

DESIGN AND FABRICATION OF A DOUBLE-CHAMBER SOLAR DRYER

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ABSTRACT

Object of research: This paper discusses the design and construction of a modified, cost effective solar dryer for use by the average Nigerian farmer or agri-business entrepreneur. Investigated problem: Local farmers often have a lot of difficulties in properly drying harvested agricultural produce for storage and processing purposes, safely and efficiently due to capital constraints. There was therefore a need for an efficient, low cost solar dryer design to aid in this pursuit.

Methodology: The designed dryer is a passive dryer that makes use of heat energy tapped through glass collectors placed over the drying and air inlet chambers respectively. The dryer was designed and constructed with carefully selected, inexpensive materials with dimensions of 40×40×60 cm for the drying chamber and dimensions of 10×80×40 cm for the heating chamber. The glass collectors (4 mm thick) were inclined at an angle of incidence of 17.26°. Okra slices were used to test the performance of the dryer.

Results/Area of practical use: The study yielded a low cost (€145.60) modified solar dryer capable of drying agricultural produce in a safe and clean way. During eight (8) hours of drying under a temperature range of 39–45 °C, the initial weight of the okra slices reduced from 150 g to 9 g, 9 g, 10 g and 9 g on each of the four trays of the drying chamber respectively. Local farmers and agripreneurs will be encouraged to make use of this clean alternative of drying food produce without the drawbacks from regular sun drying.

Conclusion: There is need for more work to be done in terms of installation of solar panels to enhance dryer performance. More work should also be carried out on tests during the dry season for increased dryer efficiency.

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1. Introduction

In many countries of the world, the use of solar thermal systems in the Agricultural sector to conserve vegetables, fruits, coffee and other crops has shown to be a practical, economical and responsible approach to the environment. Energy derived from the sun can be utilized for many purposes, ranging from heating, drying, pumping of water and cooking to production of electricity by solar cells [1]. Using solar energy to dry food and other crops can improve the quality of the product [2]. The purpose of drying an agricultural product is to reduce its moisture content to a level that prevents its deterioration. In drying, two processes take place: one is a heat transfer to the product using energy from the heating source, and the other is a mass transfer of moisture from the interior of the product to its surface and from the surface to the surrounding air [3]. Mechanical drying of agricultural products is an energy consuming operation hence greater emphasis is given to using solar energy sources in this process due to the high prices and shortages of fossil fuels [4]. Mechanical drying of agricultural products is an energy consuming operation in the post-harvesting technology. Greater emphasis is given to using solar energy sources in this process due to the high prices and shortages of fossil fuels. For these purposes, a new natural convection solar dryer consisting of a solar air heater and a drying chamber was developed. This system can be used for drying various agricultural products like fruits and vegetables. The traditional method used throughout the world is open sun drying where diverse crops such as fruits, grains, vegetables, tobacco, etc. are spread on the ground and turned regularly until sufficiently dried. Solar drying is dependent on different parameters, such as weather parameters like ambient air temperature,

relative humidity, solar radiation and wind speed, amount of initial moisture content, type of dryer etc. [5].

1. 1. The object of research

The object of this research is to design and construct a modified, cost effective solar dryer for use by the average Nigerian farmer or agri-business entrepreneur.

1. 2. Problem description

For centuries, various nations have preserved fruits, meat, fish and other crops by drying. Drying is also beneficial for hay, copra, tea and other income producing non-food crops. With solar drying, the availability of all these farm produce can be greatly increased. Solar drying is the oldest method of food preservation wherein dried food is preserved and concentrated. Dried foods do not require any special storage equipment and are easy to transport. Studies show that food items dried in a solar dryer were superior to those which are sun-dried when evaluated in terms of taste, color and mold count. Solar dried foods can be stored at less cost while still providing excellent nutritive value [2].

