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Development of A Novel Double Exposure Solar Cooker And Its Comparative Performance With The Conventional Box Type Solar Cooker

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Abstract: *A developed novel solar cooker is introduced and constructed using the locally available materials. The absorber plate is exposed to solar radiation from the top and the bottom sides. A frame work of parabolic mirror reflector is used to direct the solar radiation onto the lower side of the absorber plate while a plane diffuse reflector is used to direct the solar radiation onto the upper side. This is therefore referred to as double exposure solar cooker. The thermal and cooking performance of the new cooker and the conventional box type solar cooker is extensively investigated and compared. The first and second figures of merit for the double exposure solar cooker were found to 0.17 and 0.48 respectively. While the first and second figures of merits for the conventional box type was found to be 0.11 and 0.22 respectively. Maximum absorber plate and oven air temperature for the double solar cooker are 159.7^{0}C respectively at solar radiation level of 870w/m^2 while the maximum absorber plate and oven air temperatures for the conventional type solar cooker obtained are 110^{0}C and 105^{0}C respectively. The time for cooking various food items was between 30 to 58 minutes and 51 to 110 minutes for double exposure and conventional box type solar cooker respectively. Cooking time for various food items was remarkably reduced.*

Keywords: *Solar cooker, Locally materials, Absorber plate, Diffuse reflector and Air temperature*

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Nomenclature

G	*Global solar radiation (W/m^2)*
A	*Aperture area of cooker (m^2)*
F_1	*First figure of merit*
F_2	*Second figure of merit*
α	*Absorbility of cooking tray*
T	*Transmitting of glass/cover*
V_L	*Heat loss coefficient of solar cooker (W/m^{2}k)*
Ta	*Ambient temperature*
Tw_1	*Initial water temperature (^{0}C)*
T_{w2}	*Final temperature of water (^{0}C)*
(t_2-t_1)	*Time taken to heat the water from Tw_1 to T_{w2} seconds*
$(Mc)w$	*Product of mass of water and specific heat (J/k)*

I. Introduction

The three necessities of life are food, clothing and shelter and their provisions depends on the availability of energy in one form or the other. The priority of any nation depends on the availability of cheap and abundant supply of energy. In Nigeria and many other developing countries, commercial fuels like coal, oil, gas and electricity are not sufficiently available and therefore people mostly depend on fuel wood for cooking purposes. This has brought fast depletion of our forest and therefore increased fuel wood prices which imposes economic and social burden on the people as well as cause ecological problems.

Solar energy offers a possible solution to these problems. One of the practical applications of solar energy is to harness is for partial cooking needs of the people living in areas blessed with abundant sunshine, like Nigeria. The solar energy, if available will be a partial solution to the multitude cooking problems faced by people.

However, there are many factors that affect people's approach to solar cooking. Among these factors are access to materials, tradition cooking fuels, climate, food preferences, cultural factors and technical capabilities (Amer, 2003). Solar cookers (or commonly solar ovens) are of two types, box type cookers and concentrating cookers. In concentrating cookers the radiation is concentrated by a parabolic reflecting surface.

The cooking vessel is placed at the focus of the paraboloid reflector and is, thus, directly heated. This results in a remarkable reduction of cooking time. A common plane in concentrating cookers is food spillage, unless a vapor light vessel is used. Further, some form of tracking is needed which adds to the cost of the device. The box type cooker is the simplest device to collect the incoming solar radiation and convert it to heat energy. Part of this delivered as useful energy to the cooked food. Box type cookers have the advantage of being simple in design and do not cost much; it requires no tracking, which allows unattended cooking (Amer, 2003).

Box type solar cookers are suitable mainly for the boiling type of cooking. The cooking temperature is, in this case, a close to 100^0C. A large fraction of the mass of most food products is due to water, and more water may be added in the boiling type cooking. Loff, (1963) has stated that the quantities of heat required for the physical and chemical changes involved in cooking are small compared to the sensible heat of increasing the food temperature and the energy required for meeting heat losses.

Thus, once heat content of the vessel has been sensibly heated to 100^0C, the speed of cooking is practically independent of the heat rate as long as the thermal losses are supplied. The differences in the time required to cook equal quantities of various foods in cookers are due mainly to different sensible heating periods.

Solar cookers have attracted the attention of many researchers Khalifa (1985) have studied the heat transfer in the cooking process as an approach to develop outdoor and indoor cookers. Channiwala and Sohi (1989) have presented a correlation for the determination of the top loss coefficient in terms of cooking configuration, optical properties and wind velocity.

