DESIGN, CONSTRUCTION AND PRELIMINARY TESTING OF AN AUTOMATED SOLAR DRYER FOR CASSAVA CHIPS
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doi: https://doi.org/10.37017/jeae-volume5-no2.2019-3

ABSTRACT

An automated solar dryer was designed, constructed and tested under no-load condition and load condition. The components of the dryer include an electromagnetic actuator jack, electronic positional controller, magnetic compass, solar collector and drying cabinet. The actuator jack is designed in such a way that the collector angle varies automatically as the sun rises and sets. In this manner, the drying products get maximum heat energy from the sun rays at any given time. This technology enables the product to be left inside the dryer without any need for manual turning of the collector along the direction of the sun rays. In operation, the actuator jack receives a signal from the electronic positional controller and the resulting inward and outward movement of the jack leads to an angular displacement of 15° for every hour of drying. The result of no load test showed that the average air temperature inside the dryer was 66°C given a rise of 22°C over the ambient condition in Ilorin (42°C) at the time of testing. 1kg of cassava chips was dried to a moisture content of 11.1% (wb) in 9 hours showing that the dryer has performed satisfactorily and is recommended for cassava chips drying.

Keywords: automation, actuator jack, cassava chips, design, solar collector, solar dryer

INTRODUCTION

Open sun drying is the conventional method of drying most agricultural products in most developing countries, especially the tropics and sub-tropics. Open sun drying involves spreading of crop on the ground or other platforms and drying the crop directly in the sun. The method appears free in term of energy cost but it is labour intensive and produces high loss with low product quality. The disadvantage of this is that, during the rainy season, drying of crop can be delayed for a long time leading to growth of mould on the product. During favourable weather period, insolation is high in the midday and product can be subjected to over-drying. The quality of the product can be improved by regularly and frequent turning on the drying floor and covering the product when heat is too much. Sun drying on the open floor exposes the product to wetting and rewetting and danger of contamination. The product is also exposed to damage by dust, rain, rodents, birds and insects and thereby reducing its quality and quantity.

Due to demand for high quality foods (El-Shiatry et al, 1991), ever increasing production capacity, and unpredictable weather conditions, the use of direct sun drying is not economically and technically feasible. The use of mechanical dryers, which is an alternative method, is capital extensive and therefore not suitable for the small-scale cassava processors in the rural developing countries. Solar drying is a good alternative to open sun drying and it is a cheaper method of drying compared with the use of mechanical dryer. Solar drying generates higher air temperatures and, consequently, lower air relative humidity, both of which are conducive for
improving the drying efficiency and product quality.

The insolation and consequently, the output of any solar collector vary with the period of time during which it is used no matter its slope or orientation. The tilt angle of the collector also varies with different periods of the year; therefore, the dryer needs to be positioned in such a way that sufficient energy is available when it is most needed (Alonge and Oje, 2006a, b). The collector should be designed in such a way that it will be perpendicular to the insolation at solar noon. A manually adjusted solar dryer was developed by Alonge and Omoniwa (2012). Depending on the time of the year and location, the collector should face either directly south or directly north. Solar dryers are of many types based on designs; there is natural convention (Eke, 2002), forced convention, active system, passive system, and so on. Therefore, the objective of this study was to design, construct and preliminarily test a solar drying device that automatically varies the angle of tilt of the collector with respect to time and weather conditions.

**MATERIALS AND METHODS**

**Conceptual Design of the Dryer**

The solar drying system consists of drying chamber, drying tray, solar collector, supporting frame, actuator jack, the compass and the position controller (Figure 1). The solar collector is made up of a silicate glass of dimension 800 mm x 600 mm and 2.5 mm thickness. It absorbs radiant energy from the sun and also minimizes heat loss. The drying cabinet is where the actual drying process takes place. It is made up of wood of dimension 700 mm x 500 mm x 250 mm inside which is the drying tray of dimension 659 mm x 450 mm x 100 mm. Made of hard wood with dimension 1000 mm x 500 mm x 100 mm, the frame holds the drying cabinet and the actuator jack. The actuator jack performs a mechanical motion in response to a signal the position controller and converts the signal to a mechanical displacement and thereby controls the forward and backward motion of the collector. In this way, the actuator jack is an electromagnetic device which is powered by the position controller. It has a maximum thrust of 200 kg in both forward and backward direction with a length of 900 mm.

**Design Considerations**

The following criteria were considered in the design of the solar dryer (Basunia and Abe, 2001; Alonge and Oniya, 2011): (i) quantity of product to be dried – 1 kg of cassava chips per batch; (ii) initial moisture content of product – 70% (wb); (iii) final moisture content of product – 12% (wb); (iv) average temperature and relative humidity of Ilorin – 27°C and 70% respectively; and (v) useful sunshine hour in Ilorin – 9.00h to 17.00h Nigeria time (Alonge and Hameed, 2007; Alonge and Oniya, 2011, A5); (vi) the actuator jack to be regulated by a timer in such a way that it will move at an interval of 1 hour; and (vii) power required to activate the actuator jack and sensor.

**Design Computations**

1. **Moisture to be removed from the Product**

The amount of moisture to be removed from 1 kg of fresh cassava chips is determined by the equation below as:

\[
W_w = \frac{W_g (M_i - M_f)}{100 - M_f}
\]

where: \(W_w\) and \(W_g\) are the amount of moisture to be removed from the product and initial mass of the product respectively in kg; \(M_i\) and \(M_f\) are initial moisture content and final moisture content of the product respectively in g.