All drying systems can be classified according to their temperature range i.e. high temperature range dryer and low temperature range dryer [3]. Nowadays, optimization of solar systems is used to reduce system total cost, increase life cycle savings and improve thermal efficiency. It is very demanding for optimal utilization of solar resources to meet the energy demands [6]. Several solar dryers, with different variations have been designed. In 2007, [7] designed a mixed-mode natural convection solar crop dryer (MNCSCD) for drying cassava and other crops in an enclosed structure. [1] (2020) designed an active indirect-mode solar dryers for drying cooking banana s in Nigeria. The dryers were constructed with special focus on the air inlet, to examine if the air inlet area had effect on the performance of the dryers. Solar drying generates high air temperatures and produces low air relative humidity. Alonge and Jackson [1] developed an indirect forced convection solar dryer for cassava in their bid to address concerns related to time of drying of cassava chip by other methods of drying.

1. 3. Suggested solution to the problem

Passive solar dryers are also called natural circulation or natural convection systems. These dryers can be either direct (e.g. tent and box dryer) or indirect (e.g. cabinet dryer). Natural-circulation solar dryers depend for their operation entirely on solar-energy (Behera *et al.*, 2017).

Active solar dryers also called forced convection or hybrid solar dryers utilize forced convection throughout the drying process to control temperature and moisture in wide ranges independent of the weather conditions. The use of forced convection can reduce drying time by three times and decrease the required collector area by 50 % [3].

Aim of research was to design and construct a passive modified two-chamber solar dryer for use by rural farmers.

2. Materials and Methods

The following factors were considered in the design of the solar dryer.

1. Materials' Selection: The materials used were sourced locally and at the cheapest price. They were selected on the basis of availability, cost, and durability amongst others.

2. Dimensions: The external dimensions of the solar dryer are 40×40×60 cm, with internal dimensions of 35×35×55 cm. The difference is due to the thickness of the metal used and the lagging material. The drying chamber is 57 cm in 36×36×56 cm with air passage out of the chamber through an outlet of 5 cm in diameter.

Fig. 1 shows the external dimensions of the dryer.

3. Air Flow: The designed air vent to the solar collector aids in air suction to the drying chamber. The hot air is directed by the fan and it rises into the drying chamber. The heated air passes through the trays and around the farm produce reducing the moisture content and exits through the outlet near the top of the chamber. Thus the system is a passive solar system. The machine consists of the following parts:

- a. The Drying Chamber: This is designed to accommodate four layers of drying trays made of net cloth on which the produces are placed for drying.
- b. Dryer Trays: Net cloth is used as the dryer screen to aid air circulation within the drying chamber. 4 trays of dimensions 30×30 cm are used in the design. The trays are spaced 10 cm apart.
- c. The Air Inlet and vents: This is the opening through which air enters the system. The dimension of the air inlet is 22×35cm. For air to flow out of the solar dryer, two air vents were made at the back of the drying chamber. The vents have a diameter of 5 cm each.
- d. Fan: A fan with a blade height of 7 cm, standing 8 cm from the floor and powered by a battery is placed 20 cm in front of the air inlet to help in driving heated air into the drying chamber. The fan’s speed is 1300–1550 rpm.
- e. Glass plate Collector: Transparent glass is used to collect heat from the sun radiation. A glass covering of 4 mm thick is used to make the roofing of the chamber.
- f. Battery: A battery of 12 volts is used to power the fan. The battery is detachable and can be charged when the dryer is not in use.
- g. The Frame of the Dryer: The frame was constructed from square pipe. The pipe was cut and welded.
- h. The Door and Vents of the dryer: The door of the dryer was constructed from a metal plate of 799 mm long and 599 mm wide for both the external and internal surfaces. The door was filled with lagging material to reduce heat loss, and joined to the main dryer with the use of hinges.