Grupp *et al*. (1991) have presented a novel design of the box type solar cooker in which the cooker has a fixed cooking vessel in good thermal contact with, the conductive absorber plate. The cooking vessel is also set into a glazing to enable easier access to the vessel. The cooker have been used for boiling water, and it has been reported that 5 liters of water per square meter of opening surface can be brought to full boiling in less than one hour. Sohi (1992) have reported the performance of a solar cooking oven design that collects solar energy and stores it in a phase change material located in a heat exchanger. Suharta *et al*. (2000) have described several generations of solar cookers and other field testing in Indonesia. It has been reported that, an oven temperature up to 175^0C has been reached and that solar oven proved their ability to cook effectively. However, results obtained under the local environmental conditions are very few.

In this present investigation, a developed novel double exposure solar cooker was constructed. The top and the bottom of the cooker are covered with glass and both sides are exposed to solar radiation. The bottom of the cooker receives solar radiation by means of a parabolic mirror reflector while the top side receives solar radiation by means of a plane mirror reflector. The thermal and cooker performances of the cooker were evaluated and compared with the conventional box type solar cooker.

II. Materials And Experimemtal Procedures

The double exposure solar cooker was developed and constructed using the locally available materials. Plate 1 shows the photograph of the double exposure solar cooker.

Plate 1: Photograph of the Double Exposures Solar Cooker

The cooker consists of a box type solar cooker with a double glazed bottom which allows the absorber plate to receive solar radiation on its lower side with the help of a parabolic mirror reflector disposed under the cooker.

The cooker box is provided with a single glass mirror (62cm by 62cm) encased in wooden frame fixed using hinges to the main frame work of the upper side of the cooker. The back of the mirror was protected with plywood sheet. In this manner, the cooker is exposed to solar radiation from two sides. When the cooker is not in use, the hinged glass mirror is used as a cover for the box cooker. The absorber plate consists of a galvanized steel sheet painted black and has a surface area of 60cm by 60cm and 0.15cm thickness. The parabolic reflector is a section of a linear parabolic concentrator. It is made up of rectangular strips of glass mirrors fixed on a wooden frame work of 65cm and 3cm width. The cooking pots used in this evaluation are made of aluminum painted black. Important general considerations in the selection of materials for constructions of the cooker included, local availability, low cost, easy handling during fabrication, lightness of weight for easy handling during use, ability to withstand environmental and operating conditions and non toxic effects. Commercially available galvanized iron sheet (G1) was used as absorber plate, this was painted black to improve its absorptivity. Galvanized iron satisfies good thermal conductivity and high resistance to corrosion. The glazing material was commercially available. Glass satisfies the cover desirable properties of high optical transmittance, low transmittance to heat and low absorbance of solar radiation. Double glazing was adopted as it is most appropriate for the desired temperature elevation. Glass wool was used for insulation, it has low thermal conductivity, it is stable at operating temperature regimes, is cheat and readily available. Commercially available plywood of 0.013m thick was used for the casing, plywood is cheap and readily available, easy to handle during construction and has low weight and rigidity.

The plane mirror was made of commercially available specular mirror, which has the desired property of high optical reflectivity.

2.1 DESCRIPTION OF THE CONVENTIONAL BOX TYPE SOLAR COOKER

The conventional box type solar cooker constructed in this investigation is of the same specifications with the double exposure solar cooker. However, in this case the cooker was only exposed to solar radiation on the top, while the bottom side was covered with plywood.

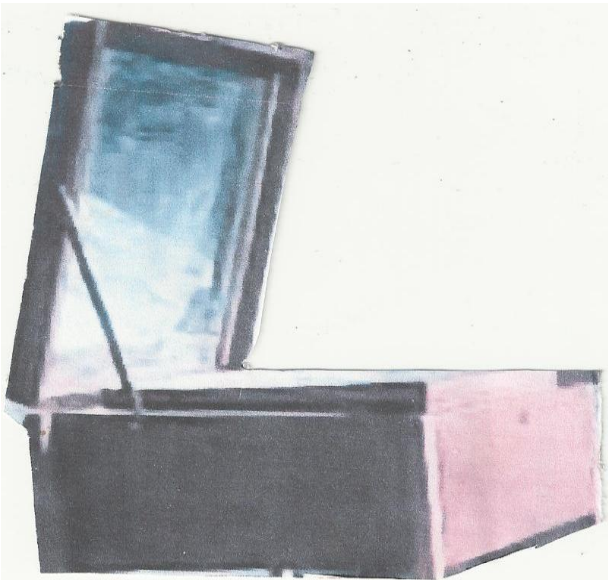

Plate 2: Photograph of the conventional box type solar cooker.

