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DEVELOPMENT OF A MICROCONTROLLER-BASED PHOTOVOLTAIC POWERED CROP-DRYER FOR AGRICULTURAL DEVELOPMENT IN NIGERIA

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ABSTRACT

One of the major contributory factors responsible for the economic non-viability in farming is farmers' inability to handle and store produce efficiently hence leading to the reduction of the quality and even destruction of produce available for sale. The investment into farming can be preserved not only upon the capacity to grow in large quantity, but also upon the facilities for efficient handling, drying and storage before marketing.

This paper therefore, presents the 'Development of a Microcontroller-Based Photovoltaic Powered Crop-Dryer as a Strategy for the Improvement of Agricultural Sector in Nigeria'.

Although the design can be used for various drying purposes, the focus is on its use for drying agricultural produce (Ginger).

This Solar dryer comprises of a PIC Microcontroller, a Perspex-covered flat Plate Collector, the drying Chamber, Heater and a d.c. Blower (suction fan) powered by a solar module.

This solar dryer with improved features will in no doubt increase the income of farmers and industrialists who need to preserve their products by dehydration in a developing nation like Nigeria.

In the Crop dryer, dehydration of samples was carried out at temperatures 32^{o}C, 40^{o}C and 50^{o}C. In this design, the drying of the produce and the powering of the suction fan and heater are both solar driven that is why the Dryer can be used on farm where there is no public power supply.

The PIC Microcontroller is used to turn ON the fan at very high temperature, and to turn the

heater at low temperatures in order to maintain the temperature of the drying Chamber.

However, for drying to continue in the absence of solar radiation it is recommended a battery be provided as power back-up.

Keywords: Photovoltaic, Crop- Dryer, Temperature, Blower, Microcontroller, Produce.

1.0 INTRODUCTION

Drying is one of the high energy consuming processes in the food processing, chemical, printing, fabric drying industries etc. It is therefore important to work towards achieving efficient, convenient and cost effective means of drying (Lambert et al, 1980).

Drying is thus an excellent way to preserve food, and Solar Crop Dryer is an appropriate food preservation technology for a sustainable world.

According to food technologists, dried foods are high in fiber and carbonhydrates and low in fat, making them healthy food choices (El-Amin et al., 2007). Drying preserves foods by removing enough moisture from it to prevent decay and spoilage.

Water content of properly dried food varies from 5 to 25 percent depending on the food.

The optimum temperature of drying food is 60ºC. This is adequate for removing the moisture from food so that yeasts, bacteria and moulds cannot grow on it (El-Shiatry et al., 1991). If higher temperatures are used, the food will cook instead of drying. When drying foods, it is important to remove moisture as quickly as possible at a temperature that does not seriously affect the flavour, texture and colour of the food (Gomez, 1982). If temperature is low in the beginning, microorganisms may grow before the food is adequately dried. Too high temperature can cause hardened foods: food that is hard and dry on the outside but moist on the inside is vulnerable to spoiling. The key to successful food dehydration is the application of a constant temperature and adequate air flow

The traditional methods of drying and preserving foods make much use of direct solar and wind energy. As practiced in the rural areas, it involves spreading of the agricultural produce on the ground and allowing it to dry in open sun. It has been seen that open sun drying has the following disadvantages;

- It requires both large amount of spaces and long drying times.
- The crop may become damaged because of the hostile weather condition.
- The crop is subjected to insect infestation and.

- The crop is susceptible to re-absorption of moisture if left on the ground for a long period of time (Madhlopa, 2002).

The Direct Solar Dryer comprises of closed, insulated box inside which both solar collection and drying take place. Radiation is collected by green house effect through a transparent glass or plastic cover in the drying chamber, which air can enter and exit. Heated air circulates through or above the product, removes moisture, and carries it out through the vents. (El-Amin et al, 2007). It operates at a higher temperature, dries crops more quickly and prevents attack from insects and microorganisms. However, the product in direct sunlight may be damaged by the sun

The Indirect Solar Driers is an improvement over the direct solar drier to overcome its disadvantages.. The indirect solar dryer has a flat plate collector and a separate drying chamber, which makes it more efficient and allows more control over the drying process than direct solar dryers. The solar collector heats air and, by convection, forces it through racks of drying products in the drying chamber (Madhlopa 2002). The Products dry much faster and are protected from direct solar radiation. However, it is more expensive than the Direct Solar Dryer and special skill is required for its construction.

