Original Research Article

DEVELOPMENT OF AN AUTOMATED SOLAR POWERED HOT-AIR SUPPLEMENTED DRYER

ABSTRACT

The world is facing two major challenges: one is to meet the exponential growing demand for energy particularly in developing and underdeveloped countries and other is to deal with global, regional and local environmental impacts resulting from supply and use of conventional energy. The cost-effective technology for solar drying that can be easily adopted among the rural farmers of developing countries needs to be developed in areas where solar energy is abundantly available. As cheap as the solar energy could be, there are associated problems with the stability of the energy for different purposes due to instability of climatic conditions. For this research, a solar powered hot-air supplemented dryer (SPHSD) with a capacity of 20 kg of sliced yam was designed and developed. The SPHSD has three sections which are solar collector chamber, drying chamber and hot-air supplement chamber which is powered with two 150-watt solar panel and a 200 amps solar battery for continuous operation during bad weather. All data were logged digitally for accuracy and test was done using yam slices. Difference in drying time and stability in drying temperature was evaluated using SPHSD and indirect solar dryer. The result shows stability of temperature in the drying chamber when SPHSD was used while the drying temperature fluctuates throughout the indirect solar drying test period. Drying experiment was conducted for 481 minutes (between 0910 hrs to 1713 hrs) reducing the moisture content from 71.91 %, 72.1 % and 72.8 % to 27.95 %, 25.78 % and 28.23 % for MC_1, MC_2 and MC_3 in wet basis respectively. Drying experiment was conducted for 832 minutes (between 0901 hrs to 2257 hrs) reducing the moisture content from initial moisture content levels of 72.66 %, 71.48 % and 71.48 % to 13.47 %, 12.53 % and 12.54 % for MC_1, MC_2 and MC_3 in wet basis respectively.

Keywords: Solar dryer, solar controlled hot-air supplemented dryer, indirect dryer, drying chamber, solar collector.

1. INTRODUCTION

An analysis of the present situation of world agriculture according to [1] shows a completely contrasting situation between industrialized and developing countries. This disparity has greatly influenced the possibilities of utilizing solar energy in agriculture especially in crop preservation, processing and storage. In developing countries like Nigeria, the possibilities of utilizing solar energy are economically feasible compared with its use in industrialized countries. High solar insolation, decentralized use, and the low energy demand favor its use in the country.

Solar thermal technology is a technology that is rapidly gaining acceptance as an energy saving measure in agriculture application. It is preferred to other alternative sources of energy such as wind and shale, because it is abundant, inexhaustible, and non-polluting [2]. It is a major driver of holistic development in any nation of the world. Adequate access to energy is crucial for the social wellbeing and economic transformation of any state [3]. With very few exceptions, the developing countries are situated in climatic zones of the world where the insolation is considerably higher than the world average of 3.82 kWh/m^2 day.

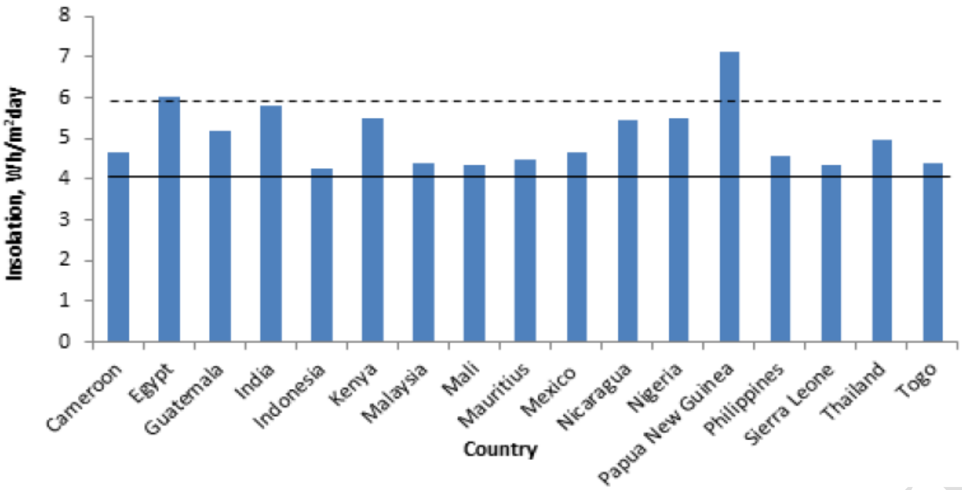

Figure 1. Total horizontal solar insolation for some developing countries

In recent years, attempts have been made to develop solar dryers that can be used in agricultural activities in developing countries. Sun drying is still the most common method used to preserve agricultural products in most tropical and subtropical countries. However, being unprotected from rain, wind-borne dirt and dust, infestation by insects, rodents and other animal, products may be seriously degraded to the extent that sometimes become inedible and result in loss of food quality.

