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Construction Of A Solar Dryer For Agricultural Produce In Oyo State, Nigeria

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***Abstract*—Food is easily preserved by drying, when moisture is reduced. Drying is a process whereby 5-25% of water content in food produce is removed depending on the food type. The use of open sun to dry food produce has been proven unhygienic due to contaminations, this prompted a need for the construction of portable solar dryer for every farmer and home-use. The construction materials were locally sourced and drying of maize and gmelina seeds sample were carried out both in the open sun and the solar dryer for five days. The maize seeds sample with initial mass of 300.00g lost 75% moisture content to open sun drying and 94% to solar drying. The gmelina seeds sample with initial mass of 400.00 g at the end of three days drying period lost 45% moisture content in the open sun and 63 % in solar dryer. The result revealed that drying agricultural produce by the traditional open sun method is neither efficient nor clean and has lowest drying rate, the solar-dryer method is more efficient, clean and controllable with higher drying rate. Therefore, it is confirmed that solar dryer perform better in terms of drying agricultural produce and reduces bacterial action on the food product. Having constructed and tested one and established the operating parameters, it was recommended that the farmers and individual households can use this solar dryer for drying agricultural grains and seeds.**

Keywords—Food, Dryer, Solar, Maize, Gmelina.

Introduction

Traditional method of drying fruit and vegetable in the rural area in Nigeria is to spread the product on the ground and expose to sun in the open air. The separation operation of drying converts a solid, semisolid or liquid feedstock into a solid product by evaporating of the liquid into a vapor phase via application of heat [1]. It is a better means of increasing the quality of final dried product, reducing post-harvest losses and generally reduces the drying times as compared to open sun drying. [2]. It is estimated that 20% of the world's grain production is lost after harvest because of inefficient handling and poor implementation of post-harvest technology, says [3].

Sun drying may be efficient and cheap but has disadvantages on the product such as contamination by dust, insect and bacteria and loss due to the wetting of dew. Actually, sun drying food is one of the oldest Agricultural techniques related to food preservation, but every year, millions of dollar (worth of gross national product) is lost through spoilage. The reason include, lack of storage facilities, lack of adequate knowledge of the properties of the agricultural produce to be dried and lack of fund to purchase processing material. Estimation of these losses are generally cited to be of the order of 40% but they can under very adverse condition, be nearly high as 80%. Significant percentages of these losses are related to improper or untimely drying of agricultural produce such as vegetable, fruit, seed, fish and meat etc.

The application of dryer in developing countries can reduce postharvest losses and significantly contribute to the availability of food in the country. The use of solar dryer for agricultural produce will significantly allow farmers to earn more income which will increase savings; these savings could help strengthen the economic and food security situation of many farmers in developing countries and will change as well as nutritional status in these countries. There are various drying methods, one of such is the use of heated air by fan air circulation and electric or gas heater to produce dry air that circulate over the produce. This method is however expensive. Solar dryer of force convention type need electricity, which unfortunately is none-existing in many rural areas to operate the fans. Even when electricity exists, the potential users of the dryer are unable to pay for it due to their very low income. Force conventional dryer are for this reason not going to be readily applicable on a wide scale in many rural area. Natural convention dryer circulate the drying air without a fan. They are therefore, the most applicable to the rural area in developing countries [4].

In many cases, only a small temperature rise in the air is necessary to achieve proper drying conditions [2]. Properly designed solar dryers have the advantage of giving faster drying rates by heating the air to about 10-15^{O}C above room temperatures [5]. Various forms of solar dryers exist and they vary from very simple direct dryers to more complex indirect designs [5]. In direct solar dryer, the air heater contained the drying product and solar energy passes through a transparent cover and is absorbed by the product. Essentially, the heat required for drying is provided by radiation to the upper layers and subsequent conduction to the drying bed. In direct drying, solar energy is collected in a separate solar collector air heater and the heated air then passes through the drying bed, the simplest of solar cabinet dryer was reported by [6].

The focus of this study is to construct a low cost solar dryer for agricultural produce that can be adopted by the rural farmers. This if adopted will remove the challenges of over drying, low drying and the risk of spoilage. The objectives of the study are to access the efficiency of drying agricultural produce using solar dryer compared with the tradition way of drying and to determine among the two drying methods the one improves the quality of the agricultural produce.

Materials and Method

Component Parts

Tray

The tray for this solar dryer is made from wire mesh. Since most of the moisture from the produce is being removed "during boiling" the mesh wire would be perfect to use as tray. The solar radiation can penetrate through the tray and so as the air from air vent making the drying process quicker. The wire mesh will also have two pieces of wood nail on each side of the tray to hold the tray. This idea is for practical reasons in terms of loading and unloading the produce.