2.0 MATERIALS AND METHODOLOGY

2.1 Materials of the Solar Dryer (see Figure 1).

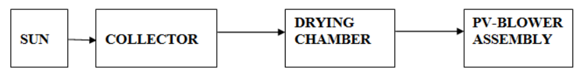

Figure 1: Block Diagram of the Solar Dryer

The Solar dryer consists of three major parts namely:

(1) The Collector
(2) The drying Chamber (Bin)
(3) The PV- Blower Assembly

2.1.1 The Collector

The Collector consists of the following:

(i) Collector Box (frame and box)

The collector box serves as the passage for air into the drying chamber.

The dimension of the collector box (made of wood) is 120 x 75 x 18 cm^3. The wooden frame of the collector is easy to build and has some natural insulating capabilities.

The collector box is however properly seasoned and treated for aging and drying.

(ii) Absorber plate (flat plate solar collector)

This is the actual material that absorbs the

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solar radiation. Hence, aluminum sheet having a high thermal conductivity (204 W/m-k) is selected. Similarly, the absorber should be able to release the absorbed radiant energy inform of heat energy to the working fluid (air) readily. For this reason, the absorber is painted black so as to behave as a black body. A black body is a perfect absorber and emitter of radiant energy.

(iii) Glazing (transparent cover: Perspex)

A typical sheet of Perspex having the following properties for a given amount of visible light striking it selected.

$\tau = 91.8\%$
$\rho = 8\%$
$\alpha = 7\%$

Where, τ, ρ and α, are the transitivity, reflectivity and absorptivity of the material respectively.

In the design, Perspex is used instead of glass because of its relative 'elasticity" and less possibility of breakage. It is easier to transport and handle than glass. It can withstand large amount of sunlight without cracking.

2.1.2 The Drying Chamber (Bin)

The dimension of the drying chamber is (75 x 62 x 40) cm^3. This serves as the drying unit. It is basically a hot box where the agricultural produce is dehydrated. The drying chamber is fabricated from a seasoned wood, which helps in conserving heat as a result of its low thermal conductivity. It has a door on its backside. There is a transparent glass to allow view to the drying chamber. It has two wooden mesh trays for putting the farm produce to be dried.

2.1.3 P-V Blower Assembly

To facilitate airflow and the quick removal of saturated air, forced convection is utilized by the use of a photovoltaic powered direct current (DC) blower. The 11W PV panel drives the 12V DC blower, which sucks or evacuates moisturized air within the drying chamber, hence preventing air stagnation.

2.2 Methodology

Technical Criteria

It should be noted that there are more than one material that can be used for each component but the methods used in selecting any particular material used in this design depend on:

(i) Availability of the material
(ii) Proximity of the market to point of construction
(iii) Suitability of the material for the purpose intended
(iv) Cost of the material
(v) Formability
(vi) Ease of handling and transportation.

In the design, the solar energy incident on the collector is absorbed by 'black' surface.

ISSN: 2456-1851

Volume:02, Issue:04

The absorbed energy is transferred to the working fluid (air) which moves up into the drying chamber. In the chamber, the hot air aided by a PV operated d.c. blower exchanges heat with the content (ginger, was used) of the chamber. The evaporated moisture is sucked out by the blower.

Determination of the Mass flow rate

From basic thermodynamics, energy absorbed by collector is;

$$Q_u = mc_p(T_2 - T_1)$$

T_a = Ambient temperature = 32°C

T_c = Average collector temperature = 45°C

C_p = Specific heat capacity at constant pressure = 1005 J/kg-k

m = mass flow rate kg/min

$$m = \frac{Q_u}{A_C C_p (T_c - T_a)}$$ …… (Sodha et al, 1987).

$$m = \frac{343.58}{0.826 \times 1005(45 - 32)} = \frac{343.58}{0.826 \times 1005 \times 13} =$$ 1.5 Kg/min.

3.0 DESIGN ANALYSIS

The major analyses involved in this design are:

- Thermal analysis
- Fluid (air) flow analysis
- Solar module's output analysis

3.1 Concept of a Black Body

Let the total energy incident on the black collector = I

ρI, αI and τI are the portions reflected, absorbed and transmitted respectively.

Thus, $I = \rho I + \alpha I + \tau I$ …………….1

$I = I(\rho + \alpha + \tau)$

$\rho + \alpha + \tau = 1$ …………….2

By definition, a black body (in this case the solar collector) is a perfect absorber and emitter of radiant energy.

For a black body, $\rho = \tau = 0$; $\alpha = 1$

For an opaque body, $\tau = 0$; $\alpha + \rho = 1$

For a white body, $\alpha = \tau = 0$; $\rho = 1$

3.2 Thermal Analysis

Combining the laws of conversion of energy and the first law of thermodynamics, one can say that the energy gained from the collector at a given time is the difference between the amount of solar energy absorbed by the absorber plate and the energy lost to the surrounding.

