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THE DEVELOPMENT OF A SOLAR DEVICE FOR CROP DRYING AND COOKING

R. Akinoso

Department of Food Technology, Faculty of Technology,
University of Ibadan, Nigeria.
E mail akinoso2002@yahoo.com

ABSTRACT

An absorber-type collector device for crop drying or cooking was fabricated and tested. It comprised a doubled-walled wooden box with a double-glazed tight-fitting glass lid. The gap between the walls of the box was stuffed with dry sawdust. A soot-coated, metal plate was attached to the bottom of the box as the heat absorber. Small pebbles also coated with soot, placed around the inner edges of the box act as heat storage medium. There were inlet and outlet ports with plastic pipes leading into and from the cooking chamber. Inlet air was made to pass through a container that was stuffed with dehydrating agent and from there, through a plastic tube into the chamber. There was a valve provided on the plastic tube. Air outlet was from the cooker through another plastic tube and leads into drying chamber. Another was provided on this plastic tube. A chimney was provided at the outlet from the drying chamber. Both vales were closed when the device was operating as a cooker, and opened when it was operating as a drier. It took 57 minutes to cook beans, 37 minutes to cook yams and 43 minutes to cook rice, within the device, when there was bright sunshine. For the dying test, beef samples initially at 73 % moisture content dried to 17 % in 5 hours and cassava samples at 56 % moisture content dried to 14 % in 5 hours all in bright sunshine. The heat collection and conserving capacities of the device were found to be quite high, 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.

Keywords: Cooking, drying, heat storage, solar device, temperature,

INTRODUCTION

Crop drying is essential, as it facilitates crop handling by reducing its weight and improving the resistance of the crops to pests' infestation. Cooking is a prerequisite to making most crops edible and palatable. Solar energy has, for ages, been used in crop drying while cooking with solar energy is a more recent practice. Solar energy utilization in drying and cooking has few advantages and these include its being almost totally free of environmental degradation. In utilizing sun radiation as an energy source, some basic characteristics that determine its efficiency must be considered. The most important factors determining the amount of solar radiation reaching the earth's surface stated by Bamiro (1983), Fagbenle (1991) and Messel and Butler (2004) are composition of the atmosphere, depth of the atmosphere that radiation must pass through before reaching the surface, time of day, latitude of location, tilt angle of the surface to the horizontal and earth rotation. The annual total horizontal solar radiation in Nigeria varies from 5,000MJ/m^2 in the humid Niger Delta area to over 9400MJ/m^2 in Northeastern Nigeria. Mean maximum temperature across the country varies from 32.2 °C at the coast in the south to 40.6°C in the extreme north (Arinze, 1986).

Much work has been undertaken to considerably improve the performance of solar devices for drying and cooking. Countries within the tropics are potentially the greatest beneficiaries of research and development in solar energy utilization (Lucas, 1997). It has the potential of aiding rural development. The work herein reported is on the fabrication and test usage of a single device, which can function either as a crop drier or cooker, with solar energy being the source of heat..

DESCRIPTION OF THE SOLAR DRIER/COOKER

The device comprises the chamber housing the solar collector, which holds the pot containing the material to be dried or cooked; the lid, the air inlet system and the air outlet system.

The chamber

This is made up of wooden (*Antiaris africana*) box inside which is placed a smaller wooden box, the gap between both being tightly stuffed with dried sawdust to reduce the conduction from within the chamber during operation. Both boxes are without lids. A flat metal plate is fitted on the inner base surface of the smaller box. The surface of the metal plate is covered with soot, rendering it a black body to efficiently absorb radiation. Small pebbles, also covered with soot, are placed around the edges of the inner box, on the metal plate, and these serve as heat storage medium. Two ports lead into the chamber for the pipes from the air inlet system, while one port leads from the opposite surface for the air outlet system (See Plate 1).

The lid

The lid used during solar collection operation is a doubled-glazed, glass sheet with air-gap within. The glass sheets are fitted onto a wooden frame. The air-gap (50mm) within the double walls of the glass sheets is to restrain radiation being transmitted from the interior of the chamber. The wooden frame is connected to the chamber by means of hinges and a tight fit is maintained between the lid and top of the chamber. There is another lid, which is of plywood, and goes directly on to the top of the glass lid when the system is shut down

The pot

This is shallow metal box with the outer surface coated black. There is a tight-fitting lid provided for the pot for use only during cooking. There is the need to prevent vapour coming out of the pot for such vapour clouds the glass lid, as this reduces the transparency of the lid to solar rays. The pot serves also to hold the material to be dried, but for drying, the pot lid has to be removed.

