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Use of solar cooker in Nigeria

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Abstract

The sources of energy used in cooking in most Nigeria homes are fossil fuel and biomass. The fuel is becoming expensive beyond the reach of common person. There is need to source for suitable alternative. Therefore, the work focused on use of solar cooker for cooking some staple food in Nigeria. Preliminary study was carried out to quantify appropriate water requirements for cooking some staple foods (rice, bean, maize and yam) in Nigeria. Four levels of crop-water ratio was use in cooking on electric stove. Used quantity of water was determined by material balance analysis. Solar device was used to cook rice, beans, yam and fish. In addition was baking of cake. Temperatures of device were recorded when un-loaded and loaded. Water required to cook a given quantity of rice was 1.25 times the quantity of rice. To cook a given weight of beans about 1.4 times of water by weight was used while1.63 times the quantity of the maize was required. Yam was properly cooked by water of 0.2 times weight. Mean stagnation temperatures of the solar device were 134 ± 8.9°C, 120 ± 6.2°C and 121 ± 7.1°C for first, second and third year respectively Jollof rice (520 g), beans (420 g) and yam (1400 g) were properly cooked in 50, 60 and 50 minutes respectively. In addition, flour (650 g) was successfully baked into cake after 60 minutes. The study reinforced the views that solar devices can play a major role in solving Nigerian's domestic energy problem especially in the rural areas rather than being a novelty demonstration of solar energy use.

Introduction

Solar energy is clean, renewable, abundant and available in the tropical region of the world. Its increased utilization would result in an all-round benefit, both in terms of cleaner environment and monetary gain, for the individual users as well as the nation (Ghobeity and Mitos, 2012). The earth receives annually, energy from the sun amounting to 1×10^{18} kWh (Ahmed, 2012). This is equivalent to more than 500000 billion barrels of oil or about 1000 times the energy of known reserves of oil or more than 20000 times the present annual consumption of energy of the whole world.

Due to her geographical location (lying between 4 and 14° north of the equator), Nigeria is blessed with a significant level of solar insolation. The country receives about 5.08×10^{12} kWh of energy per day from the sun, and if solar appliances with 5% efficiency are used to cover 10% of the country's surface area, then 2.54×10^{6} MWh of electrical energy, from solar energy resource, which is equivalent to 4.656 million barrels of oil per day will be realisable (Aremu, 2004). There are between 2000 – 3000 hours of sunshine per year in Nigeria translating to between 3.5 – 7 kW/m^2/day of energy being received from the coastal latitude to the far North (Okonkwo and Mageswaran, 2001). A major aspect of food preparation in the home is cooking. Cooking is the process of treating food with heat in order to enhance its taste and nutritional value. Energy is therefore essential if adequate food supplies are to be converted into adequate diets.

The technology of solar cooking involves the conversion of solar energy to heat energy. The heat is then directed to cooking pot for food preparation. Solar cooking systems could be box type, concentrating type or a hybrid of the two. Box-type solar cooker makes use of both diffuse and direct radiation while the concentrating type depends on its ability to make use of direct radiation only. The performance of box type solar cooker depends on many parameters such as climatic parameters, design parameters and operational parameters. Previous work on use of solar energy in food processing including using solar tunnel drier to dry hot red and green chillies under the tropical weather conditions of Bangladesh (Hossain and Bala, 2007). The study concluded that use of a solar tunnel drier and blanching of sample led to a considerable reduction in drying time and dried products of better quality in terms of colour and

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pungency in comparison to products dried under the sun. Akinoso (2009) also reported development of solar device of high heat collection and conserving capacities, with the maximum temperature reaching 134°C when in use as cooker. Temperature in the cooker was 74°C after 5 hours after shut down.

Cooking using firewood has led to wood shortages. Search for wood by people, which include pregnant women, infants and elderly people has become increasingly difficult as heavy loads of wood have to be carried over long distances. In addition, many families now avoid nutritious foods such as beans which require hours of cooking and instead substitute faster-cooking but less-nutritious foods. The use of firewood requires constant attendance to the fire and stirring of the food to prevent burning. The pot is covered by soot on the outside and food sticks to the bottom inside, wasting food and causing extra work to clean. There are dangers of wind spreading big fires and small children falling into open fires. Smoke from the fire causes lung and eye diseases. The cost of replacing cut trees is the market price of cut wood the proceeds of which are never used to replace the cut trees. Extraction of crude oil and coal from the earth and felling of trees for fuel, disrupt the natural ecosystem. Using solar energy for cooking affords man the opportunity to live in a more natural environment.

