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MODEL SOLAR BOX COOKER DESIGNED FOR RURAL HOUSEHOLD ENERGY NEEDS

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ABSTRACT
Water heating was used to evaluate the cooking performance of a solar box cooker developed at the Samaru College of Agriculture, Ahmadu Bello University, Zaria, Nigeria. The test was conducted for 3dys and temperature variations at the intervals of 30minutes were observed for 5hours daily. Ambient temperature (T_a), maximum heating temperature (T_{max}) and the average heating temperature (T_{av}) were found to be important parameters for measuring the performance of the solar box cooker. The results of the study showed that the solar box cooker attained a maximum heating temperature of 82^{o}C at 12:30 pm during the heating period, with an average heating temperature of 77^{o}C. Available literature suggests that food cooking with solar cookers is faster between the two hours before and after the local solar noon (12:00noon) compared to the hours of early morning or late afternoon. The heat absorption rate of the heating water at each time interval was 280kj. The maximum heating temperature of 82^{o}C attained by the solar box cooker suggests that the solar box cooker is quite effective for use as an alternative to both open-fire biomass stove and kerosene stove. It is suggested that a built up provision on the solar box cooker to enable the use of thermometer during observation of temperature variation without opening the box will produce higher heating performance above 82^{o}C.
Keyword: Cooking, heating; Solar box cooker; Solar radiation; household energy source

INTRODUCTION
A significant proportion of Nigeria's population depend on fossil fuels (e.g. kerosene) and biomass fuels in form of firewood, charcoal, animal dung and agricultural waste for cooking and other household energy requirements. About 60-80% Nigeria's population living in the rural areas depend on firewood as the main energy source for household energy requirements (Abubakar, 2010; Abubakar, 2003; Fumen *et al*, 2010; Igboro, 2009). Household cooking and heating accounting for more than 70% of energy needs of most rural households (Bello *et al*., 2010; Bello *et al*., 2003; Bala *et al.*, 2002). Although the cost of rural household energy requirement in terms of cash, may be nil due to the widespread use of firewood and other biomass wastes as energy sources, the equivalent cash expenditure is the value of time used in gathering firewood and the socio-economic loss due to desertification, environmental pollution and soil depletion due excessive deforestation, emission of poisonous gases into the air and failure to fertilize the soil (Otegbeye, 2001). On the availability and affordability of conventional energy sources in rural areas, it is obvious that dependence on such energy sources like natural gas (LPG), kerosene and electricity in Nigeria is characterized by irregular supply, scarcity, incessant unit price increase and their associated environmental unfriendliness (Bello *et al*., 2010). To effectively address the negative impacts of

open fire cooking with solid biomass fuels, insufficient and irregular supply of petroleum products (kerosene and natural gas) and poor electric power supply, solar cooking is the most appropriate and sustainable alternative technology. It has zero emission, free from environmental hazard and is an inexhaustibly available energy source (Sponheim, 2006). It is a vital technology for a more comfortable, healthy and better way of life as it gives rural dwellers a feasible alternative to the costly and time consuming chores of cooking over open fires as well as dangerous time consuming necessity of scavenging for cooking fuels in desolate and dangerous country sides, distressed by famine, wars and political turmoil. Like the development of all other energy sources, the success of solar energy technology will involve a lot of planning, generation and dissemination of information as well as the provision of infrastructures or devices to harness it for efficient and various effective uses (Bello *et al*., 2010).

Nigeria is blessed with abundant amount of sunshine estimated at 3000 hours per annum (Bello *et al*., 2010; Buari and Sambo, 2001). Annual average daily sunshine hours and annual global solar radiation in the Guinea Savannah region of the country have been estimated at 6 hours and 4.5kwm^{-2} per day (Bello *et al*., 2010; Umar *et al*., 2000). Promoting the use of solar cookers would help to slow down deforestation and desertification, caused by using firewood as cooking fuel.

A Solar oven or cooker cooks with direct sunlight, the cheapest and most sustainable energy source on earth. Every morning brings a fresh supply of clean and renewable fuel for solar cooking. Because solar cooking uses no fuel and costs nothing to run, its technology is being promoted worldwide to help slow deforestation and desertification, caused by using firewood as fuel for cooking (McArdle, 2007). A solar cooker is a form of outdoor cooking and is often used in situations where minimal fuel consumption is important, or the danger of accidental fires is high. Solar cooking has many advantages over traditional cooking methods, especially when environmental sustainability is of immense consideration. Using a solar cooker has a negligible environmental impact, as the only energy being used comes from the sun. Direct sunlight is very important for solar cooking, hence if the solar cooker is partially in shadow, food will be unevenly cooked or not at all. Thus for effective solar cooking, ensure that nothing shields the cooker from the sun during cooking. With traditional cooking, stirring, peeking, poking and prodding are all a part of the process. Some dishes are even traditionally stirred continuously. This however is not the case with solar cooking. Essentially there are two types of solar cookers namely box type cookers and concentrator or panel type cookers.