The air inlet system

Air from outside the chamber is admitted into a cylindrical container of 200mm diameter, which contains a small quantity of a drying agent (*gari,or* uncooked rice, beans etc). This is to act as an air-dehydrating agent for the in-coming air during crop drying. Two tubes lead from the container into the interior of the chamber. The gap between the box sections at the joint is made air tight, using sawdust mixed with *cascamite* adhesive as sealant. A valve is fitted on to each of the tubes. These are to be closed during cooking operation. During drying operation, there would be intermittent opening and closing of the valves, to allow air admitted into the chamber to be laden with moisture extracted from the material being dried, as the admitted air gains heat from the metal plate and stones (Fig. 1).

The air outlet system

This comprises a plastic tube with one end tightly secured to the other end of the box, leading to the inside the chamber, while the other end is fitted on to a meter long, erect, metal tube. The outer surface of the metal is painted black so that it may absorb heat from the sun and moisture condensation from the exhaust air would be prevented.

The plastic tube that leads from the interior of the chamber to the metal tube has a valve, which should be closed during cooking, and intermittently opened and closed during drying, as the air inlet valves are opened and closed.

Collector energy capacity

Energy gain of the device was calculated using the expression below

$$Q = A\left[\delta I - U(T_p - T_a)\right] \ldots\ldots\ldots\ldots 1$$

Bamiro (1983)

where

Q – collector energy gain, kJ/h = 800.25kJ/h

A – collector area, $m^2 = 5.5\ m^2$

δ - effective transmittance = 0.7

I- Solar radiation, kJ/h. m^2 = 765 kJ/h. m^2

U – Collector overall heat lost coefficient, W/m^2. °C = 5 W/m^2. °C

T_p - mean collector temperature, °C = 112 °C

T_a - mean ambient temperature, °C = 34 °C

TESTING OF THE DEVICE

Three sets of tests were carried out on the solar device. These were tests on the performance of the device as a drier, the performance tests on cooking and heat storage capacity. Each experimental procedure was repeated 30 times and means values recorded.

Drying tests

Beef samples purchased from Bodija, a local market in Ibadan were sliced into 10 mm thick pieces and initial weights were determined. The devices was set up and oriented so that its shadow lines up with its longer sides. One end was raised by about 10 degree to allow for the rays of the sun to fall more or less vertically on the surface. A thermometer was placed inside the chamber for monitoring the temperature within, every 15 minutes. The samples to be dried were placed in the chamber and the glass lid securely placed on. The inlet and outlet valves were initially left opened and the initial temperatures within and outside (under shade) were recorded. After every 30 minutes, the inlet and outlet valves were closed for 5 minutes to allow for a rising of the air-drying temperature and ensure greater moisture absorption capacity of the air. Drying took place around 11.00 a.m. and was terminated just after 4.00 pm. daily, these being on days with high solar insulation. The samples were then removed from the chamber and their weights determined. They were then carefully dried in a moisture extraction oven set at 103 °C ± 2 °C for 4 hours. The final weight was determined. The initial and final moisture content of the meat were determined using ASABE 2008 method (ASABE, 2008). The procedure was repeated for cassava tuber harvested from Department of Agricultural and Environmental Engineering, University of Ibadan farm.

Cooking test

Initially, tests were conducted using the traditional cooker to determine the quantity of water required to cook beans, rice and yam per unit weight of the material to be cooked. This was achieved by determining the weight of each material before and after cooking. From series of preliminary tests, the times for cooking beans, rice and yam in the chamber were determined. This was by setting a number of such chambers on, and examining the food materials within, after 30 minutes and every 15 minutes thereafter. The operating temperature within and outside the chamber were recorded, and cooking was terminated just about 30 minutes before the expected cooking time, and the device was shut down with the plywood lid placed on for the remaining 30 minutes. During this period, the heat stored in the chamber was in use to complete the cooking. This procedure was repeated for rice and for yams. In testing the palatability of the cooked foods, members of staff of Agricultural and Environmental Engineering, University of Ibadan were invited to taste them.