Another significant limitation of solar dryer is that it can only be used during the daytime when there is adequate solar radiation leading to limited production, and moreover it can result in an inferior finished product. Drying methods and the physicochemical changes that occur in tissues during drying affect the quality of the dehydrated products [4]. More specifically, the method and time used for drying affects properties such as colour, texture, density, porosity and sorption characteristics of materials [4, 5] A controlled drying environment is required to deliver a quality dried product. Therefore, it is necessary to provide solar dryer with a back-up heating source with ability to regulate and condition the machine parameters in order of arrive at a more quality dried product faster and continuous.

Hot air drying is one of the most frequently used operations for food dehydration. It is a method in which heated air is blown over food materials with the aid of fan(s) to remove most of the moisture from the food material. The drying of wet materials induces a number of physico-chemical changes in the product, often reflected by colour. By choosing suitable drying methods and the appropriate conditions, the final product quality can be controlled. Since environmental conditions are not so reliable and predictable, mechanical dying system can be incorporated into a solar system thereby reducing the cost of drying and also stabilizing the conditions of drying parameters [6]. The objective of this paper is to develop a fully automated solar powered hot-air supplemented dryer (SPHSD) with moisture metering and data logging system.

2. MATERIALS AND METHODS

The solar dryer considered in this research paper is the Passive Mixed Mode Solar Dryer (PMMSD) or Hybrid Dryer (HD). Here the product is located on trays or shelves inside an opaque drying chamber. Solar radiation is thus not incident directly on the crop. Preheated air warmed during its flow through a low-pressure thermos phonic solar energy air heater, is ducted to the drying chamber to dry the product with an additional DC heating element powered with PV cells and battery. Because the products are not subjected to direct sunshine, Localized heat damage, do not occur. For the purpose of this study, the major components designed for are discussed below.

- **Drying Chamber**

The drying chamber is a cabinet type with a designed capacity of 20 kilograms yam slices. The chamber accommodates a total of 6 detachable trays with dimension 0.65 m by 0.65 m which are made from stainless wire mesh to prevent small chips from falling off into the chamber and at the same time ensure easy passage of heated air across the bed fixed to a wooden frame. The trays are spaced at vertical distance of 10 cm from each other. The chamber was constructed using plywood, fiberglass and having its interior part lined with reflective surface. At the upper part of the chamber lies the outlet vent and it also has insulated roof inclined at an angle 18°.

- **Solar Collector**

The solar collector is a flat plate type with a dimension 1.27 m by 0.7 m. It has a fiber glass insulation of about 5 cm thickness. The absorbing surface which receives radiation is a malt cellulose black painted metal screen sheet which is placed normal in between the solar collector chamber. A single tempered glass cover with a thickness of 5 mm is placed above the absorber. The collector is attached to the backside of the drying chamber, oriented at angle 17.5° at the horizontal. The convective current inside the collector flows into the drying chamber by forced convection using an axial fan allowing the ambient air to pass through the absorber and rise up to the load.

- **Hot-air section**

The hot air section houses the DC heating filament of 88 watt and vane axial fan having a flow rate of 0.47 m^3/s and 95.729 watt. The vane axial fan transports hot air generated from the heating element into the drying chamber. The fans are fixed with regulator for adjusting the fan speed thereby regulating the air flow rate.

- **The PV Solar Collector Setup**

The dryer was design solely on solar power both for the direct and the hybrid therefore the need for PV solar system. For this design, 2 solar panels of 150 watt each connected in series and a 200 Amp was used to power the power-based component parts.

- **The Control Board/Data Logger**

The control board is used to control the DC fan speed and the electric filament voltage white the data logger was designed to preset and stored information like temperature, moisture level, relative humidity and air velocity at preset time interval. The control board and data logger are attached to the solar panel stand.

2.1 Design calculation for automated hot-air supplemented solar dryer.

M_w (kg) is calculated using the following equation according to [7].

$$M_w = M_p \frac{(m_i - m_f)}{(100 - m_f)} \quad (1)$$

Where M_p (kg) is the initial mass of the product to be dried which for this design will be 20 kg of white yam.

m_i and m_f = initial moisture content and final moisture content respectively.