2. **Quantity of Air Required to Dry the Product**

The quantity of air required to remove the moisture from the product (cassava chips) is determined from the equation given below as:

\[
W_a = \frac{W_{wL}}{C_a \rho_a (T_i - T_f)}
\]

where: \(L\) is the specific latent heat of vaporization of water; \(C_a\) and \(\rho_a\) are the densities of drying air and product respectively in kg/m³; \(T_i\) and \(T_f\) are
initial and final temperatures of drying air respectively in °C.

3. Volume Flow Rate and Speed of Drying Air
The volume flow rate and linear speed of drying air are calculated using the Equations 3 and 4 respectively as:

\[ Q_a = \frac{W_a \cdot t_d}{\Delta t} \]  \hspace{1cm} (3)

\[ V_w = \frac{Q_a}{A_r} \]  \hspace{1cm} (4)

where: \( Q_a \) is the volume flow rate of drying air in m³/s; \( t_d \) is the drying time; \( V_w \) is the linear speed of drying air in m/s; and \( A_r \) is the area of air vent.

4. Pressure head of air in the dryer
The pressure head of air in the dryer is determined using the expression given by the Equation 5 below as:

\[ P = 0.0038 t \Delta h \]  \hspace{1cm} (5)

Where: change in temperature between ambient air and heated air in the dryer in °C; \( g \) is the acceleration due to gravity in m/s²; and \( h \) is the length of hot air column in m.

5. Design of electronic positional controller
The design of electronic positional controller is based mainly on AC and DC circuits and the design computations are in four stages mainly: (i) input power stage; (ii) switching stage; (iii) positional timer stage; (iv) driver stage.

Material Selection and Construction
Fabrication was carried out at the Fabrication Workshop, Department of Agricultural and Biosystems Engineering, University of Ilorin. The specification of construction materials is shown in Table 1.

Testing Procedure

Figure 1: Exploded view of the conceptual solar dryer design: 1-Solar collector surface; 2-Collector frame; 3-Drying cabinet; 4-Beam support; 5,9-Column support; 6-Actuator jack; 7-Drying tray; 8-Tray wire gauze
After construction and assembly of the component parts, the dryer was tested under four conditions which include: (i) no-load test without automation; (ii) no-load test with automation; (iii) load test without automation; and (iii) load test with automation. For the first no-load test, the angle of inclination for maximum insolation was 30°, therefore the collector angle was set at 30°. During the second no-load test, the electronic position controller was used to control the movement of the dryer. At the beginning of the experiment, the dryer was set at angle 60° at 9.00 am and the angle was changed automatically by 15° at every 1 h interval.

For the load test, cassava was purchased from a farm in Ilorin, washed, peeled, cut into chips and blanched. The position controller was set based on the fact that the angular displacement of the sun is 0° at solar noon and changes at the rate 15° per hour. The position controller was therefore pre-set at angle 60° in the morning at 8.00 am so that at every 1 hour the collector would rotate automatically and reduce to 15° at 12.00 noon.

One kg of cassava chips processed as above was dried by the solar dryer with and without automation. Moisture content of samples were monitored on hourly bases along the drying process. Data obtained from the tests were statistically analyzed using paired t-test.

**RESULTS AND DISCUSSION**

**Design Results**

The results of the design calculations including the design specifications of the solar dryer are as shown in Tables 2 while Figure 2 shows the orthographic projections.

**Results of Testing**

The result of no load test showed that the average air temperature inside the dryer was 66°C given a rise of 22°C over the ambient condition in Ilorin (42°C) at the time of testing. 1kg of cassava chips was dried to a moisture content of 11.1% (wb) in 9 hours showing that the dryer has performed satisfactorily and is recommended for cassava chips drying.

| Component Parts   | Materials Used                              | Quantity          |
|-------------------|---------------------------------------------|-------------------|
| Drying cabinet    | Hard wood                                   | 3 standard lengths|
| Frame support     | Hard wood                                   | 2 standard lengths|
| Cabinet case      | Plywood                                     | 2 sheets          |
| Insulation        | Saw dust and wood glue                      |                   |
| Drying tray       | 90 mm x 60 mm wire gauze                    | 1                 |
| Driver            | Actuator jack                               | 1                 |
| Compass           | Plastic and magnet                          | 1                 |
| Sensor            | Reed switch                                 | 1                 |
| Controller        | Automatic electronic position controller     | 1                 |

Table 1: Materials of Construction of the Solar Dryer and their Specifications
Table 2: Design Parameters and Specifications

| Design Parameters                          | Specifications     |
|-------------------------------------------|--------------------|
| Capacity of the dryer                     | 1 kg/batch         |
| Quantity of water to be removed from the product | 0.55 kg            |
| Total drying time                         | 8 h                |
| Quantity of air needed for drying         | 53.69 m³           |
| Drying rate                               | 68.50 g/h          |
| Volume flow rate of drying air            | 6.71 m³/h          |
| Speed of drying air                       | 0.38 m/s           |
| Energy required to remove water from the product | 165 kJ            |
| Dimensions of the solar collector         | 800 mm x 600 mm    |
| Dimensions of the column                  | 25 mm x 25 mm      |
| Depth of the collector                    | 300 mm             |
| Dimensions of the drying tray             | 660 mm x 520 mm x 54 mm |
| Pressure drop in the dryer                | 0.14 N/m²          |
| Load on each column                       | 300 N              |
| Permissible stress of the column          | 2.78 N/m²          |
CONCLUSIONS

The following conclusions can be drawn from the study:

- The automated solar dryer can efficiently dry cassava chips at any location.
- The position controller effectively powered the actuator jack which in turn positioned the solar collector at the required angle.
- The air temperature in the dryer was with automation was considerably higher than that without automation.
- The drying rate of cassava chips was higher with automation as compared with without automation.
- All the above showed that the dryer performed satisfactorily.

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