DESIGN AND FABRICATION OF EXPERIMENTAL SOLAR FOOD DEHYDRATOR FOR ROOT CROPS AND VEGETABLES DRYING

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ABSTRACT

In the majority of African countries, agriculture represents the most important part of the economy. However, national food production still doesn't meet the requirements of the population. The decrease in food production caused by crop-failures, significant seasonal fluctuations, lack of appropriate and affordable preservation and storage systems can be resolved by way of drying. Locally, crop drying has been accomplished by burning wood and fossil fuels in ovens or outdoors drying under screened sunlight. These methods, however, have their shortcomings. The previous is expensive and not environmental friendly and the latter is vulnerable to the variability and unpredictability of the weather. This paper discusses the development of a hybrid solar food dehydrator using locally available materials like plywood, wire mesh, and a glass, to supply an honest method for food preservation that maintains a high level of flavor and nutrients, at the same time providing a convenient, compact, easy-to-store supply of Agricultural produce at a far lesser cost.

KEYWORDS: Food drying, vegetable drying, root crops, Solar dehydrator, Machine design

INTRODUCTION

Drying was probably the primary food preserving method employed by man, even before cooking (Alamu, et al., 2010). It involves the removal of moisture from agricultural produce as such provide a product which will be safely stored for extended period of time. Microorganisms are effectively killed when the interior temperature of food reaches 63°C. Dried foods basically do not require any special storage equipment and are easy to move (Waewsak, et al., 2006).

Dehydration of vegetables and other food crop by traditional methods of open-air sun drying isn't satisfactory, this is simple because the products deteriorate rapidly. Studies have shown that agricultural produce dried using a solar dryer were superior to those which are sun dried when thoroughly evaluated in terms of taste, colour and mold counts (Gallali, et al., 2000). Solar dried agricultural products are a better quality product which can be stored for extended period of time, easily transported at less cost while still providing excellent nutritive value (Alamu, et al., 2010).

Solar heat technology is rapidly gaining acceptance as an energy saving measure in the field of Agriculture. It's more preferred to other alternative sources of energy like wind and shale, because it's abundant, inexhaustible, and environmental friendly (Akinola 1999; Akinola and Fapetu 2006; Akinola et al., 2006). Traditional drying method, which is usually done on the ground within the outdoors, is the most widespread method utilized in developing countries because it's more simple and even the cheapest method of conserving agricultural produce. Some disadvantages of outdoors drying are exposure of the agricultural products to: rain and dust; direct sunlight which is undesirable for a few foodstuffs; infestation by insects; attack by animals; etc (Madhlopa, et al., 2002). To enhance traditional drying method, solar dryers which have the potential of substantially reducing the above-mentioned disadvantages of outside drying with direct sunlight, have received considerable attention in recent times. The application of dryers in developing countries can reduce post-harvest losses and greatly contribute to the general food supply in these countries. Estimations of those losses are cited to be of the order of 40% but they will, under very critical conditions, be nearly as high as 80%. A big percentage of those losses are associated with improper and/or untimely drying of the agricultural products like cereal grains, pulses, tubers, meat, fish, etc. (Togrul and Pehlivan, 2004).

The nutritional value of food is merely minimally suffering when drying is used (Ikejiofor 1985). Also, food scientists have found that by reducing the moisture content of agricultural produce to about 10% to 20%, bacteria, yeast, mold and enzymes are all well prevented from spoiling it (Gallali, et al., 2000). There are several indigenous fruit trees that provide very cheap sources of protein, vitamins and high value of medicinal properties, which are still underutilized in developing countries but however, have a place within the cosmetic, pharmaceuticals, medical and food and beverage industries, hence revealing their high economic values. The energy consumed for drying is way smaller than the energy needed to freeze or can, also the space for storage is minimal compared with that needed for canning jars and freezer containers.

Hence, this paper discusses the development of a hybrid solar food dehydrator that provide a good food preservation method which maintains a high level of flavor and

nutrients, at the same time providing a convenient, easy-to-store supply of Agricultural produce at a far lesser cost.

