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In order to eliminate the drudgery involved in cooking and improvement on the current technologies of food preparation systems, material selection becomes imperatives. At present, different designs of solar cooking systems ranging from box to concentrating solar types exist in Nigeria. Major considerations have been on the mode of energy collection little or no attention given to materials of construction as an important factor.

Material selection as it is known is one of the most considered factors in engineering practice. Many types of materials have been used in solar cooker construction. These materials range from low cost materials such as mud and paper boards to high cost materials such as steels, mirrors (Seire, 2006) and concrete. Fabricating solar reflectors out of steel is time consuming and expensive and also subject to optical distortion due to fabrication stresses (Warren, 1991). The use of mud and concrete materials are considered to be cumbersome and a burden to carry in most cases. But one material that have not been really given fair consideration in Nigeria for solar cooker construction is fiber reinforced plastic (FRP). FRP is a composite, made up of polyester resins and glass fibers. It is widely used in engineering design because of its high strength, weight, flexibility and ease of fabrication. FRP can withstand large stresses and is considered cheaper than steel and concreted materials.

Construction of concentrating solar cooker requires maximum collector efficiency, which in all respect requires high tolerance construction techniques. In this report the design, development and characterization of a fibre reinforced plastic concentration solar cooker is presented. Light weight and high flexibility to form informed the choice of FRP over other materials in this study.

2 DESCRIPTION OF FIBRE REINFORCED PLASTIC CONCENTRATING SOLAR COOKER

2.1 COMPONENTS DESCRIPTION

The pictorial and diagrams of the fibre reinforced plastic (FRP) concentration solar cooker are shown in Fig. 1. The FRP concentrating solar cooker consists of three essential parts namely the concentrator, the support and the pot trestle. The concentrator is an elliptical shaped structure with 160cm and 124cm as major and minor diameters formed on a mould with circular diameter of 220cm constructed on a platform above the ground surface using block and concrete materials Fig 2. The solar cooker was molded and constructed with fiber reinforced plastic material using a scraper to form the shape. This was left for two days to harden. FRP material is considered suitable because it is easy to mold to size and shape. It is light in weight to be transported and a non corrosive material, an advantage over using mud or concrete materials or steel. The concentrator inside surface is covered with reflective surface for radiation reflection. The concentrator receives solar radiation, reflects and concentrates the same at the focal spot of the cooker. The focal point is 50cm away from the centre of the concentrator. The FRP concentrating solar cooker is mounted on a support, which allows manual rotation of the concentrator to track the sun across the shy. The support is made constructed with mild steel. The trestle holds or carries the pot at a fixed position where it receives concentrated solar radiation at the focal point. The trestle has a rotational rod and horizontal adjustable mechanism that ensures that pots are placed at the focal point during time of cooking. The trestle has a circular diameter of 20cm.

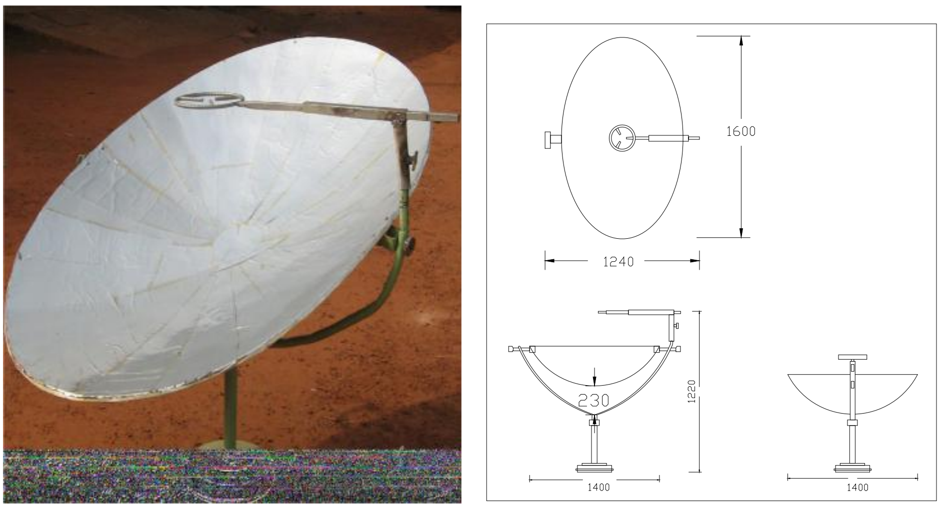

Fig 1: Fibre reinforced plastic solar energy cooker

Fig 2: A mould with FRP materials to form the concentrator and a scraper.