According to Funk (2000), the United Nations Food and Agricultural Organization statistics indicated that 2.4 billion people would be facing fuel wood shortages by the year 2001. This statistics may translate to the fact that in the nearest future, about half the people on earth will not be able to cook supper (Funk, 2000). Presently, there are increasing amounts of the greenhouse gases, (carbon dioxide and nitrous oxide) in the atmosphere. This phenomenon is known as global warming and is a product of intensive use of fossil fuels and the destruction of the tropical rain forests. There is need to source for suitable alternative. Therefore, the work focused on use of solar cooker for cooking some staple food in Nigeria.

Materials and Methods

Description of solar device used for the study

A box-type solar device was used for the study. The base dimensions of the box were 78.5 mm x 78.5 mm while the side dimensions were 78.5 mm x 100 mm x 760 mm. The inner box of each cooker was fabricated using 3 mm thick hardboard. The base dimensions were 360 mm x 360 mm. The four slanting sides were inclined at 45° to the horizontal and measured 600 mm x 360 mm x 170 mm. The box

Plate 1. Solar cooker used for the research

has a double wall glass cover made from tempered float glasses were framed using *terminable superb* (Afro) wood. Additional component of the device is reflector lid made from aluminium foil to boost the energy production in the cooker, improve insulation and protect the glass covers when closed (Plate 1).

The cooking pot

Cooking pot used in the experiment was made of aluminium sheet of 1.4 mm gauge. The diameter of the pot is 250 mm and it has a depth of 80 mm. It was painted with flat black paint on the exterior. The special features of the pot are the red-like projections attached to the underside of the lid. The projections are 60 mm long and are six in number arranged around the circumference of the inner side of the lid. These are to ensure faster heat transfer from the top into the food and increase the area of conduction heat transfer to the food.

Determination of water requirement for cooking

Preliminary study was carried out to quantify appropriate water requirements for cooking some staple foods in Nigeria. The food items used for the study were three varieties of rice; *Siemes*, *Ilesha*, *Dangote* (*Oryza* spp), four varieties of bean; Drum, *Zobo* Drum, *Oloyin*, (*Vigna* spp.); three varieties of maize: TZB – SR, AK 96 DMR- ISRW, SUWAN2 - SR, (*Zeamerg*) and three varieties of yam; *Efuru*, *Lasinrin*, *Okunmado*, (*Diascorea* spp). The choice of these staple foods were based on cooking times; as rice belongs to the easy-to-cook category of food, yam belongs to the medium category and beans and maize belong to the hard-to-cook category of food. Moreover, these foods are common to all the tribes in Nigeria.

These food items except maize were procured from a local market in Nigeria, and hence most of the names given above are the popular names by which they are identified with in the market. The maize was obtained from International Institute of Tropical Agriculture (IITA). The moisture content of these samples were determined using ASAE Standard

(ASAE, 2008) before and after cooking the foods. Four levels of crop-water ratio was use in cooking on electric stove (1 kW). Used quantity of water was determined by material balance analysis (Equation 1).

$$A + B = C + D \qquad (1)$$

Where
A is the mass of raw food item
B is the mass of water added for cooking
C is the mass of cooked food
D is the mass of steam that has evaporated or otherwise.

Rice cooking

A sample of 150 g each of a variety of rice was put in 3 pots and 345, 517.5 and 690 g of water by weight were added to the pots respectively. This translated to 1:2, 1:3 and 1:4 by volume of rice to water ratio. These were cooked and the moisture content of three randomly selected 10 g samples of cooked rice from each of the pots were determined by oven-dry method. This procedure was repeated for the other two varieties.

Beans cooking

A sample of 135 g each of a variety of the beans was put in 3 pots and 517.5, 690 and 862.5 g of water by weight were added to the pots respectively. This translated to 1:3, 1:4 and 1:5 by volume of beans to water ratio. These were cooked and the moisture content of three randomly selected 10 g samples of the cooked beans from each of the pots were determined by the oven-dry method. This procedure was also carried out on the other two varieties.