Heat storage capacity

Heat storage capacity of the device was determined by placing un-loaded device under sun radiation. A thermometer was placed inside the chamber for monitoring the temperature within, every 30 minutes. After 4 hours the solar device was removed and placed in a shaded area while temperature monitoring continued for another 5 hours.

RESULTS AND DISCUSSION

Drying

Bright sunshine was experienced throughout all the test period. This was during the month of April in Ibadan, Nigeria. For the drying tests, beef samples at initial moisture content level of 73 % wet basis dried to 17 % wet basis after 5 hours. This is an improvement on Modibo (1986), who dried beef of initial moisture content of 69 % to 28 % wet basis in 5 hrs. The rate of moisture removal using the solar device ambient temperature is shown in Table 1. Maximum drying temperature was 128 °C at ambient temperature of 40 °C, which is 88 °C difference (Fig. 2). During the closure of exhaust pipe, moisture condensed in the pipe. This indicated that the moist airflow through the channel. Cassava moisture content was reduced from 56.86 % to 14.86 % wet basis in 5 hrs. Table 2 shows rate of moisture loss in cassava using solar device and ambient temperature. A maximum temperature difference between direct sun-drying surface and device-drying chamber is 83 °C. The obtained mean temperature of 53 °C is suitable for drying. According to Igbeka (1982), most food products are dried at temperature $\leq$ 60 °C to avoid loss of volatile nutrients and surface case hardening. Long time recorded for drying these products is associated to the fact that the device operated with natural air movement and at atmospheric relative humidity. If mechanical blower is used, the rate of moisture removal will likely be increased. Also to improve the efficiency of the device, the generated heat energy can be concentrated.

Cooking

There was the usual need to have a little more water than required in cooking beans. This was left at about 10 % of the actual required quantity of water, which was just about the weight ratio of 1 measure of beans to 1.3 measures of water. Non-salting was observed to considerably reduce the cooking period. Boiling point of a liquid is affected by presence of solute (Onwuka, 2003). This explains the reason for dependence of cooking time on salt concentration. Maximum cooking temperature was 115 °C at ambient temperature of 42 °C (Fig. 3) of rice to 1.1 measures of water and 0.2 kg of Beans of 0.2 kg were fully cooked within 57 minutes. Rice required a weight ratio of 1 measure rice cooked very well after 43 minutes, 10 minutes of which were when the unit was shut down (covered with the plywood lid). Yams required 1 measure of yams to 0.4 measures of water by weight to cook and cooking of 25 mm thick slices took 37 minutes, ten of which were when the unit was shut down. Members of staff of Department of Agricultural and Environmental Engineering, University of Ibadan who ate the foods remarked on each occasion that the food tasted normal. This is satisfactory since intention was not to analyse the chemistry of food but cooking ability of solar device.

Heat storage capacity

The heat storage capacity of the unit was found to be quite high. On no-load, the maximum temperature achieved was 134 °C at ambient temperature of 37 °C (Fig. 4), it took 5 hours after shutting down to bring the chamber temperature down to 74 °C. This quality may be associated thermal properties of constructional materials. Pebbles of high heat storage capacity (55kJ/kg) were used as heat storing medium. Likewise, the transparent glass used as cover and wood used for chamber construction were good insulators. The heat thus trapped was found adequate for light cooking such as for fish and yam thin (25 mm) slices.

CONCLUSION

The results presented here represent series of trials and focus on the utility aspect of solar device to prevent losses and improve quality rather than on the physics of solar devices operations or chemistry of food. Although temperatures were measured periodically during the experiments, the intent was not to compute efficiency, solar radiation, and other mechanical parameters, but to determine if there are vast differences in utilization between solar device and ambient condition. This device is quite satisfactory, especially as a solar cooker/food warmer. It has good application potential especially in the rural areas. Required skill for operation of the device is simple and the maintenance cost is cheap.

Table 1: Percentage moisture loss in beef samples during drying using solar device.