The scraper was developed with Fig.3 generated using equation 1

$$x^2 = 4fy \tag{1}$$

Where,

Y = values on the y-coordinate (depth of reflector)

x = values on the x-coordinate (diameter of reflector)

After plotting the above values on a cardboard paper, it was placed on a metal sheet and cut to shape to form the scraper

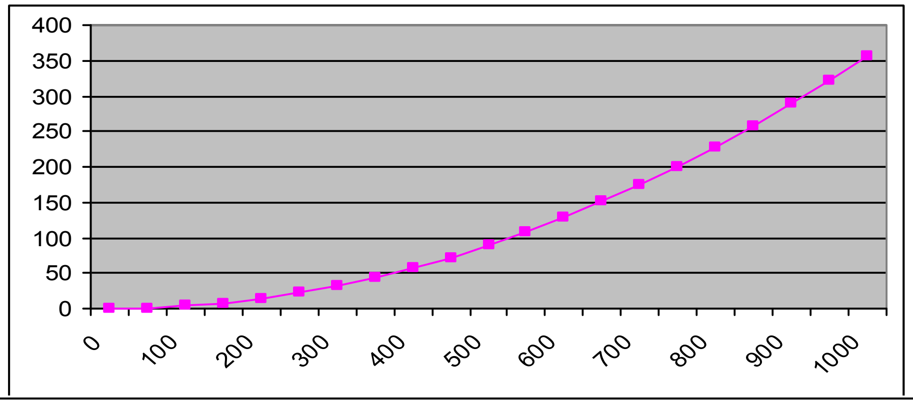

Fig 3: Graph of parabolic scraper

3 Theoretical Considerations

3.1 Design Consideration

Portability, malleability, resistance to environmental conditions and ability to withstand thermal and mechanical stress for a long time are major considerations in this design. The cooker could cook local food stuff under normal circumstances of clear sky sunny day with ease for five persons.

Heat requirement to complete a cooking operation is estimated by

$$q_u = C_p \frac{\partial T}{\partial t} \tag{2}$$

Concentrating solar collectors make use of direct radiation only. The direct radiation incident on the solar cooker is estimated by ASHRAE (1986) as

$$H_{BN} = A\ell^{\frac{B}{\sin\beta}} \tag{3}$$

A and B in the above equation were obtained using Hsieh (1986) with month of February as a reference. The latitude angle was determined by

$$\theta = Arc\sin[\sin\phi\sin\delta + \cos\phi\cos\delta\cosh] \tag{4}$$

h = hour angle, degrees

= ¼(number of minutes from local solar noon)

n = the nth day of the year.

The area of solar collector was determined based on the amount of heat required to accomplish cooking operation. This is given by

$$Asc = \frac{qu}{\eta cHB} \tag{5}$$

$$H_B = H_{BN} x \sin\theta \tag{6}$$

The diameter of the solar concentrator was calculated using

$$D = \frac{\sqrt{4Asc}}{\Pi} \tag{7}$$

The area of point of placement of cooking pot was determined by

$$Ar = \frac{\Pi D_r^{\,2}}{4} \tag{8}$$

The concentration ratio, Cr, was determined by Duffie and Beckman (1980) as

$$Cr = \frac{A_{sc}}{A_r} \tag{9}$$

4 CHARACTERIZATION OF FRP CONCENTRATING SOLAR COOKER

A comparative performance evaluation of the fibre reinforced plastic (FRP) concentrating solar cooker and three others - a Japanese made concentrating solar cooker, an NCERD concentrating solar cooker and a box type solar cooker was conducted at the National Centre for Energy Research and Development, University of Nigeria, Nsukka, Nigeria, lat. 6.8^{o}N and long. 7.29^{o}E. Equal samples of local food stuff to include yam, rice, beans, eggs and water were cooked and boiled using the solar cookers respectively and simultaneously in an open air. Rise in temperature of the cooking samples, the receiver and ambient condition were monitored with thermocouple wires connected to a common switch system and mercury-in bulb thermometers. Measurements were taken at ten minutes intervals. Solar radiation data for the period of the test experiment were collected from the Meteorological Unit of the National Centre for Energy Research and Development, University of Nigeria, Nsukka, Nigeria.