Final relative humidity or equilibrium relative humidity

ERH (%) is calculated using sorption isotherms equation given as given by [8]

$$a_w = 1 - exp[-exp(0.914 + 0.5639 \ln M)] \quad (2)$$

$$M_w = \frac{m_f}{(100 - m_f)}$$

$$\text{ERH} = 100a_w \quad (3)$$

a_w = water activity

M (kg_w/kg_s) dry basis

From section 1 for white yam, M_{wy} is 14.54 kg, Final moisture content of white yam is between 12 to 13 percent.

$$a_w = 1 - exp[-\exp(0.914 + 0.5639 \times 2.61)]$$

= -exp(1.4718); a_w = 0.881, ERH = 88.1

Quantity of air needed for drying

Using a psychometric chat and taking input air temperature of 26 °C (dry bulb) and a relative humidity of 72 %, the psychometric gives a humidity ratio of 0.015 kg (H_2O/dry air). Hence 14.54 kg will require

2147.7 volume of air to effect drying. The volume flow rate of air V_a (m^3/h) is calculated according to equation 4:

$$V_a = \frac{w_a}{t_d} \qquad (4)$$

$$V_a = \frac{2147.7}{8}\ m^3/h = 0.0746\ m^3/s$$

According to [9] the mass of air required to remove moisture in the drying process is calculated using equation 5:

$$M_a = \frac{m_w}{\Delta w_{CB} \times n} \qquad (5)$$

M_a = mass of air required to remove moisture from white yam slices, M_w = mass of water to be removed; n = pick up factor; ΔW_{CB} = change in humidity ratio which is the moisture that can be removed by heated air.

The quantity of heat energy required to evaporate the H_2O in the tuber samples is shown in equation 6

$$E = m_a\left(h_i - h_f\right)t_d \qquad (6)$$

E is total heat energy kJ

m_a is mass flow rate of air kh/hr = 157.89 kg/hr = 0.436 kg/s

E = 139.498 MJ

Initial moisture content of white yam according to [10, 11] when freshly harvested is 72.7 % (w.b.).

Total volume of 20 kg of white yam slices at maximum thickness of 1.0 cm is calculated using equation 7 below

$$V = \frac{m}{\rho} \qquad (7)$$

Where;

m = mass of white yam = 20 kg, ρ = density of yam = 1104 kg/m^3

$$V = \frac{20}{1104}$$

$$n = \frac{V}{A \times thickness}$$, n = 640.07 slices

Total area required to dry 640 slices of white yam was derived from Equation 8 according to [12]

$$A_t = n \times surface\ area\ of\ a\ slice \qquad (8)$$

$$A_t = 640(3.142 \times 0.03^2)$$

Equation 9 show the formula for calculating numbers of trays required in the drying chamber

$$Number\ of\ trays = \frac{A_t}{Area\ of\ tray} \qquad (9)$$

$$6 = \frac{2.54}{Area\ of\ tray}$$

The dimension of the tray is 0.65 m by 0.65 m

Angle of tilt of the solar collector/air heater

According to [13, 14] the angle of tilt (β) of a solar collector is

$$\beta = 10° + lat\Phi \qquad (10)$$

Where Φ is the angle of the solar collector location.

Latitude of Akure, Ondo State where the drying experiment took place was 7.25° N [15]. Hence, the suitable value of β used for the collector is

β = 10° + 7.25; β = 17.25°

Insolation of the collector surface area

Insolation = $I_c = H_T = H \times R$ (11)

H = Average daily solar radiation on horizontal surface = 465.9 W/m^2 [16]

R= ratio of solar energy on tilted surface to that on the horizontal surface.

$$R = \frac{T_s}{H} \qquad (12)$$

$$R = \frac{900.3}{465.9} = \ 1.94$$

T_s = average daily radiation on tilted surface for the test location

Total Solar Collector Area/Dimension

Using the formula according to [12]

$V_a' = V_a \times A_h \times W_c$ (13)

V'$_a$ = Volumetric flow rate of Air, V$_a$ = average air speed, A$_h$ = air gap height, W$_c$ = Width of collector

V'$_a$ = 0.15 × 0.10 × 0.70 m = 0.105 m^3/s

Mass flow rate of air M$_a$ = V'$_a$ρ$_a$ [12]

Where, ρ$_a$ is the density of air = 1.28 kg/m^3; M$_a$ = 0.105 × 1.28; M$_a$ = 0.01344 kg/s

Area of Collector

$A_c = \frac{M_a \times C_p \times (T_o - T_a)}{0.5 \times I_c}$ (14)

Where;

C$_p$ = Specific heat capacity of air = 1005 J/kg/K, T$_o$ = Optimum temperature of the dryer = 60 °C T$_a$ = air inlet temperature of ambient temperature approximately 30 °C, I$_c$max = Maximum insolation on the collector surface = 903.22 W/m^2