Glass roof

The glass roof is used for transparency and easy access, to observe and examine the drying grains and seeds. The collector chamber is covered with the glass material while the drying chamber is covered with the plastic glass.

Mosquito wire

The mosquito wire is used to cover the hole of the air outlet ventilation so that air sucked in by the fan can be passed out and as well insect will not be able to enter the drying chamber.

Black painted component

The black paint in this solar dryer is only used to paint the inside wall of the dryer so that maximum heat can be retained in the dryer for maximum heating effect.

Drying chamber

The drying chamber made of a highly polish plywood box held in place. The material has been chosen since wood is a poor conductor of heat and it has a smooth polished surface; heat loss by radiation is minimized. To further reduce heat loss by radiation and to avoid moisture absorption by the wood, polystyrene is wrapped on the inside of the chamber.

Cover plate

This is transparent sheet used to cover the absorber, thereby preventing dust and rain from coming in contact with the absorber. It also prevents the heat from escaping (i.e. forming a confinement for heated air) It is placed about 25.4mm above the absorber. Common materials used for cover plates are glass, flexi glass, fiber-glass, reinforced polyester, thin plastic films and plastics but for this study, transparent glass is used.

Absorber plate

This is a metal plate painted black and placed about 25.4mm below the cover to absorb the incident solar radiation transmitted by the cover, thereby heating the air between it and the cover. In its plainest form, it is no more than a blackened metal plate exposed to the sun.

Fan

A centrifugal fan is incorporated on the solar dryer to remove excess temperature. The fan is automatically operated by a thermostat set to a particular temperature depending on the temperature of seeds or produce to be dried and it is powered by a 6V4.5Ah battery.

Insulator

This is used to minimize heat loss from the system. It is placed under the absorber plate. The insulator must be able to withstand considerable high temperature. It must be fire resistant and not subject to out-going gassing, it must not be damageable by moisture or insect. Insulating materials are usually fiber-glass, mineral wool, Styrofoam and urethanes. The insulator used for this study is fiber-glass.

Theory of Drying

Most agricultural products, which are dried may be seen as solid, porous or coarse material in a loose bulk state (i.e. in piles or in layer).The pile is blown through by preheated air during drying, by means of which energy needed for evaporation is provided for the materials. Evaporating water (moisture content) from the surface of the material is removed by air. The mass and heat transfer that do occur during drying constitutes a complex mathematical description based on approximation. Therefore, it is a common practice to apply semi empirical methods based on experimental data. Moisture is removed as a result of the difference in vapour pressure between the surface and its surroundings, there is migration of moisture to the surface under the effect of the moisture gradient forming between the inner parts of the surface. Drying process lasts until equilibrium is attained between the surface and the inner part and between the surface and the ambient. Temperature is a decisive factor in drying. Both the concentration gradient and the diffusion coefficient increase with temperature, whereby the amount of water removed is also increased. For a temperature above 100°C, the partial pressure of water vapour increases in the material such that it may exceed the external pressure. In this case, removal of water is also promoted by the pressure gradient. The drying time is a complex function of temperature, since its effect differs in the various phases of drying [7]. The following are the factors that need to be put into consideration when drying;

Dryer efficiency is **Collector Efficiency (EF)**

Collector efficiency is computed mathematically as:

$$\eta = \rho V C_P \,{}^{\Delta T}\!/_{AI_C} \qquad (1)$$

Where ρ is the density of air (kg/m^3), I_C is the sun intensity (maximum of 25MJ/m^2 in Nigeria) on the collector, ΔT is the temperature elevation, Cp is the specific heat capacity of air at constant pressure (J/kgk), V is the volumetric flow rate (m^3/s), and A is the effective area of the collector facing the sun (m^2) [8].

Dryer Efficiency

expressed as:

$$\eta_d = \frac{ML}{I_c A t} \qquad (2)$$

Where:

L is the latent heat of vaporization

M is the mass of product before drying

t is the drying time

Rate of Heat Flow into the Dryer

Heat flow rate into the dryer is the sum of the convective heat, conductive heat, and radiative heat transfers and is expressed as

$$q = q_c + q_k + q_r \quad (3)$$

$$\frac{q}{A} = \frac{T_a - T_d}{{}^{1}/_{h_a} + {}^{\Delta x}/_{k} + {}^{1}/_{h_d}} + \varepsilon\sigma(T_a - T_d) \quad (4)$$

where $\frac{q}{A}$ is the heat transfer per unit area, h_a is the heat transfer coefficient for the ambient, h_d is the heat transfer coefficient for the dryer chamber, T_a is the ambient temperature, T_d is the drying chamber temperature, σ is the Stefan-Boltzman constant, Δ_x is the thickness of the glass cover, and ε is the emissivity and k is the thermal conductivity [9].