4.1 RESULTS AND DISCUSSION

The results of cooking tests are tabulated in Tables 2 and 3. The results consist of data collected under clear sky and cloudy days respectively. The performance test showed that the FRP concentrating solar cooker maintained maximum and minimum temperatures of 270^{o}C and 60^{o}C, and 80^{o}C and 33^{o}C under clear and cloudy weather conditions. Under the same conditions the Japanese, NCERD made solar cookers, and the box type solar cookers maintained temperature range of 350^{o}C and 80^{o}C, 85^{o}C and 40^{o}C, 250^{o}C and 33^{o}C, and 67^{o}C and 29^{o}C, while the box solar cooker maintained a temperature range of 78^{o}C and 45^{o}C respectively.

Results showed that the FRP concentrating solar cooker was able to cook food under Nsukka climate. The cooking test by FRP solar collector was considered better than the NCERD concentrating solar cooker and the box type solar cooker, however the performance was observed to be lower than the Japanese concentrating solar cooker on both the days of operation (Table 1 and 2). While it took the FRP solar cooker 56, 67, 115, 34 and 23 minutes to cook and boil water, the Japanese made solar cooker took 48, 53, 96, 23 and 17 minutes respectively to cook and boil the same quantity of sampled food stuff under the same weather conditions on a clear sky day. While the Japanese solar cooker showed better performance, the FRP concentrating solar cooker performed better than the other two, the NCERD and box type solar cookers (Tables 1 and 2). The better cooking performance of the FRP solar cooker over the NCERD and the box solar cooker could be attributed to the ability of the FRP cooker to concentrate and converge the incident and reflected rays from the concentrator at the domain of the focal point of the cooker. The contribution of the material of construction may have some contributory effects. The Japanese solar cooker performed better than all others because of design precision and quality of materials used in construction. The cooker is made of a reflective shinning surface of stainless metal sheet while the FRP and NCERD solar cookers were made of aluminum foil, which must have affected their low performance. The solar radiation intensity during the period of the performance test was between 754W/m^2 and 176W/m^2 maximum and minimum respectively. It was observed that the solar cookers performed better on clear sky days than the cloudy days. The indication is that the performance of solar cooker is a function of solar radiation intensity. On cloudy weather, the performances of solar cookers were poor. This further suggests that solar cooking can only be a supplement to other cooking fuel system such as kerosene stoves and fuel wood rather than be a substitute (Okonkwo et al 1999). Figs 4 and 5 show the temperature variations of boiling water with the solar cookers.

Table 2: Cooking test performance of solar cookers on typical clear sky day

Samples	Quantity	Japanese Cooker time (mins)	FRP cooker time(mins)	NCERD cooker time (mins)	Box type cooker time(mins)
Yam	800g	48	56	68	94
Rice	5cups	53	67	83	102
Beans	3cups	96	115	125	152
Eggs	5	23	34	45	87
Water	1400g	17	23	32	116

Table 3: Cooking test performance of solar cookers on typical cloudy day

Samples	Quantity	Japanese Cooker time (mins)	FRP cooker time (mins)	NCERD cooker time (mins)	Box type cooker time(mins)
Yam	800g	118	146	158	123
Rice	5cups	130	165	169	187
Beans	3cups	187	193	225	194
Eggs	5	43	65	68	125
Water	1400g	56	75	79	158