Duration (Hour)	Mean moisture loss (%wb) Beef place inside the device	Beef exposed to the ambient
0	0.00 ± 0.00	0.00 ± 0.00
1	25.88 ± 1.24	10.58 ± 1.09
2	30.72 ± 1.01	18.68 ± 1.11
3	42.61 ± 1.44	27.29 ± 1.73
4	53.43 ± 1.15	33.50 ± 1.24
5	56.75 ± 1.63	37.22 ± 1.67

NB: Values are mean of 30 replicates

Table 2: Percentage moisture loss in cassava samples during drying using solar device.

Duration (Hour)	Mean moisture loss (%wb) Meat place inside the device	Meat exposed to the ambient
0	0.00 ± 0.00	0.00 ± 0.00
1	10.03 ± 1.11	08.55 ± 1.09
2	24.18 ± 1.64	21.71 ± 1.20
3	31.69 ± 1.31	26.97 ± 1.53
4	37.22 ± 1.70	32.43 ± 1.19
5	42.00 ± 1.96	35.90 ± 1.95

NB: Values are mean of 30 replicates

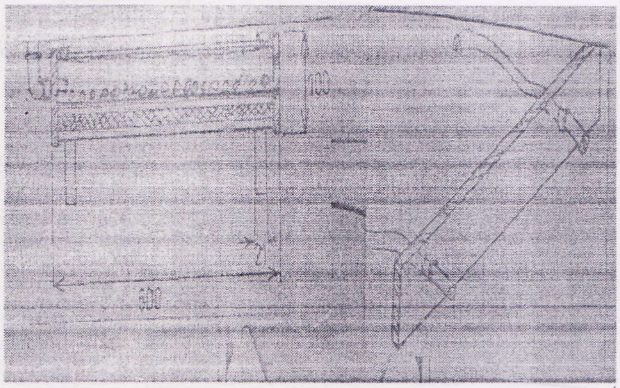

Fig. 1: Section view of inner chamber of the solar device.

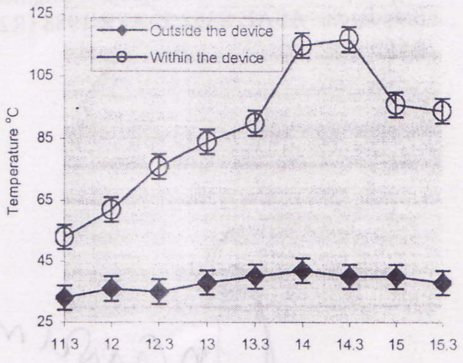

Fig. 3: Graphical illustration of temperature within and outside the solar device for cooking

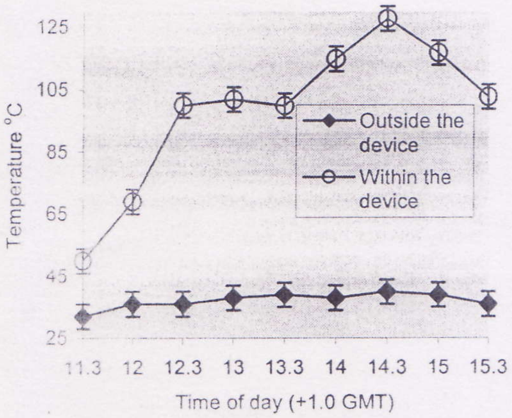

Fig.2: Graphical illustration of temperature within and outside solar device for drying

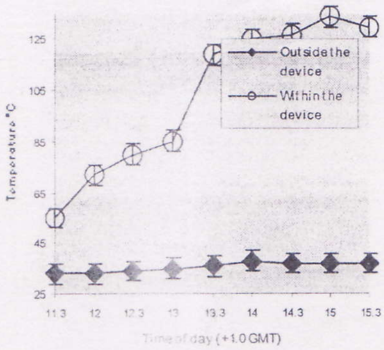

Fig.4: Graphical illustration of temperature within and outside the unloaded solar device

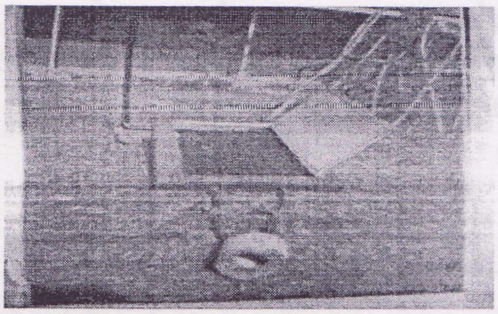

Plate 1: The solar device

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