Heat Energy (Q) Needed for Crop Drying

The heat energy required for crop drying is a function of the mass and latent heat of vaporization and it is expressed mathematically as:

$$Q = M_i L \quad (5)$$

Where

M_i is the mass of the crop before drying

L is the latent heat of vaporization [7].

Mass of Air Needed for Drying: This is calculated using equation given as follows:

$$\dot{m} = \frac{m_w}{t_d[w_f - w_i]} \quad (6)$$

where:

m_w is the amount of moisture to be removed, kg.

w_f and w_i are the final humidity ratio, respectively, kg H_2O/kg dry air.

t_d is the total drying time, hrs.

Moisture Content (MC)

The moisture content of crops samples is given mathematically as:

$$MC(\%) = \left(\frac{M_i - M_f}{M_i}\right) \times 100\%; \text{ Wet basis} \quad (7)$$

Where;

M_i is the mass of sample before drying and
M_f is the mass of sample after drying

Moisture Loss (ML)

The moisture loss (g) is given as [9].

$$ML = M_i - M_f \quad (8)$$

Average Drying Rate (Rd)

$$R_d = \frac{\Sigma(M_i - M_f)}{t_d} \quad (9)$$

Results and Discussion

Two samples of two (2) specimens (maize and *Gmelina* seeds) of known masses were subjected to drying inside the passive crop dryer (control) and same samples in the open-air for days and three hour each day. The sample are weighed after the drying periods with a sensitive scale to determine the weight (moisture) loss and the temperature was taken with digital thermometer suspended inside the dryer. The results of the tests are recorded in tables below.

Table 1: Maize seed samples inside the solar dryer and in the open sun

Day	Initial mass (m_i)$_{(g)}$		Final mass $m_{f\,(g)}$		Differences in mass (m_i-m_f)		Moisture content (%)		Temperature (°C)	
	Solar dryer	Open sun	Solar dryer	Open sun	Solar dryer	Open sun	Solar dryer	Open sun	Ambient temp.	Dryer temp. (°C)
1	300.00	300.00	266.00	270.00	34.00	30.00	11.30	10.00	40.00	47.00
2	223.00	230.00	288.00	199.00	35.00	31.00	15.70	13.48	40.00	48.00
3	143.00	169.00	113.00	147.00	30.00	22.00	20.98	13.02	42.00	47.00
4	73.00	128.00	54.00	111.00	19.00	17.00	26.03	13.28	34.00	42.00
5	35.00	92.00	17.00	74.00	18.00	18.00	48.57	19.57	38.00	43.00

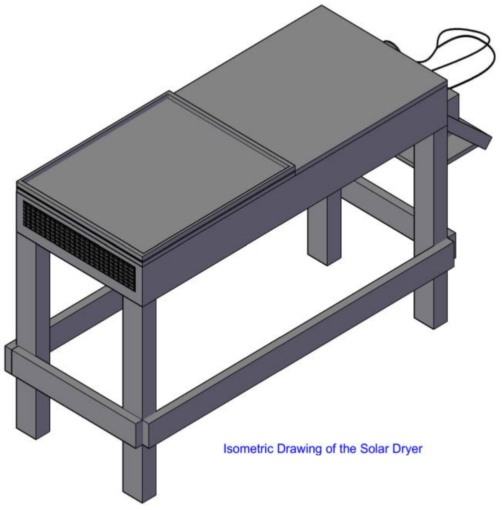
As shown in table one, the initial mass of the maize samples to be dried was 300g both for the open sun drying and the solar dryer. It was discovered that at the end of the five days drying process, the final mass of the open sun method was 74.00g and that of the solar dryer was 17.00g. The results indicated that only 75% moisture content was removed in the open sun drying while that of the solar dryer was 94%, which shows that the solar dryer is more efficient, fast and neat compared with the open sun drying method.