Energy Balance Equation

As earlier said, the useful energy delivered is the difference between the absorbed incident radiation and the total heat loss from the collector.

i.e. Useful energy gained =

$$\begin{pmatrix} Energy\ absorbed \\ by\ collector\ \ plate \end{pmatrix} - \begin{pmatrix} Energy\ lost\ to \\ the\ surrounding \end{pmatrix}$$

Useful energy (Qu) = $Q_i - Q_L$
Input energy = Q_i
Losses = Q_L

$$Q_u = F_R \times A_C \left[I_C \tau_\alpha - U_L (T_c - T_a) \right]$$

Where,
Q_u = Useful energy is collected (w)
F_R = Collector's removal efficiency factor
A_c = Area of the collector (m^2)
τ = Solar transmittance/transmitting of the transparent cover Perspex
α = Solar absorptance / absorptivity of collector plate
U_L = Collector's overall heat loss coefficient (W/^oC-m^2)
T_c = Inlet fluid temperature (^oC)
T_a = Outside ambient temperature (^oC)

Collector Plate and Overall Dryer Efficiencies (η_C & η_D)

The useful energy gained by the collector can be obtained from;

$$Q_u = m_u A_C C_p (T_c - T_a) \quad \ldots\ldots\ldots\ldots\ldots 3)$$

Where m_u = Fluid (air) mass flow rate per unit area
A_c = Inlet area
C_p = Specific heat capacity of fluid (air)
For air, C_p = 1.005KJ/Kg –K
If useful energy gained = Q_u
Total Energy supplied = $A_C I_C$
Then, Collector Plate efficiency (ηc) =

$$\frac{Energy\ gained}{Energy\ Supplied}$$

$$\eta c = \frac{Q_u}{A_c I_c} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Also, the dryer is intended to remove moisture from produce.

$\therefore$ Work done, W = mL

Where,
m = mass of moisture evaporated from produce
L = Latent heat of evaporation of water

$\therefore$ Overall dryer efficiency (η_D) is given by

$$\eta_D = \frac{Workdone}{Energy\ \ Supplied}$$

$$\eta_D = \frac{mL}{A_c I_c} \quad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Heat Removal Factor, (F_R) is defined as the energy collected if the entire Collector plate is at the inlet fluid temperature T_c

$$\therefore \quad F_R = \frac{I_c \tau_\alpha - U_L (T_{av} - T_a)}{I_c \tau_\alpha - U_L (T_c - T_a)} \quad \ldots\ldots\ldots(6)$$

Where, T_{av} = average collector plate surface temperature
T_c = Inlet fluid temperature

Determination of Collector Area (A_c)

A collector size of 118 x 70 cm^2 was used. Hence, the collector area, Ac is given as:
$A_c = 118 \times 70 = 8260 cm^2$

Determination of Heat Removal Factor (F_R)

Recall, equation (7)

$$F_R = \frac{I_c \tau_\alpha - U_L(T_{av} - T_a)}{I_c \tau_\alpha - U_L(T_c - T_a)}$$

I_c = Solar insulation = 500w/m^2
τ_α = Transmittance – Absorption product = 0.918
U_L = overall heat loss coefficient = 1.70w/m^2
T_{av} = Average collector temperature = 45°C
T_a = Ambient temperature = 32°C
T_c = inside temperature of the fluid (32°C)

$$F_R = \frac{500(0.918) - 1.7(45-32)}{500(0.918) - 1.7(32-32)}$$

$$F_R = 0.952$$

Determination of Useful energy collected

(Q_u);

Q_u = $F_R A_c \{I_c \tau_\alpha - U_L(T_c - T_a)\}$
A_c = 8260cm^2 = 0.826m^2
Q_u = 0.952 x 0.826 [500 x 0.918 – 0.7 (45 – 32)]
= 0.7864 (459 – 22.1)
= 0.7864 x 436.9
Q_u = 343.58 watts

Collector Efficiency (η_c)

$$\eta_c = \frac{Q_u}{A_c I_c} x100\%$$

$$= \frac{343.58}{0.826x500} x100\% \quad = \frac{343.58}{413} x100\%$$

= 0.832
= 83.2%

Testing and Results

The Solar Dryer was set up (see Figure 2). The Solar panel was set in place ensuring approximately 90° inclination to the solar incident radiation. Cables were connected from the panel to the Blower.

The rate of moisture loss from the specimen was determined by periodic weighing of the specimens. The experiment was conducted at 32°C, 40°C and 50°C constant temperatures (see Table 1). The 32°C was chosen because it is close to the atmospheric temperature and traditionally, farmers dry their crops by direct exposure to the sun. 50°C temperature was also chosen because it is close to 60°C which is the temperature at which most starch begins to gelatenize. Since ginger contains not less than 30% starch, heating above that temperature may initiate noticeable physical and chemical changes in the biochemistry of the crop.