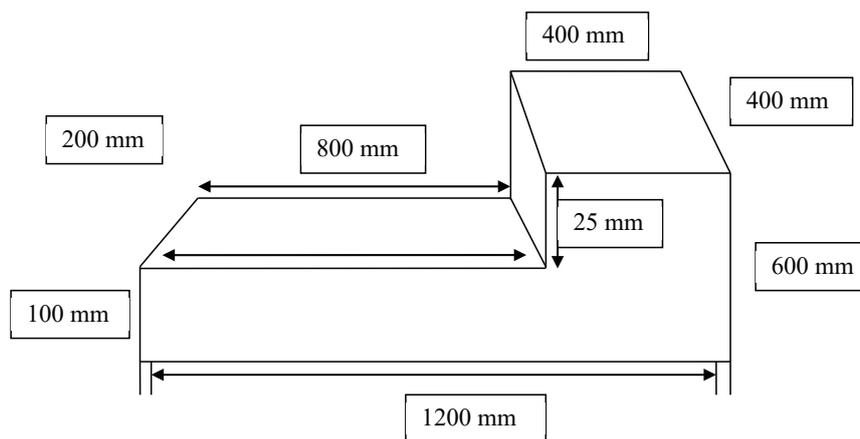


Fig. 1. External dimensions of the double chamber solar dryer

The drying chamber has four layers, by calculation; each layer with dimensions 0.3 m by 0.3 m with a total surface area of 0.09 m².

The dryer, being a tray loading type has the volume:

$$V=AT,$$

where A =Tray area (0.09 m²) and T =Average thickness of okra (2.5 mm) in $m=0.0025$ m.

$$\text{Dryer volume}=0.09\text{m}^2\times 0.0025\text{ m}=2.25\times 10^{-4}\text{ m}^3.$$

Considering the specie of okra (*Hibiscus esculentus*) used for this design, the bulk density was determined to be 670 kg/m³.

Using the formula:

$$\text{Density}=\text{Mass}/\text{Volume}.$$

$$670\text{ kg}/\text{m}^3=\text{Mass}/2.25\times 10^{-4}\text{ m}^3.$$

$$\text{Mass}=670\times 2.25\times 10^{-4}\text{ m}^3=0.150\text{ kg}/\text{load}.$$

$$\text{The capacity of the dryer for the four trays}=0.150\times 4=0.60\text{ kg}/\text{load}.$$

Using the formula for specific latent heat of vaporization

$$H_t = H_r + H_l,$$

where H_t =Total Heat required for vaporization; H_r =Heat required to increase air temperature to vaporization temperature; H_l =Latent Heat of Water at 60 °C=2359 kJ/kg [8] and

$$H_r = (T_v - T_m),$$

where T_v =vaporization temperature, T_m =temperature of material (okra), L =Specific heat capacity of the material in kJ/kg°C=3.54 kJ/kg°C [9].

Therefore

$$H_r = (60 - 29) \times 3.54 = 109.74 \text{ KJ/kg},$$

$$H_t = (H_r \times \text{mass of material}) + (H_l \times \text{mass of water to be removed at 10 \% m.c w.b}) = (109.74 \times 5.44265) + (2359 \times 0.54) = 1871.136 \text{ KJ}.$$

Optimum drying time for the okra was set at 4–12 hours (based on volume) at a range of 40–70 °C [10].

The angle of tilt of the solar collector was calculated using

$$\beta = 10^\circ + \text{lat } \Phi \text{ [11]},$$

where $\text{lat } \Phi$ =latitude of collector location (Ibadan)

$$\beta = 10^\circ + 7.26^\circ = 17.26^\circ.$$

3. Results and discussion

Fig. 2 shows the solar dryer after fabrication. The dryer has two chambers (one for heating air, and the other for proper produce drying). The fan can be powered by electricity or a small battery.



Fig. 2. The designed solar dryer

Table 1 shows that there is a steady and uniform reduction in the weight of the okra slices during the drying process. The control, which is T_0 showed decrease from the initial weight of 150 g

to 127 g, 93 g, 55 g and 15 g. Tray 1 reduced from the initial weight of 150 g to 9 g, while Tray 2 reduced from 150 g to 10 g. Tray 3 reduced from 10g while Tray 4 showed weight reduction from 150 g to 9 g. The drying temperature fluctuated between 390 °C to 450 °C. There was negligible color change in the produce while drying.

Table 1
Drying time of okra

Time (h)	Weight of okra (g)				
	T_0	T_1	T_2	T_3	T_4
0	150	150	150	150	150
2	127	120	121	121	120
4	93	85	88	87	84
6	55	39	40	41	39
8	15	9	9	10	9
Moisture content after 8 hours	–	6.0 %	6.0 %	6.67 %	6.0 %

Note: T_0 =sun dried okra; T_1 =tray 1 in the solar dryer; T_2 =tray 2 in the solar dryer; T_3 =tray 3 in the solar dryer; T_4 =tray 4 in the solar dryer. Average moisture content of dried okra=6.125 % mc

3. 1. Average drying rate

$$Adr=Mw/td,$$

where Mw =Mass of moisture (kg) and td =Drying time (hr).