A$_c$ = 0.89 m^2

Determination of the base insulation thickness for the collector

$FM_aC_p(T_o - T_i) = \frac{A_cK_a(T_o - T_a)}{t_b}$ (15)

Where;

k = thermal conductivity for fibre glass = 0.04, F = insulation factor = 10% = 0.1, T$_o$ = 60 °C and T$_i$ = T$_a$ = 30 °C

M$_a$ = 0.01344 kg/s

$t_b = \frac{A_cK_a(T_o - T_a)}{FM_aC_p(T_o - T_i)}$ (16)

$$t_b = \frac{0.89 \times 0.04(60 - 30)}{0.1 \times 0.01344 \times 1005 \times 30}$$

$= \frac{1.068}{40.53} = 0.026\ m$ = 2.6 cm

For the design, considering heat loss and heat transfer, the thickness of the insulation was taken as 5 cm.

Determination of heat losses from the solar collector

The total heat transmitted and absorbed is given by [12] as

$U_l = \frac{I_cA_c\tau_\alpha - M_aC_p(\Delta T)}{A_c\Delta T}$ (17)

I$_c$ = 903.22 W/m^2; U$_l$ = 8.126 W/m^2°C; $Q_l = 216.9\ W$

The quantity of heat loss from the solar collector is 216.9 W

Pressure drop through the drying chamber

The resistance to the flow of air through a layer of agricultural produce is expressed in the form expressed in equation 18 [17, 18]

$\tilde{U} = a\left(\frac{P_B}{h_L}\right)$ (18)

Ũ = the superficial air velocity, H$_L$ = the drying layer thickness (for the slices 10 mm = 0.010)

a = A constant whose value is determined experimentally

Note: ΔP$_T$ = 6 × (2 ΔP$_B$) = 6 × (2 × 0.0084) =1.0123 Pa

Determination of thickness of the absorber plate (δ)

The thickness of the absorber plate was calculated from [19] relationship.

kδ = 0.2 (19)

$$\delta = \frac{0.2}{k}$$

k = thermal conductivity of galvanized metal sheet 204 W/m/k

$$\delta = \frac{0.2}{204}$$

= 9.8 × 10^{-4} m = 0.98 mm which is approximately equals 1 mm.

The minimum gauge of galvanized metal sheet to be utilized is 1 mm

Height of the hot air column

$$H = \frac{\Delta P_T}{g(\rho_a - \rho^*)} = \frac{\Delta P_T R}{g\left(\frac{1}{T_{abm}} - \frac{1}{T_{dryer}}\right) P_a} \qquad (20)$$

H = 1.53 m

Loss Coefficient for the flat plate collector

a. Radiation coefficient from plate to glass cover was evaluated with the equation 21 according to [8]

$$h_{rpc} = \frac{\sigma \times (T_p^2 + T_c^2) \times (T_p + T_c)}{\left(\left(\frac{1}{E_p}\right) + \left(\frac{1}{E_c}\right) - 1\right)} \qquad (21)$$

h_{rpc} = 7.879 $Wm^{-2}K^{-1}$

b. Radiation coefficient from cover to surface was calculate out according to the experimental work of [20, 8] as expressed in equation 22.

$$h_{rcs} = \in_c \times \sigma \times (T_c^2 + T_s^2) \times (T_c + T_s) \qquad (22)$$

h_{rcs} = 6.389 $Wm^{-2}K^{-1}$

c. Convection coefficient between plate and cover

h_{pc} Experience has shown that for free convection, the Nusselt number N_u in air spaces between parallel plates with Grashof number G_r in the range 10^4 to 10^7

h_{pc} = 3.06 $Wm^{-2}K^{-1}$

Convective heat transfer coefficient for air blowing over the cover

The heat loss from the glass cover to the surroundings must be the same, in the steady state, as the heat loss from the black plate to the glass cover, heat loss from the glass cover is computed with equation 23 as illustrated by [8]

$$q_{ca} = h_w = h_{cs} \cdot (T_c - T_s) + \Sigma_c \cdot T_c^4 - \Sigma_c L \qquad (23)$$

$h_w = h_{ca}$ = 2.8 + 3.0V W/m^2K

Where; V is the wind speed in meter per seconds

h_{ca} = 2.8 + 3.0V

average wind speed of Akure is 1.388 m/s

$h_{ca} = h_w$ = 2.8 + 3.0(1.388), h_w = 44.4 W/m^2K

Top loss coefficient, was derived with the equation 24 according to [8]

$$U_T = \frac{1}{\left[\frac{1}{h_{rpc} + h_{pc}} + \frac{1}{h_w + h_{rcs}}\right]} \qquad (24)$$