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Table 1: The Drying Rate of Ginger Tubers

Temperature (°C)	Time of Drying (hr)	Drying Rate (g/hr)
32	80	0.04
40	45	0.07
50	19	0.17

Discussion: The average weights of the samples for each of the treatments were determined (see Table 1). Each of the samples stabilized at 3.2g.

The samples of 32°C drying temperature began stabilizing in weight at about 80hrs (i.e. drying rate of 0.04g/hr). Further observation of the sample 30hrs after experimentation indicated rich aroma of alcohol. The possible reason is that the rate of moisture removal was slow that it provided a conducive environment (increase in micro temperature and reduction in pH) for the growth of micro organisms which must have broken down the starch molecules to dextrose. At this point, fermentation of the starch molecules into alcohol has started. The sample treated at 40°C drying temperature equilibrated at about 46hrs (i.e. drying rate of 0.07g/hr). The products remained intact weeks after experiment.

But the 50°C treatment showed fastest falling rate and terminated at 19hrs (ie. drying rate of 0.17g/hr). Close observation of the samples after drying revealed visible cracks on the outer tissue and sharp spicing aroma indicating that some of the pungent principles may have broken.

CONCLUSION

This Solar Crop Dryer is designed to make effective use of abundant solar energy available to dry the nation's agricultural produce and other products that require drying before storage using forced convection.

The advantage of this design is that, it helps in preventing the products from contamination from dust, birds, insects and animals. The nutritive value of the produce is retained and drying is fast.
The drying of the produce and the powering of the suction fan are both solar driven that is why the Dyer can be used where there is no Electricity supply.

However, it is recommended that a 12V battery be connected to the Solar Module as power back-up for drying to continue in the absence of solar radiation especially at night.

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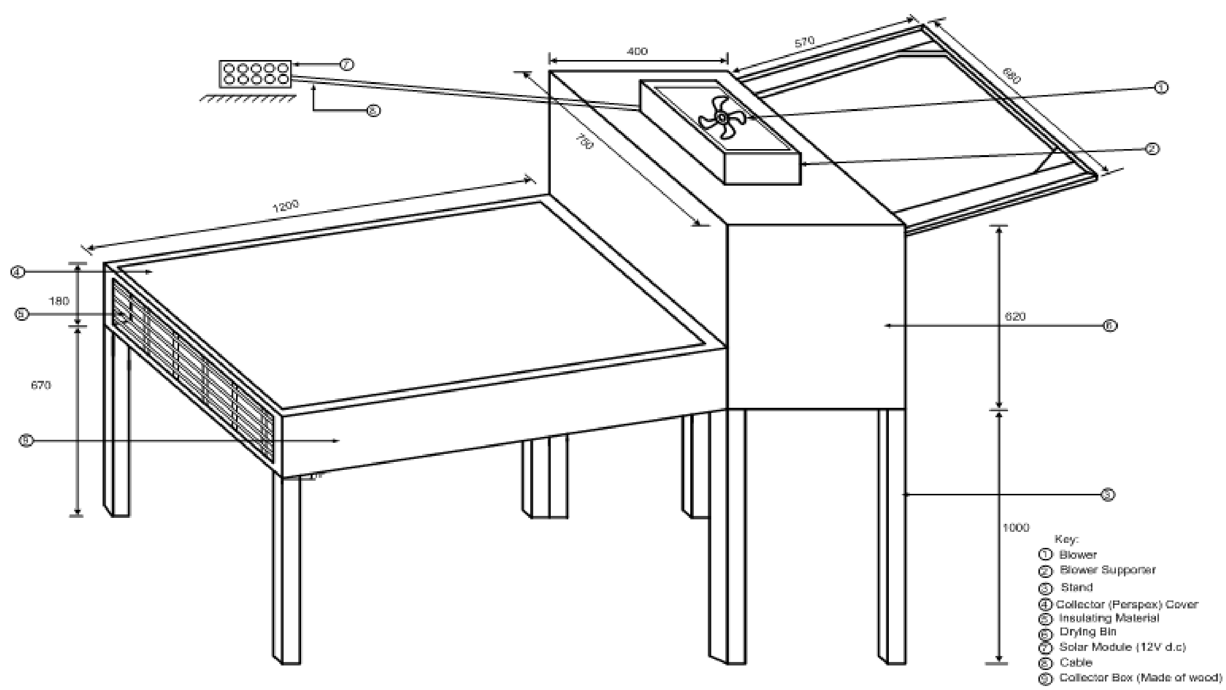

Figure 2: Constructional View of the Solar Dryer (All dimensions in millimeters)