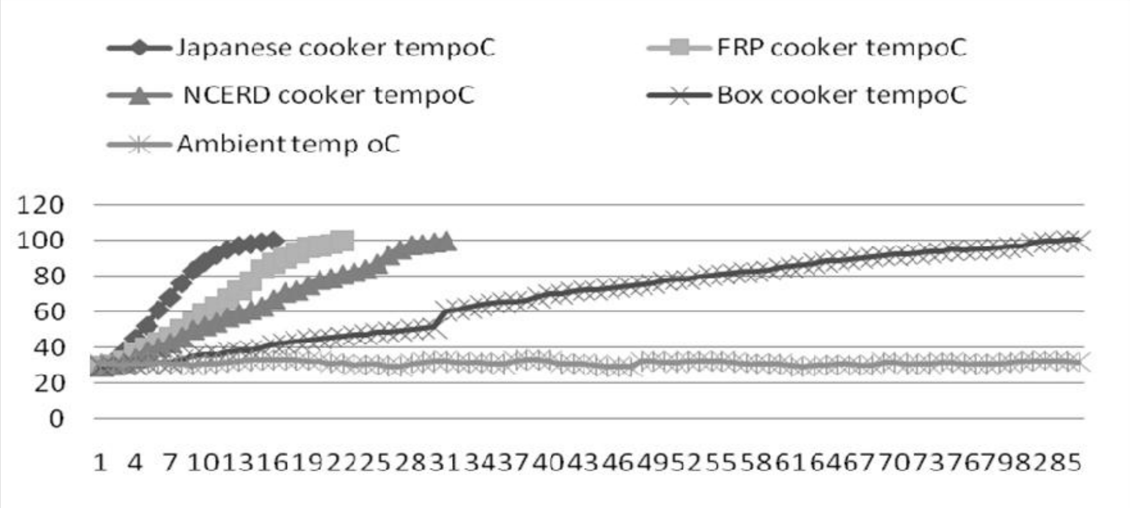

Fig.4: Ambient and Temperature profiles of boiling water by cookers on a typical clear sky day

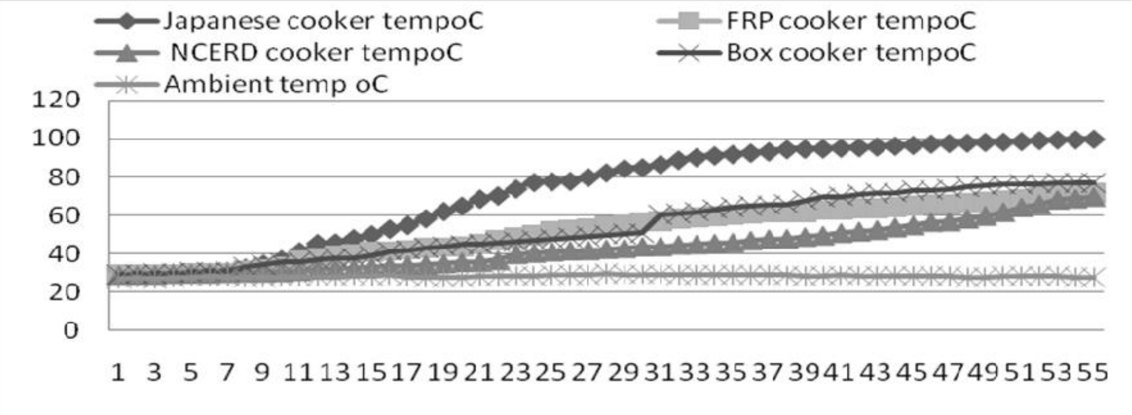

Fig.5: Temperature profiles of boiling water by solar cookers on a typical cloudy day

5 CONCLUSION

The design, construction and characterization of a fibre reinforced plastic (FRP) concentrating solar cooker have been presented. Comparative result analysis showed that FRP solar cooker performed better than an NCERD and box type solar cookers but was however lower in performance operation when compared with a Japanese made concentrating solar cooker. It was observed that solar cookers performed best under clear sky climate. This therefore makes solar cooking weather dependent. Solar cooking could only be supplement rather than a substitute to other cooking systems. The use of fibre reinforced plastic material for solar cooker has advantages of non corrosiveness, ease to form and less weight over other materials.

NOMENCLATURE

q_u	useful heat required for cooking operation, W
M	mass of food, kg
C_p	specific heat capacity of water, kJ/kg^{o}C
T	Temperature, ^{o}C
t	time required for cooking operation, mins
H_{BN}	beam radiation at normal incidence on the cooker, W/m^2
A	apparent solar radiation at air mass, W/m^2
B	atmospheric extinction coefficient, dimensionless
α	solar altitude angle
F	latitude angle, degrees
d	solar declination, dimensionless
A_{sc}	area of of solar cooker, m^2
h	efficiency, %
D_r	diameter of receiver, m

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