MATERIALS USED FOR CONSTRUCTION

The following materials were used for the construction of the domestic passive solar food dehydrator:

- ❖ Wood –used as the housing of the whole system; wood was selected being an honest insulator and relatively cheaper than metals.
- ❖ Glass –used as cover for the solar collector and the drying chamber. The glass permits the solar radiation into the system and at the same time resists the flow of heat energy out of the systems.
- ❖ Wire mesh of thickness 1mm painted black – used for the absorption of the solar radiation.
- ❖ Wooden frames-used for constructing the trays.
- ❖ Nails and glue-used as fasteners and adhesives.
- ❖ Insect net at air inlet and outlet –used to stop insects and other foreign materials like dust from getting into the dryer.
- ❖ Handle – used for the doors of the trays.
- ❖ Black Paint

FEATURES OF COMPONENT PARTS

The box collector and the drying chamber

The box collector and the drying chamber was designed to be together as a triangular shape. This unique shape places the collector box 27.5 degrees from the ground to match the average angle of the sun's approach all year around in Nigeria. The goal of the collector box is to increase the temperature and velocity of air flow in the dehydrator. The drying chamber was made with highly polished wood which contains four drying trays also made of wood.

Cover plate:

The cover plate is a transparent glass sheet used to cover the absorber, as such preventing dust and rain from getting in contact with the absorber and at the same time prevent the heat from escaping.

Absorber plate:

These are wire mesh of 1mm thickness painted black and placed below the cover to absorb, the incident solar radiation transmitted by the plane glass cover thereby heating the air between it and the cover. The wire mesh was placed in four (4) layers to intensify the heat absorption.

DESIGN CALCULATIONS

1) Energy balance on the absorber

The energy balance on the absorber is derived by equating the total heat gained to the total heat lost by the heat absorber of the solar collector. This is shown in equation (1) by Bolaji, (2008) as:

$$IA_C = Q_U + Q_{cond} + Q_{conv} + Q_R + Q_p \quad (1)$$

where:

I = rate of total radiation incident on the absorber's surface (Wm^{-2});

A_c = collector area (m^2);

Q_u = rate of useful energy collected by the air (W);

Q_{cond} = rate of conduction losses from the absorber (W);

Q_{conv} = rate of convective losses from the absorber (W);

Q_R = rate of long wave re-radiation from the absorber (W);

The three heat loss terms, Q_{cond} , Q_{conv} and Q_R are combined into one-term (Q_L), as shown in equation (2).

$$Q_L = Q_{cond} + Q_{conv} + Q_R \quad (2)$$

If τ is the transmittance of the top glazing and I_T is the total solar radiation incident on the top surface, therefore equation (3) shows that:

$$IA_c = \tau L_T A_c. \quad (3)$$

The reflected energy from the absorber is shown by equation (4) as stated by Bolaji, (2008).

$$Q_p = \rho \tau L_T A_c. \quad (4)$$

where ρ is the reflection coefficient of the absorber.

Substitution of Equation (2), (3) and (4) into Equation (1) yields:

$$\tau I_T A_c = Q_u + Q_L + \rho \tau I_T A_c.$$

Or

$$Q_u = \tau I_T A_c (1 - \rho) - Q_L.$$

For an absorber $(1 - \rho) = \alpha$ thus,

$$Q_u = (\alpha \tau) I_T A_c - Q_L \quad (5)$$

Where;

α is solar absorptance

Q_L composed of different convection and radiation parts. It is presented in equation (6) as:

$$Q_L = U_L A_c (T_c - T_a, \quad (6)$$

where:

U_L = overall heat transfer coefficient of the absorber ($\text{Wm}^{-2}\text{K}^{-1}$);

T_c = temperature of the collector's absorber (K)

Angle of Tilt (β) of the Solar Collector.

The angle of tilt (β) of the solar collector is given by equation (7) as stated by (Alamu, et al., 2010).

$$\beta = 10^\circ + \text{lat } \varphi \quad (7)$$

where $\text{lat } \varphi$ is the latitude of the collector location, the latitude of Akure Ondo State Nigeria, where the dehydrator was designed is latitude 7.30°N .

Hence, the suitable value of β used for the collector as shown in equation (8).

$$\beta = 10^\circ + 7.30^\circ = 17.30^\circ \quad (8)$$

2) **Collector efficiency:** This is computed from (Ezekoye and Enebe, 2006) as stated in equation (9).

$$\eta = \rho C_p V \Delta T / A t_c \quad (9)$$

Where:

ρ is the density of air (kg/m^3),

t_c is the insolation on the collector,

Δ is the temperature elevation,

c_p is the specific heat capacity of air at constant pressure (J/kg K),

V is the volumetric flow rate (m^3/s), and

A is the effective area of the collector facing the sun (m^2).

3) **Dryer efficiency:** This is given in equation (10) as expressed by (Ezekoye and Enebe, 2006).

$$\eta_d = ML / I_c A t \quad (10)$$

Where:

L is the latent heat of vaporization of water,

M is the mass of the crop, and

t is the time of drying.