Maize cooking

A sample of 125 g each of a variety of celled maize was put into three pots containing 517.5, 690 and 862.5 g of water by weight respectively. This translated to 1:3. 1:4 and 1:5 by volume of maize to water ratio. These were cooked and the moisture content of three randomly selected 10 g samples of the cooked maize from each of the pots were determined as mentioned earlier. This procedure was also carried out for the other varieties.

Yam cooking

Movement of moisture in yam has a direct correlation with the surface area. Hence, to ascertain a specific uniform surface area for the yam slices used, a special cylindrical module was used to cut out yam slices. Sample of 114 g of two slices of a yam variety each with surface area of 90.58 cm^2 was replicated into three pots. 172.5 g, 129.4 g and 86.3 g of water by weight were added to the pots respectively. These were cooked and the moisture content of three randomly taken samples was determined. Initially, the moisture content of 10 g randomly taken sample of the raw yam varieties was first determined. The difference between the moisture content of the cooked samples and the raw samples in addition to loss factor gives an idea of the water requirement to cook yam. The procedure was then repeated for the other varieties.

Cooking test using solar device

This was carried out to evaluate the time taken to cook a certain quantity of food using the solar cookers. A known weight of raw food was placed in the cooking pot. An amount of water (as determined in the experiment on water requirement to cook a given quantity of food) was added to the raw food. The loading and unloading time (time taken for cooking) were noted and recorded. The foods were tasted/ tested at 10 minutes intervals for first 30 minutes of cooking and subsequently at 5 minutes until it was properly cooked (Akinoso, 2009).

Cooking power

Cooking power (in Watts) was chosen because it reflects both capacity and rate (Funk, 2000). To determine the cooking power, the water temperature in the cooker was recorded at intervals not to exceed ten minutes to the nearest one tenth of a degree solar insolation (Wm^{-2}) and ambient temperature (^{o}C) recorded as frequently (ASAE, 2002). The change in water temperature for each ten-minute interval was multiplied by the mass and specific heat capacity of the water contained in the cooking pot. This product was divided by the 600 seconds contained in a ten-minute interval. Equation 2 was used for calculation of cooking power. The average insolation at average ambient temperature and average cooking vessel contents temperature was found for each interval. Cooking power for each interval was correlated to a standard insulation of 700 Wm^{-2} by multiplying the observed interval cooking power by 700 Wm^{-2} and dividing by the interval average insolation recorded during the corresponding interval (Equation 3). The cooking power prediction model was validated by comparing observation from tests of the box cooker with model performance predictions to determine fitness.

$$P = \frac{(Tf - Ti)MCw}{600} \qquad (2)\ (\text{ASAE, 2002})$$

$$P_s = \frac{Pi700}{Ii} \qquad (3)\ (\text{ASAE, 2002})$$

Where
P = cooking Power in watts
T_f = final water temperature (°C)
T_i = Initial water temperature (°C)
M = mass of water (Kg)
C_w = Heat capacity of water (4186 $Jkg^{-1}K^{-1}$)
P_s = standardized cooking power (W)
P_i = interval cooking power (W)
I = interval insolation (Wm^{-2})

Results and Discussions

Water required for cooking rice

Table 1 shows the results of cooking experiments for rice varieties with varying quantities of water maintaining a rice water ratio of 1:2, 1:3 and 1:4 (w/v) respectively. As expected, moisture loss increased with addition moisture ratio. A suggestion that excess water was used. Initial moisture content of *Obesere*, *Ilesa* and *Dangote*, were 14.0, 14.2 and 13.5% (wb), respectively. Cooking raised the moisture levels to 56.7, 55.7 and 55.0%wb for *Obesere*, *Ilesa* and *Dangote* respectively. There was uptake of 42.7, 41.5 and 41.5% moisture by the rice varieties respectively. This implies that the amount of water required to cook a given quantity of rice is about 1.25 times the quantity of rice. This result agrees with the findings of Kumar (2004) who reported that 1 kg rice required about 1.2 to 1.5 kg water. The rice was perfectly cooked and water completely absorbed in 45 minutes.