Previous efforts in solar cooking technology development include works of Abang et al (2011); Abubakar (2010); Bell et al (2010); Oyinola (2008); Ogboji (2006); Ocheche (2005); Sambo et al (1993); Oguniyi (2001); Suleiman et al (2003); Danshehu (2003), Olajuyi (2003) and Otegbeye (2001). However, the results of these studies suggest that there is need for more research as the technology is still at its rudimentary stage in Nigeria. Most of the developed solar cookers are still at the laboratory stage which hardly could boil water to a maximum temperature of 88^{O}C and the estimated average solar box efficiency at 48%. This paper is a report of a solar box cooker developed, tested and evaluated for water heating efficiency in Samaru College of Agriculture, Ahmadu Bello University Zaria.

MATERIALS AND METHODS

A solar box cooker with a wooden frame, consisting of an insulated box, transparent glass cover, a reflective glass, an absorber plate or solar collector and an aluminum pots was constructed, test ran and evaluated at Samaru College of Agriculture, Ahmadu Bello University Zaria (Figure 1). The cooker was completely developed with locally available materials such as plywood, polymer foams, nails and screws, glue, hinges/rollers, aluminum sheets, aluminum foil, black paint, plain glass, saw dust etc.

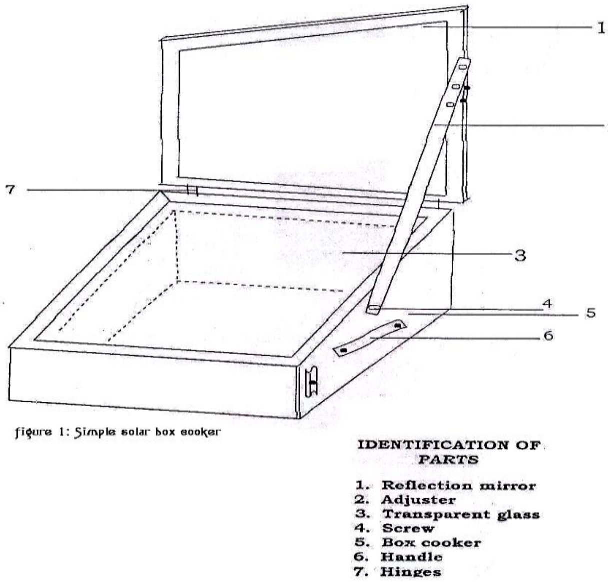

figure 1: Simple solar box cooker

Working Principles of Solar Cookers

A solar cooker is a heat trap which work on the principles of greenhouse effect. The sunlight enters through the glass window or cover. The light is absorbed by the interior of the box. The heat rays or infra-red rays cannot escape through the glass. The trapped solar radiation between the glass cover and the absorber plate is then transferred as heat energy to the cooking pot and its contents on the absorber plate for cooking. Solar box temperature could go up to 120^{o}C or higher on a very hot day, especially in very hot regions like desert conditions. However, most solar cooking is done at the temperature of 80-100^{o}C, within a period of 1-3hours (LCSD, 2011).

Testing and Performance Evaluation of Solar Cookers

For the performance evaluation test of the solar box cooker, a known quantity of water (1 ½ lt) of water was poured into an aluminum pot, painted black. Temperature of water in pot (T_a) was measured and the pot was covered with a lid. The pot was placed inside the cooker and the set up was strategically positioned in front of the College mechanical workshop, where the cooker was fully exposed to direct sunshine. Using a thermometer and stop watch to measure water temperature (T_{if}) during the heating process, the performance test was conducted for three days between October and November of 2011 (25/10, 26/10 and 7/11) at the intervals of 30minutes between the hours of 9:30am and 2:30pm, daily. After the three-day test, temperature variations over the heating periods (Table 1) were recorded and analyzed.