- 4) **Moisture Content(M.C.):** The moisture content of drying sample is given by equation (11) as expressed by (Ezekoye and Enebe,2006).

$$M.C = (M_i - M_f)/M_i \quad (11)$$

Where:

M_i= mass of sample before drying and

M_f= mass of sample after drying.

- 5) **Moisture loss (ML):** The Moisture Loss (ML) from the drying samples is given by equation (12) as shown by (Ezekoye and Enebe, 2006).

$$ML = (M_i - M_f)(g) \quad (12)$$

Where:

M_i is the mass of the sample before drying and

M_f is the mass of the sample after drying.

RESULTS AND DISCUSSIONS

Design Implementation

Two digital sensors were positioned to measure the temperature and humidity at the inlet and outlet portion of the air heater. Other sensors have been placed at the various trays 1, 2, 3 and 4 in order to measure the temperature and humidity of the trays. The Ambient temperature was also recorded during the course of experiments with the help of a digital sensor. The experiment was conducted at the Federal University of Technology Akure, Agricultural and Environmental Engineering departmental workshop Obaekere, and the orientation of the solar collector was faced towards the south direction. Successful tests were conducted between July 26 to July 31, 2017 and in this paper, one of the test data was used to evaluate the drying curves, humidity and temperature measurements in the dehydrator. During the tests period, the heated air was used to dry potato chips. The results obtained during the test period showed that the temperatures inside the dryer and solar collector were far higher than the ambient temperature during most hours of the day-light. The temperature inside the drying cabinet was up to 50⁰c for about three hours immediately after 12.00h (noon). The dehydrator exhibited sufficient ability to dry agricultural produce reasonably rapidly to a safe moisture content level and as such, ensures a superior quality of the dried product.

Table 1.1: A typical day results of the diurnal variation of temperatures in the solar dehydrator (unloaded)

Time	Ambient Temperature	Drying Temperature	Chamber	Collector Temperature
09:00	32	34		37
10:00	33	37		42
11:00	35	40		50
12:00	38	46		58
13:00	35	50		62
14:00	34	45		58
15:00	32	42		50
16:00	31	39		47
17:00	30	36		44
18:00	30	34		39

Variation of the temperatures in the solar collector and the drying cabinet compared to the ambient temperature

Table 1.1 and figure 1.1 shows the results of the hourly variation of the temperatures in the solar collector and the drying cabinet compared to the ambient temperature. The dryer is hottest about mid-day when the sun is overhead. The temperatures inside the dryer and the solar collector were far higher than the ambient temperature during the most hours of the daylight. The temperature rise inside drying cabinet was up to 50 °C for almost three hours immediately after 12.00h (noon).

Figure 1.1 Variation of temperature curves for the solar food dehydrator

The drying curve for Potato chips in the mixed-mode solar food dehydrator

Table 1.2 and Figure 1.2 show the drying curve for potato chips in the solar food dehydrator. It was observed that the rate of drying increased due to increase in temperature between 10.00h and 14.00h.

Table 1.2: Hourly Moisture Loss and Mass of the drying PotatoChips Samples

TIME	Mass of Potato (g)	Moisture Loss (g)	% Moisture Loss	Total Moisture Loss (%)
09:00	560	-	-	58
10:00	547	13	2.3	55.7
11:00	528	19	3.4	52.3
12:00	503	25	4.5	47.8
13:00	474	29	5.2	42.6
14:00	436	28	6.8	35.8
15:00	399	37	6.6	29.2
16:00	365	34	6.0	23.2
17:00	338	27	4.8	18.4
18:00	318	20	3.6	14.8

Figure 1.2: Drying curve for the sample potato chips in the solar food dehydrator

CONCLUSION

From the test conducted, the following conclusions were made.

- The product inside the dehydrator requires less attention, like attack of the food item by rain or pest (both human and animals), compared with those in the open sun drying.
- Although the dehydrator was used to dry Potato, it can be used to dehydrate other agricultural products like yams, cassava, maize, plantain etc.
- There is ease in monitoring in comparison to the natural sun drying technique.
- The financial cost involved in the construction of a solar food dehydrator is much lower to that needed for the construction of a mechanical dryer.

Plate 1.1: The fabricated hybrid solar food dehydrator

- e) From the test, locally sourced materials were used for the construction of the simple and inexpensive solar food dehydrator.
- f) The hourly variation of the temperatures inside the drying cabinet and air-heater are much above the ambient temperature during the foremost hours of the day-light.
- g) The temperature inside the trays (cupboard) was up to 50 °C for about three hours after 12.00h (noon).
- h) The dehydrator exhibited sufficient ability to dry food items rapidly to a safe moisture content level and as such ensures a superior quality of the dried product.

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