U_T = 9.00 W/m^2K

Bottom loss coefficient

Equation 25 according to [8] was used to calculate the bottom loss coefficient

$$U_b = \frac{k_i}{x_i} \qquad (25)$$

U_b = 0.8 W/m^2K

Bottom loss coefficient at the edge

A well-designed collector is also insulated at the edge and the loss coefficient was calculated with equation 26.

$$R_{p-e} >> R_{e-a} \rightarrow (UA)edge \cong \frac{k}{L_{edge}} A_e \qquad (26)$$

$$q_{loss,edge} = U_b(T_p - T_a)$$

U_e = 0.675 W/m^2K

To calculate the total loss,

$$U_{total} = U_t + U_b + U_e \qquad (27)$$

U_{total} = 10.45 W/m^2K

Total Solar Radiation Energy Calculation

The solar radiation energy on the collector area is equal to the absorbed heat energy in it. According to [21] as stated in Equation 28

$$\Sigma I_t A_c = \Sigma \frac{Q_{co}}{E_c} \qquad (28)$$

= 6.59065 kJ

Design Consideration for the Heater

$$Q = MC_p\Delta T \tag{29}$$

Where;

Q = amount of heat energy (kJ/s)

M = Mass of water to be removed (14.54 kg)

C_p = Specific heat capacity of water (4.182 kJ/kg/K)

ΔT = Temperature difference (70 – 28) °C

$$Q = 14.54 \times 4.182 \times (70 - 28)$$

14.54 × 4.182 × 42

2553.86 kJ

$$power\ rating = \frac{quantity\ of\ heat}{time}$$

88 Watt

Design consideration for the fan

Area of drying × Airflow = Airflow rate in the cabinet

$$m_v = m_a \times v_s \tag{30}$$

m_v = volumetric flow rate of the drying air (m^3/s)

v_s = Specific volume of the drying air in m^3/kg 1.087 from psychometric chart.

m_v = 0.47 m^3/s

Fan Electric Energy Calculation for Hot-air Section

According to [22], fan electric energy is equal to

$$E_f = \frac{P_w \cdot t}{E_E \cdot E_m} \tag{31}$$

Where;

E_f = fan energy (kJ), P_w = Power of fan outlet air (W), t = Time (s), E_E = Electromotor electric efficiency (%), E_m = Impeller mechanical efficiency (%)

Power of outlet air from fan according to [23] is

$$P_w = 9.81Q \cdot T_p \tag{32}$$

Where T_p = Total Pressure (mmWC)

Q = Air flow (m^3s^{-1})

Total pressure $T_p = S_p + V_p$ (33)

Where S_p = Static pressure, V_p = Velocity Pressure

Velocity pressure is calculated from [22]

$$V_p = 0.051\rho \cdot V_1^2$$

$$S_p = \left[\left(\frac{2.22L_o \cdot V_1^2}{\ln(1+0.116V_1)}\right) + \left(\frac{3.72\times10^{-6}\cdot P.n.V_1^2}{RT_3}\right)\right] \tag{34}$$

L_o = product thickness on tray

Inserting Equation 32 to 34 into Equation 35 fan electric energy would be equal to

$$E_f = \left[\frac{9.81t\cdot V_1 A_f}{1000\cdot E_E\cdot E_m}\right]\left[S_p + 0.051\frac{P\cdot n\cdot V_1^2}{R\cdot T_2}\right] \tag{35}$$

To calculate S_p,

$$\left[\frac{2.22 \times 0.01 \times 1.0^2}{\ln(1 + 0.116 \cdot 1.0)}\right] + \left[\frac{3.72 \times 10^{-6} \cdot 97.02 \times 385.26 \times 1.0^2}{8.134.4 \times 313}\right]$$

S_p = 9.81 (mmWC)

E_f = 37.39 × 147.460, = 5514.02 Js^{-1} = 95.729 watt

Fan Electric Energy Calculation for Solar Collector

The fan electric energy according to Equation 35

$$E_f = \left[\frac{9.81t\cdot V_1 A_f}{1000\cdot E_E\cdot E_m}\right]\left[S_p + 0.051\frac{P\cdot n\cdot V_1^2}{R\cdot T_2}\right]$$

A_f = 0.020

= 1508.11 kJ/s = 52.360 Watt

Solar panel and battery calculation

Total Watts per Hour (DC) = 236.04 Watts

The solar drying system is expected to run for 8 hours out of 24 hours in a day, therefore watt-hours per day = total daily usage × hours = 1888.32 watt-hrs/day