Table 1: Temperature-time variation on solar box cooker water heating performance

Day	Time interval (min)	Ambient temperature (T_a)	Heating temperature (T_{if})
Day1	9:30	26	65
	10:00	27	69
	10:30	28	74
	11:00	29	77
	11:30	30	78
	12:00	31	79
	12:30	30	81
	1:00	30	80
	1:30	29	79
	2:00	28	71
	2:30	27	68
Day2	9:30	26	64
	10:00	27	68
	10:30	27	70
	11:00	30	74
	11:30	30	80
	12:00	29	80
	12:30	28	82
	1:00	28	79
	1:30	27	78
	2:00	27	73
	2:30	26	69
Day3	9:30	26	67
	10:00	27	69
	10:30	28	71
	11:00	29	72
	11:30	30	80
	12:00	31	84
	12:30	30	82
	1:00	30	80
	1:30	29	79
	2:00	28	75
	2:30	27	70

From the analysis, average heating temperature (T_{av}) of the boiling or heating water can be determined from the following expression (Radabaugh, 2011):

$T_{av} = (T_i + 4T_{max} + T_f)/6$ (1)

Where,

T_i = initial heating temperature,

T_{max} = maximum heating temperature,

T_f = final heating temperature.

The two temperatures (Tmax and Tav) can be used to measure the heating performance of the solar cooker. However, if the insulation is poor or there is more thermal losses due to wind, then the solar box will heat slowly and lose heat faster, thereby reflecting in the initial (T_i) and final (T_f) temperatures.

To test the solar box cooker and compare it with other solar cookers, maximum temperature corrected ($T_{max}C$) and average temperature corrected ($T_{av}C$) were also determined through the following expressions:

$T_{max}C = T_{max} - T_a$ (2)

$T_{av}C = T_{av} - T_a$ (3)

Where,

T_a = ambient or temperature of water in the pot before exposure to the sunshine. Heat absorption rate of heated water at each interval of heating can also be determined through the following expression (Abubakar, 2010; Ocheche *et al*., 2011):

$Q = mc\Delta T/t\Delta$ (4)

Where,

Q = heat absorption rate (kj/min),

m = mass of water in pot (kg),

c = specific heat capacity of water (kj/kgk),

ΔT = temperature change in water (k), and

Δt = time (min).

The mass and specific heat capacity of the cooking pot, in this case were neglected.

RESULTS AND DISCUSSION

The mean temperature variation observed during the 3-day performance evaluation of the solar box cooker is presented in Table 2.The results show that from the ambient temperature of 26^{o}C, the solar box cooker attained maximum temperature of 82^{o}C within a period of 3hours, with an average heating temperature of 77^{o}C. This implies that like most solar cooking, the solar cooker cooks slowly at the temperature of 80-100^{o}C, within a period of 1-3hours (LCSD, 2011). Cooking at low temperatures, using solar box cooker has the advantage of retaining much of food nutritional value and flavor and the chance of burning food is very low.

The mean maximum heating temperature was attained at 12:30 pm, suggesting that a solar cooker cooks faster in the two hours before and after the local solar noon than it does in either the early morning or the late afternoon (McArdle, 2007; Yaffe, 2007; Halacy and Halacy, 1992). Using the given equation (eq.iv) above, the heat absorption rate of the heated water at each interval of heating time was 280kj.

Having an average heating temperature of 77^{o}C, the solar cooker can be used for toasting bread which is to do within 30minutes in a heated box at a temperature range of 60-70^{o}C pasteurization of water which helps to prevent water borne diseases due to contaminated water in rural communities. Soap making, which involves melting of glycerine base soap at 60^{o}C to add fragrance and essential oils, can be done effectively with a solar box cooker (LCSD, 2011).

Table 2: Mean temperature-time variation on solar box cooker water heating performance

Time interval (min)	Ambient temperature (T_a)	Heating temperature (T_{if})
9:30	26	64
10:00	27	69
10:30	28	72
11:00	29	78
11:30	30	80
12:00	31	81
12:30	30	82
1:00	30	80
1:30	29	78
2:00	28	70
2:30	27	67

CONCLUSIONS

The cooking performance of the developed solar box cooker was calculated on the basis of temperature variations observed during the 3-day evaluation test and the following conclusions were drawn:

i. The solar box cooker heated water to a maximum heating temperature of 82°C.
ii. Time taken for the water temperature to rise from 26°C to 82°C was 3hours hours.
iii. The average heating temperature of the solar cooker was 77°C.
iv. The heat absorption rate of the heating water at each time interval was 280kj.

The maximum heating temperature of 82°C attained by the cooker suggests that the developed solar box cooker is quite efficient for optimum use during the periods of investigation. It is suggested that a built up provision on the solar box cooker to enable use of thermometer during observation of temperature variation without opening the box will produce higher heating performance above 82°C.

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