Table 1: Specification of materials used for the construction of double exposure solar cooker

S/N	Components	Material used	Specification
1.	Cooker stand (cm)	Plank wood	120
2.	Outer box (cm)	Plywood	61x61x19
3.	Parabolic reflector (cm)	Mirror	63x3.0
4.	Transparent cover (cm)	Glass	61x61
5.	Plane reflector (cm)	Plane mirror	62x62
6.	Inner box (cm)	Galvanized iron	60x60x18
7.	Absorber plate	Galvanized iron	60x60
8.	Pivoted adjusting bar (cm)	Steel	50
9.	Cooking pot (cm)	Aluminum	2

Table 2: Specification of materials used for the construction of conventional box type solar cooker

S/N	Particulars	Specification	Material used
1.	Outer box cm	61x61x19	Plywood
2.	Transparent cover, cm	61x61	Glass
3.	Plane reflector, cm	62x62	Plane mirror
4.	Inner box, cm	60x60x18	Galvanized iron
5.	Absorber plate	60x60	Galvanized iron
6.	Pivoted adjusting bar, cm	50	Steel
7.	Cooking pot	2	Aluminum

2.2 EXPERIMENTATION

Both the double exposure and the conventional box type solar cooker were extensively tested as per IS 13429 (part 3): 1999 code of testing (Anonymous, 2006). The stagnation temperature and boiling tests for both cookers were carried out to determine the first figure (F_1) and second figure (F_2) of merit for the two cookers respectively. The empty cookers were place on horizontal surface at the same tome for measurement of stagnation temperature. The temperatures of the absorber plates of box 30 minutes continuously using data logger thermocouple with digital temperature indicators. The first figure of merit (F_1) as ration of optical efficiency to heat loss coefficient was determined using equations 1& 2

$$F_1 = \frac{\alpha T}{V_L} \qquad (1)$$

The boiling test for each of the cookers was carried out by keeping 1000g of water in blackened aluminum cooker pots in each of the cookers at the same time as per the test procedure described by IS 134429 (part 3); 1992.

The constant monitoring of water temperature at an interval of 5 minutes with average solar radiation were recorded for both cookers with the help of cmp3 pyranometer, wind speed was also recorded using digital anemometer.

The second figure of merit was determined using:-

$$F_2 = \frac{F_1(mc)w}{A(t2-t1} loge \frac{[1-(Tw_1-Ta/F_1Gs]}{[1-(Tw_2-Ta/F_1Gs]} \qquad (2)$$

Cooking test was also carried out to compare the performances of both the double exposure and the conventional box type solar cooker. The commonly used food items like rice, potatoes, yam, eggs and beans were cooked. The quantity of water used for cooking each food item was measured.

Equal quantity of food items and mixing water were put in two pots of the same size at the different types of food in both cookers was recorded.

III. Results And Discussions

Both the double exposure and the conventional box type solar cookers were constructed and tested at the testing area of Sokoto energy research centre, UDUS ($13^0 4^l$ latitude and $5^0 13^l$ longitude). Stagnation temperature tests i.e no load test for the two cookers was carried out on 2-11-2011 at 9:00am till maximum temperatures are achieved. The two cookers were set to test at the same time. Three different test i.e stagnation temperatures, boiling and cooking tests were carried out for both cookers and compared.

In each of the test carried out, the ambient temperature, plate temperature, wind speed, oven air, and glass temperatures were recorded. The stagnation temperature test result was used to determine the first and second figures of merit for the two cookers using equations 3 and 4.

$$F_2 = \frac{F_1(mc)w}{A(t2-t1)} loge \frac{\left[1-(Tw_1 - \frac{Ta}{F_1Gs})\right]}{\left[1-(Tw_2 - \frac{Ta}{F_1Gs})\right]} \qquad (3)$$

$$F_2 = \frac{0.17(3771}{0.36(40)} loge \frac{[1-(30-34.6)/0.17x773]}{[1-(98.5-34.6)/0.17x773]} \qquad (4)$$

The values of F_1 and F_2 were found to be 0.17 and 0.48 respectively for double exposure solar cooker while 0.11 and 0.22 were obtained as the values of F_1 and F_2 respectively for the box type solar cooker.