Mass of moisture=Mean initial okra weight–Mean final weight after drying=0.140 kg.

$$Adr=0.140/(8\times 60\times 60)=4.86\times 10^{-6} \text{ kg/hr.}$$

3. 2. Solar Dryer Efficiency

Efficiency=(Useful Energy (Qc)/Solar Energy Available (Qi) $\times 100$

$$Qi=397.065 \text{ W/m}^2 \text{ [12],}$$

Qc =Useful heat gain,

$$Qc=\{CpWp (Tc-Ta)+LvDm\} \text{ [13],}$$

where Cp =Specific Heat Capacity of Okra in KJ/kg; Wp =Initial Weight of Product before drying in kg; Lv =Latent Heat of Vaporization in J/kg; Dm =Dry Matter in kg; Tc =Final Temperature of Drying; Ta =Initial or Ambient Temperature.

$$3.54 \text{ KJ}\times 0.15 \text{ kg} (45-39)+433.586\times 0.140,$$

$$0.53(7)+60.70=3.71+60.70=64.41 \text{ KJ.}$$

$$\text{Efficiency}=64.41\times 100.$$

$$397.065=16.2 \text{ \%}.$$

3. 3. Solar dryer cost analysis

The dryer cost forty thousand naira (€ 80) to construct. Factoring in labor (30 % of material cost), overhead (10 % of material cost) and a modest thirty percent profit margin gave the final selling price of the dryer at seven two thousand, eight hundred naira only (N 72.800) or one hundred and forty five euros (€ 145.60).

Table 2 shows the bill of materials used in the production of the solar dryer. Prices are shown both in Naira and in Euro (Exchange rate used: €1=N500).

Table 2
Bill of materials

Item No.	Description	Specification	Quantity	Unit Amount (N/€)	Total price (N/€)
1	Glass	4 mm gauge	1	2000/4	2000/4
2	Steel plate	1 mm gauge	1 sheet	6000/12	6000/12
3	Angle (iron)	25 mm by 25 mm	1 length	600/1.2	600/1.2
4	Iron pipe	25 mm by 25 mm	4 lengths	1200/2.4	4800/9.6
5	Wire net	–	1 yard	2000/4	2000 /4
6	Insect net	–	2 yards	200/0.4	400/0.8
7	Lagging materials	–	–	3000/6	3000/6
8	Hinges	–	2	200/0.4	400/0.8
9	Lock	–	1	400/0.8	400/0.8
10	Body filler	–	1	1500/3	1500/3
11	Paint	–	½ gallon	2400/4	1200/2.4
12	Fan	–	1	2500/5	2500/5
13	Tires (rollers)	–	4	800/1.6	3200/6.4
14	Miscellaneous	–	–	–	10000/20
Total	–	–	–	–	40000/80

The result showed that there is reduction in the weight of the okra slices throughout the eight hours of the drying process. The control which is T_0 showed decrease from the initial weight of 150 g to 15 g over the drying period. Tray 1 reduced from the initial weight of 150 g to 9 g, Tray 2 reduced from 150 g to 10 g, Tray 3 reduced from 150 g to 10 g, and Tray 4 from 150 g to 9 g all in an 8 hour drying period. Negligible color changes were noticed throughout the drying period in the oven.

Solar dryer efficiency was calculated to be 16.2 %. This was due to the limiting fact that the project work was carried out during the rainy season. It is advised that further research work should focus on drying during the dry season.

4. Conclusion

Solar drying is a more effective drying medium for agricultural produce by small and medium scale farmers in Nigeria. The study yielded a low cost (€ 145.60) modified solar dryer capable of drying agricultural produce such as okra in a safe and clean way, to an acceptable moisture content, at medium heat ranges of 39–45 °C. Low solar dryer efficiency of 16.2 % was determined to be due to the rainy weather, hence the dryer should be used during the dry season for better and more effective performance. Solar panels can be incorporated into the dryer to increase drying efficiency and drying time. A regulator can also be mounted to regulate the speed of the suction fan.

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