Amp-hour calculation

Note: total watt daily requirements = 1888.32 watt-hrs/day

Corrected for battery losses (assume static average loss) = 1.926.086 watt-hrs/day

System voltage DC voltage only 24 v

Amp-hours per day = Watts divided by volts 80.254 Amp-Hrs/day

Battery bank calculation

Number of days' backup power required (average 24 hours' period) = 2 days

Amp-hour storage (raw capacity needed) 160.5072 Amp-Hrs

Depth of discharge (Assume 50%) 0.5 fraction

Required amp backup (also ensure excessive discharge is prevented = 321.0144 Amp-hrs

Battery amps rating (20 hrs) (Battery capacity in Amps) 100 Amps

Actual numbers of batteries wired in parallel raw number = 3.21

Batteries wired in series related to system voltage 2.00 Amp

Rounded number of batteries round up = 2 batteries

Solar panel array calculation

Sun hours per day (Direct only) = 4 (worst situation condition)

Worst weather multiplier 1.55 default (constant).

Total sun hours per day (assumes average sun = 2.581 Amp-hrs

Panel size selection based on watt rating (watt hour rating) = 250 watts

Nominal panel voltage Approximately solar output = 16 volts

Amps required from solar panel watts divided by volts = 15.625 Amps

Number of solar panels in parallel = 1.990

Number of panels in series (12 v) = 2

Rounded number of solar panels = 4 panels

The essence of the component design is to ascertain the quantity of energy required to optimum operation and to be able to make categorical statement about the energy economy and sustainability of energy in the system.

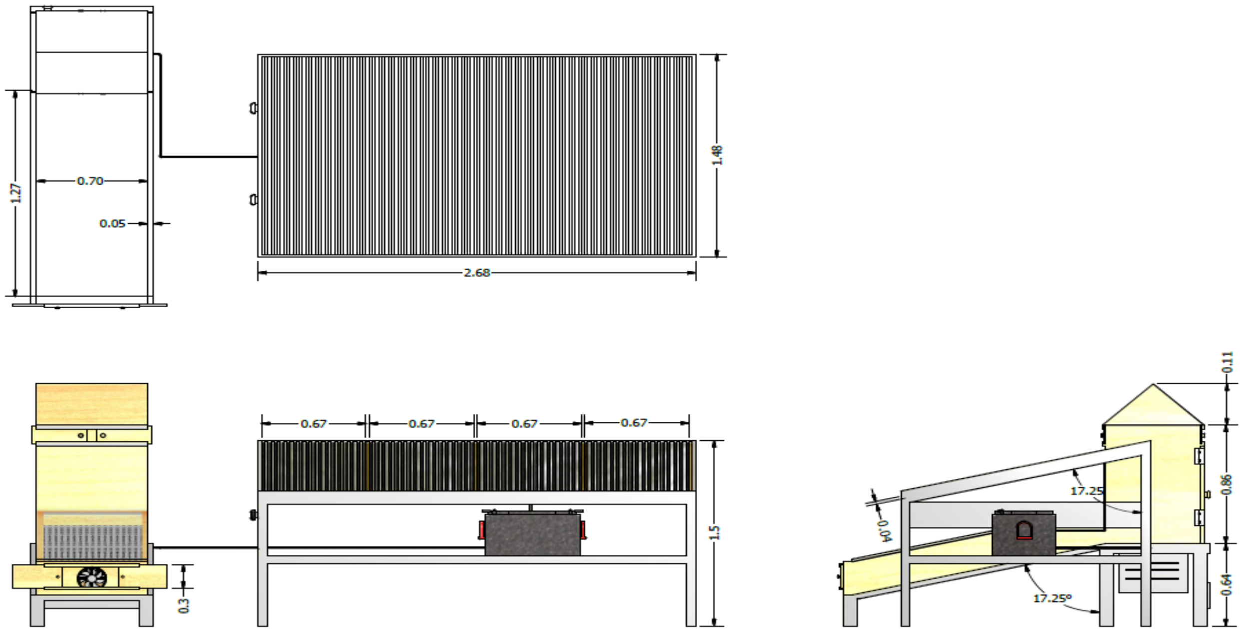

Figure 2: Orthographic projection of the designed SPHSD.

Figure 3: The developed solar controlled hot-air supplemented dryer

The developed machine was tested using white yam slices. Drying experiment was conducted using the dryer without supplemented hot-air and also with supplemented hot-air both in automated form. The southern azimuth of the testing location (Federal University of Technology Akure) was located using a GPS, after which the solar panel and the dryer were positioned according to the direction from the GPS in order to obtain maximum insolation during the experimentation.