Water required for cooking beans

From Table 2, mean percentage water losses to evaporation were 70, 97 and 83% for drum, *zobo*-drum and *oloyin* varieties of beans respectively. Calculated moisture uptake were 43.3, 40.5 and 41.1% for drum, *zobo*-drum and *oloyin* respectively. Initial moisture content of drum, *zobo*-drum and *oloyin* were 15, 16.2 and 15.8%wb. This implied that 1 gm of beans required an average of 1.4 g of water. That is to cook a given weight of beans about 1.4 times of water by weight is required. This is because beans require a long time to get sufficiently tender. Akinoso (2009) reported similar observation.

Water required for cooking maize

Table 3 shows water requirement for maize cooking. Cooking increased moisture content white maize, yellow maize and pop corn maize from 17.0, 14.0 and 14.6%wb to 61.7, 61.7 and 62.3%wb. From this, it could be inferred that the quantity of water in terms of mass required to cook a given quantity of shelled maize is 1.63 times the quantity of the maize. That is 1g of shelled maize required on the average about 1.63 g of water. This result agrees with the finding of SCI (1994), who reported that in solar cooking of dry cereals, which include barley, corn, millet oats, wheat and sorghum, one part of the cereals to two parts water was adequate.

Table 1. Cooking of rice with varying water content

Variety	Mass of rice (g)	Mass of water (g)	Volume Ratio rice: water	Total mass after cooking (g)	Water loss to evaporation (g)
Obesere	147	328	1:2	312	161
	147	492	1:3	374	263
	147	637	1:4	419	382
Ilesa	147	328	1:2	302	173
	147	492	1:3	349	290
	147	637	1:4	414	389
Dangote	147	328	1:2	307	166
	147	492	1:3	382	255
	147	656	1:4	433	368

Table 2. Cooking of beans with varying water content

Variety	Mass of beans to be cooked (g)	Mass of water (g)	Volume ratio beans: water	Total mass after cooking (g)	Water loss to evaporation (g)
Drum	122	492	1:3	219	385
	122	656	1:4	232	536
	122	820	1:5	297	635
Zobo-Drum	122	492	1:3	213	391
	122	656	1:4	232	536
	122	820	1:5	242	650
Oloyin	122	492	1:3	195	409
	122	656	1:4	216	552
	122	820	1:5	237	672

Table 3. Cooking maize with varying amount of water

Variety	Mass of raw maize (g)	Mass of water (g)	Volume ratio maize : water	Total mass after cooking (g)	Water loss to evaporation (g)
TZB-SR	112	656	1:4	276	470
	112	820	1:5	298	636
	112	984	1:6	363	735
AK 96 DMR-LSRW	112	656	1:4	254	482
	112	820	1:5	280	654
	112	984	1:6	345	753
Suwan 2-SR	112	656	1:4	262	479
	112	820	1:5	290	644
	112	984	1:6	355	743

Table 4. Cooking of yam with varying quantity of water

Variety	Mass of yam (g)	Mass of water (g)	Volume ratio yam : water	Total mass after cooking (g)	Water loss to evaporation (g)
Efuru	114	82	1:½	101	86
	114	123	1:¾	103	122
	114	164	1:1	107	157
Lasinrin	114	77	1:½	103	86
	114	125	1:1½	105	118
	114	164	1:2	106	160
Okunmado	114	82	1:1½	102	85
	114	125	1:1½	105	112
	114	164	1:2	106	162

Water required cooking yam

The results of cooking three varieties of yam with varied quantities of water and the determination of the moisture content of both the raw and cooked samples are as given in Table 4. From moisture content determination, an average sample of 114 g raw yam contains 86.78 g of water and 27.22 g dry matter, indicating the fact that yam unlike the other food staples, which were dry, contains a lot of moisture in the raw form. This indicates that the raw yam absorbed an average of 22.50 g more water to be cooked. The inference that could be drawn from these results is that the mass of water required to cook a given mass of yam is 0.2 times the given quantity of yam. In cooking of yam, it was observed that the dry matter content of raw yam was greater than that of cooked yam. This might be because during cooking the yam is subjected to higher temperature heat which might loosen some bounded water molecule, from the core of the yam which are now free and are thus removed during drying of cooked yam. Hence the reduction in the weight of the dry matter content.