Figure 1: Shows a comparison between the absorber plate temperature of the double exposure solar cooker and the conventional box type solar cooker at stagnation test.

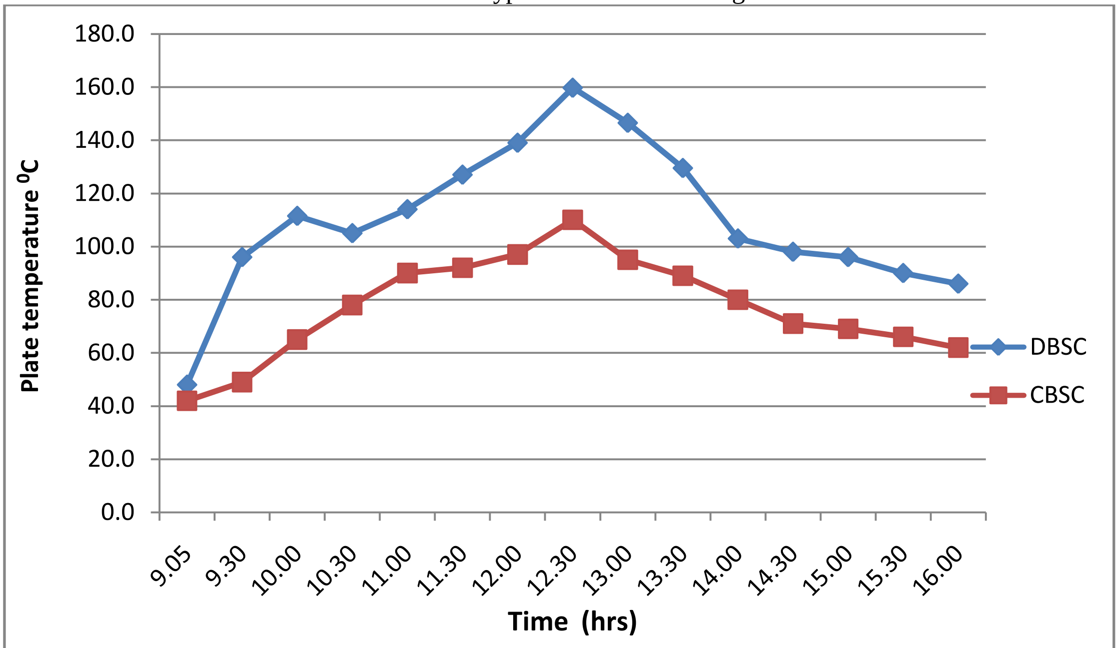

Fig 1: Comparison of plate temperature between double exposure solar cooker and conventional box type solar cooker

Figure 2: Shows a comparison between oven air temperature of the double exposure solar cooker and the conventional box type solar cooker at stagnation test.