For the two experimental processes, the yam after peeling was washed and sliced and shaped 30 mm square and 2mm thickness using a locally designed cutter. 250 g of the shaped yam slices was weighed and used for each run of experiment after blanching by soaking in hot water of 80 °C for a period of 3 minutes [23] using a using an electronic precision scale (KD-TBE-1200) with a sensitivity of 0.01 g and maximum load of 1200 g. After this, the blanched yam slices were drained using a plastic sieve and then placed in the drying tray of the dryer in single layer.

The dryer is always prepared at least 30 minutes to the commencement of each experimental run to allow thermal balance in the chamber. The probe of the moisture meter was placed inside the yam slices gently and other sensors were positioned as necessary prior to the commencement of the drying process. For the drying experiment without supplemented hot-air there was not external influence of heat or air. For the experiment with supplemented hot-air, the temperature in the drying chamber was present from the data logger to 50 °C, the heater and the fans were allowed to run on the PV solar system at 0.8 m/s^2 before the yam is placed on the tray for drying process. After the experimental run for each day, data is downloaded from the data logger via the SD card for analysis. Recorded data during the drying process are moisture content, product temperature, working temperature (temperature inside the drying chamber), drying chamber relative humidity, solar collector inlet and outlet temperature. Ambient temperature, relative humidity and solar insolation data was collected from the University meteorological station. The result of the study shows that there were tremendous improvements recorded in terms of drying time when hot-air supplement was used compared to when hot air supplement was not. Likewise, a complete thermal stability was experienced when hybrid system was used giving a better drying result.

3. MACHINE TESTING

3.1 *Variation of Drying Parameters with Weather Condition at no-load.*

The developed SPHSD was tested at no load condition in order to evaluate the effect of incorporating heater and control system into the dryer. The dryer was tested under two conditions firstly indirect solar drying and secondly solar powered hot-air supplemented drying. During the indirect solar drying, fluctuation of drying temperature was experienced in the drying chamber throughout the test period with maximum temperature of 49.87 °C at 1437 hrs after 325 minutes of drying experiment. Between 0904 hrs and 1219 hrs, the drying chamber temperature was between 24.87 °C and 44.13 °C and also at 1546 hrs and 1652 hrs the temperature in the drying chamber was between 43.65 °C and 39.45 °C leaving the system at a drying limit below 45 °C.

A no load test was also carried out for SPHSD at a preset drying chamber temperature of 50 °C and it was observed that there was relative stability of temperature in the drying chamber throughout the drying period which lasted for 481 minutes. At the start of the test experiment, between 0904 hrs and 0930 hrs, the temperature increased from 35.51 °C to 45.01 °C after which the temperature in the drying chamber was relatively at 50 °C throughout the entire test period. Figure 4 and 5 shows the variability of weather condition during the no load test for indirect solar drying and SPHSD respectively. Similar trends were reported by [24, 25] during the experimental testing of combined solar and mechanical dryer and [26] during the experimental testing of hot-air supplemented solar dryer for white yam.