Generally, one of the problems associated with solar cooking is the prolonged period of cooking which can be due to, among many other things, the quantity of water used in cooking the food. The largest of the heat losses in cooking is usually the heat consumed in vapourizing water present in the food or added for cooking, about 2.5 MJ/Kg (Hobbs, 2003). It was also reported that 1kg of water needs as much as 0.6 kWh of energy to be evaporated (Ekechukwu and Ugwuoke, 2003). It could then be deduced that the more the quantity of water added to cook a given food the more energy and time expended to evaporate the water after the food might have cooked. In view of this there is a need to determine the exact quantity of water that will be adequate to cook a given amount of food without having to add excess, in order to save time, energy and conserve water.

In using solar box cooker as the cooking device, the kind of pot(s) used is one with very tight fitting lid where evaporation of water is prevented unlike the conventional pots used for household cooking. In addition, the design and construction of the cooker ensures that the joints are made airtight as much as possible to limit heat loss to the outside. Lastly there is no chance to open the pot during cooking until the food is adjudged cooked. All these factors suggest that cooking with solar box cookers requires an amount of water excluding the evaporation loss factor that was included for other cooking devices like using the electrical stove, kerosene stove and charcoal stove.

Food cooking test

Mean stagnation temperatures of the solar device were 134 ± 8.9°C, 120 ± 6.2°C and 121 ± 7.1°C for first, second and third year respectively. These were recorded at corresponding ambient temperature of 31 ± 2°C. Since cooking is done in the sub-100°C temperature range (Aremu, 2004); this was an indication that the cookers would be able to cook most foods that required boiling and baking. The gradual reduction in stagnation temperatures can be attributed to deterioration (scratches of the foil, dirt, weakness of the joints) of the cookers with time. Peak stagnation temperatures were attained between 12:00 (13.00GMT) and 14.30 (15.00 GMT) when the solar insolation was between 867 W/m^2 and 946.5 W/m^2. Increase in cooker plate temperature (except for drops recorded during cloud covers) with time up until about 15:00 (16.00 GMT) were noticed.

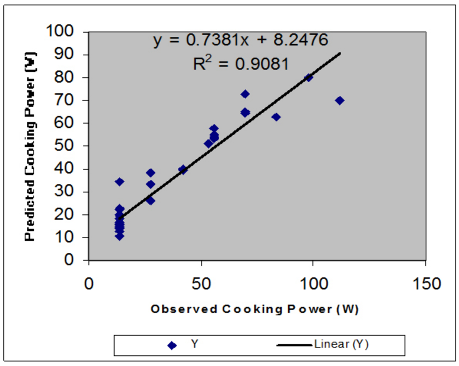

Figure 1. Correlation of predicted and observed cooking power

Jollof rice (520 g), beans (420 g) and yam (1400 g) were properly cooked in 50, 60 and 50 minutes respectively. In addition, flour (650 g) was successfully baked into cake after 60 minutes. The recorded time durations are closed to what obtained using 1 kW electric stove. However, it should be noted that the time taken to cook various food items and the doneness of the food are dependent on type of food, quantity of food, intensity and constancy of sunshine. In addition, it was not possible to prepare food that requires frying and roasting in the box solar cookers.

Cooking power

As the pot warms, the rate of heat-loss through the cooker envelope (walls, base and glass) increases in direct proportion to the temperature difference, hence the linear decrease in power. Regression intercept power was 58.15 W. Recorded coefficient of determination was higher than 0.75 satisfying the standard (ASAE, 2002). Coefficient of determination (R^2), intercepts and slope of fitness plot were 0.9, 8.25 and 0.74 respectively (Fig 1). These parameters are indication of good fitness.

Conclusions

The water requirement of some food staples determined shows that the long cooking rate associated with solar cooking could be reduced by avoiding excess water usage. In Nigeria, the potential of using solar for cooking is high. The cooker was able to cook most foods that require cooking by boiling and was able to bake in reasonable times. The study reinforced the views that solar devices can play a major role in solving Nigerian's domestic energy problem especially in the rural areas rather than being a novelty demonstration of solar energy use. Since solar energy, availability is intermittent because of cloud cover and day and night cycle, further research is recommended on storage in form of heat energy.

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