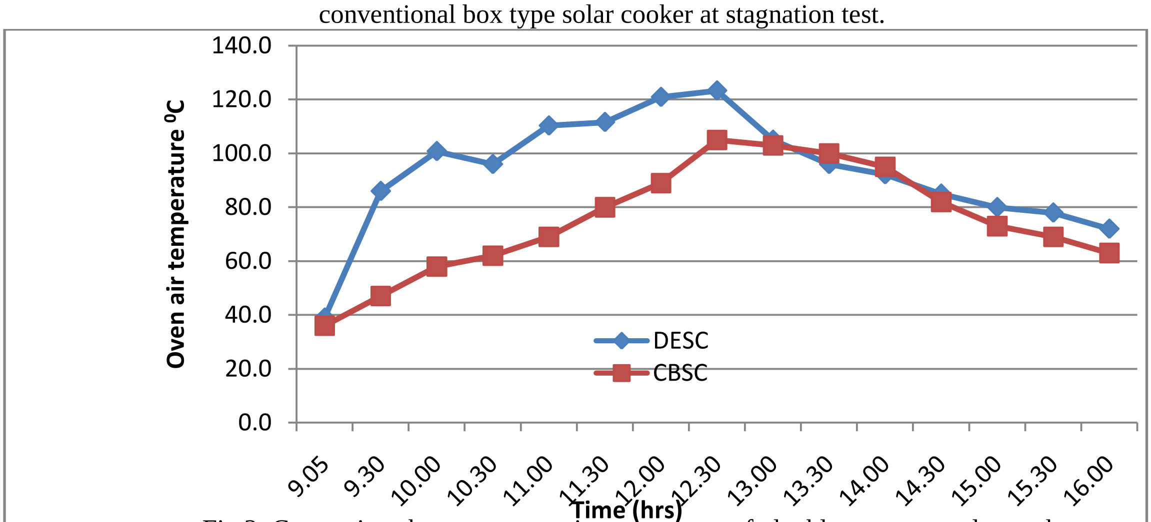

Fig 2: Comparison between oven air temperature of double exposure solar cooker and conventional box type solar cooker with time of the day

3.1 DISCUSSIONS

Both the double exposure and the conventional box type solar cookers were exposed to the sun under steady weather conditions. The wind speed was less than 1.18m/s on average during the day. The changes in the temperature of each part of the two cookers are measured and recorded.

Figure 1 and figure 2 show that the change in temperature has the same trend as that of the solar radiation. It increases at the start and continued to increase till around 12:30nooon and decreases thereafter. Similar behaviour is seen in fig 1 for double exposure solar cooker. However, the order of magnitude of all temperatures is higher than the corresponding values for the boxy type solar cooker. It could be noted that the trend of temperature of the absorber plate in fig 1 increases sharply. This is attributed to the adjustment of the position of the reflectors. However, the obtained values of the first figure of merit F_1 (0.17) for double exposure solar cooker is marked as A- grade cooker. For the conventional box type where F_1 was found to be 0.11 is marked as B-grade solar cooker. The performance test therefore complies with the suggested value of F_1 by (Mullick, 1987). The calculated second figures of merit for the full load test using water as load is (0.48) and (0.22) for double exposure and the conventional box type solar cooker respectively.

COOKING TEST

The field performance of the double exposure solar cooker for the cooking of commonly food items was carried out on 4-11-2011 on a clear sunny day. The cooking performance is shown in table 3.

The cooking performance for the commonly food items i.e. rice, yam potatoes, eggs and beans using conventional box type solar cooker was similarly recorded, and shown in table 4.

Table 3: Food items and their cooking times using double exposure solar cooker

S/N	Food item cooked	Quantity (gm)	Mixing water (gm)	Cooking time required (minutes)
1	Rice	1000	600	45
2	Potatoes	900	400	41
3	Yam	900	400	41
4	Eggs	8nos	500	30
5	Beans	1000	450	58

Table 4: Food items and their cooking time using conventional box type solar cooker

S/N	Food item cooked	Quantity 1gm	Mixing water (gm)	Cooking time required (minutes)
1	Rice	1000	600	90
2	Potatoes	900	400	75
3	Yam	900	400	75
4	Eggs	8nos	500	51
5	Beans	1000	450	110

It is observed that it required 51 to 110 minutes to cook the same quantity of food using the box type solar cooker. While it required 30 to 58 minutes to cook same listed food items using double exposure solar cooker. From the obtained results in table 3 and table 4, it is observed that cooking times for various food items has remarkably reduced when cooking with double exposure solar cooker.

IV. Conclusions

The double exposure solar cooker provides the availability of cooking energy in the house hold. The values for the figures of merit obtained (F_1=0.17 and F_2=0.48) for the developed double exposure solar cooker justifies its high performance as compared to the values of figures of merit of the conventional box type solar cooker (F_1=0.11 and F_2=0.22). The cooking results shows that maximum absorber plate and inside cooker air temperatures for the double exposure and the conventional box type solar cookers are 159.7^{0}C and 123.3^{0}C, and 110^0 and 105^{0}C respectively.

Cooking times for various food items like rice, egg, potatoes, yam and beans using the developed double exposure solar cooker was between 30 to 58 minutes as against the cooking time when cooking with the conventional box type solar cooker which is between 51 to 110 minutes. The results obtained show that cooking times of various food items was ready reduced to half.

The double exposure solar cooker can be used to cook food up to 5 to 6 times a day provided the solar radiation does not fall below 600w/m^2. The obtained values of figures of merit of the double exposure solar cooker F_1=0.17 and F_2=0.48 indicated that, the cooker belongs to category of grade A cooker. While the results of the figures of merit obtained for the conventional box type solar cooker F_1=0.11 and
F_2=0.22 indicated that the conventional box type solar cooker used in this work belongs to category of grade B cookers.

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