Table 2: *Gmelina* seed samples in the solar dryer and in the open sun

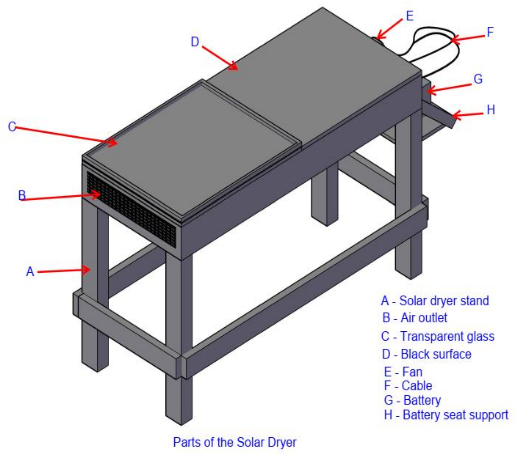
Day	Initial mass $M_{i(g)}$		Final mass $m_{f(g)}$		Differences in mass (m_i-m_f)		Moisture content (%)		Temperature (°C)	
	Solar dryer	Open sun	Solar dryer	Open sun	Solar dryer	Open sun	Solar dryer	Open sun	Ambient temp	Dryer temp (°C)
1	400.00	400.00	320.00	360.00	80.00	40.00	20.00	10.00	39.00	41.00
2	31.00	340.00	250.00	300.00	60.00	40.00	19.35	11.76	38.00	40.00
3	230.00	290.00	150.00	220.00	80.00	70.00	34.78	24.13	39.00	42.00

The initial mass of the *Gmelina* seeds samples to be dried was 400g both for the open sun drying and the solar dryer. It was discovered that at the end of the three days drying process, the final mass of the open sun method was 220.00g and that of the solar dryer was 150.00g. The results indicated that only 45% moisture content was removed in the open sun drying while that of the solar dryer was 63%, which shows that the solar dryer is more efficient and free from insects and dirt and have a better shelve life compared with the open sun drying method.

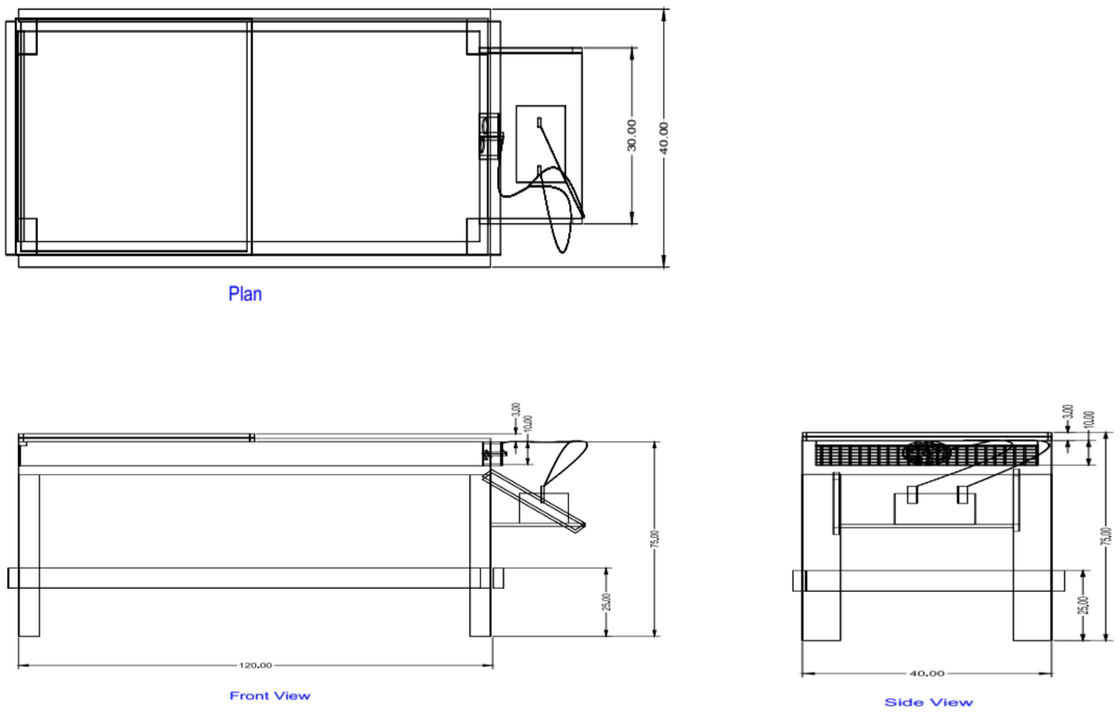
Therefore, it was concluded that crop drying in solar dryer reduces contamination of crops by dirt, fungi, insects and animals. The study of the drying process has shown that it may be characterized in two (2) stages in which the rate of drying varies differently. In the first stage, starting with a short heating up period, the drying rate is constant and maximum. There is movement of moisture under the effect of capillary and osmotic force from the inside to the surface of the material and saturated vapour prevails over the surface. The second stage begins when the materials moisture content is less than maximum hygroscopic content. Drying rate decrease further in this case and tends asymptotically to zero. However, more significant controlling mechanism in the falling rate period is those of diffusion and capillary. The dryer is recommended for small scale farmers and household use.



Isometric drawing of the solar dryer



Component parts of the solar dryer



Orthographic views of the solar dryer

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