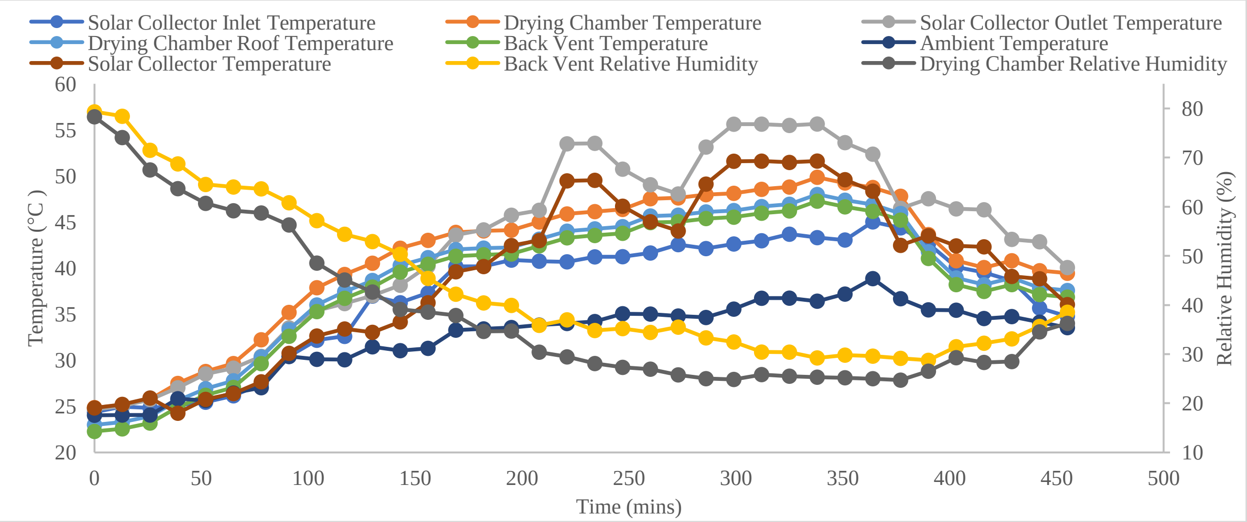

Figure 4: Variability of weather condition during no-load test for indirect solar dryer

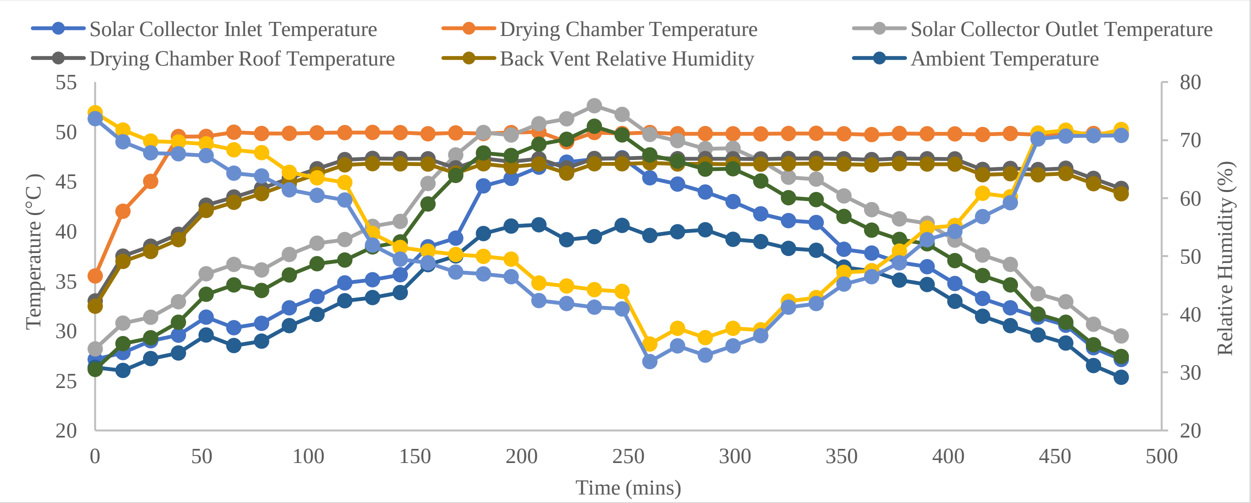

Figure 5: Variability of weather condition during no-load test for SPHSD at 50 °C

3.2 *Variation of Drying Parameters with Weather Condition at load.*

Figure 6 shows a graphical representation of result from loaded laboratory experimental test where white yam slice of 3 mm was used to determine the moisture content of yam with respect to other drying parameters using indirect solar dryer. Drying experiment was conducted for 481 minutes (between 0910 hrs to 1713 hrs) reducing the moisture content from 71.91 %, 72.1 % and 72.8 % to 27.95 %, 25.78 % and 28.23 % for MC_1, MC_2 and MC_3 respectively. The environmental weather conditions affected the drying process and the ambient temperature reduced below 30 °C with an increase in relative humidity. The amount of moisture removed was low with low drying rate compared to experiment carried out with the SPHSD and this was due to the effect of fluctuating ambient weather condition on drying rate of indirect solar dryer.

Figure 7 shows a graphical representation of result from loaded laboratory experimental test where white yam slice of 7 mm was used to determine the effect of supplemented drying system on moisture content of white yam at 50 °C with respect to other drying parameters. There was temperature build up in the drying chamber for the first 40 minutes before the pre-set CT_2 value was attained at 1006 hrs. Between 2008 hrs to 2257 hrs there was a fall of about 3 °C from the pre-set temperature value in the CT_2 value. Drying experiment was conducted for 832 minutes (between 0901 hrs to 2257 hrs) reducing the moisture content from initial moisture content levels of 72.66 %, 71.48 % and 71.48 % to 13.47 %, 12.53 % and 12.54 % for MC_1, MC_2 and MC_3 respectively. The incorporated DC heating system enabled continuous drying even when the temperature is relatively low with high relative humidity during the nigh when there was extremely poor solar insolation.

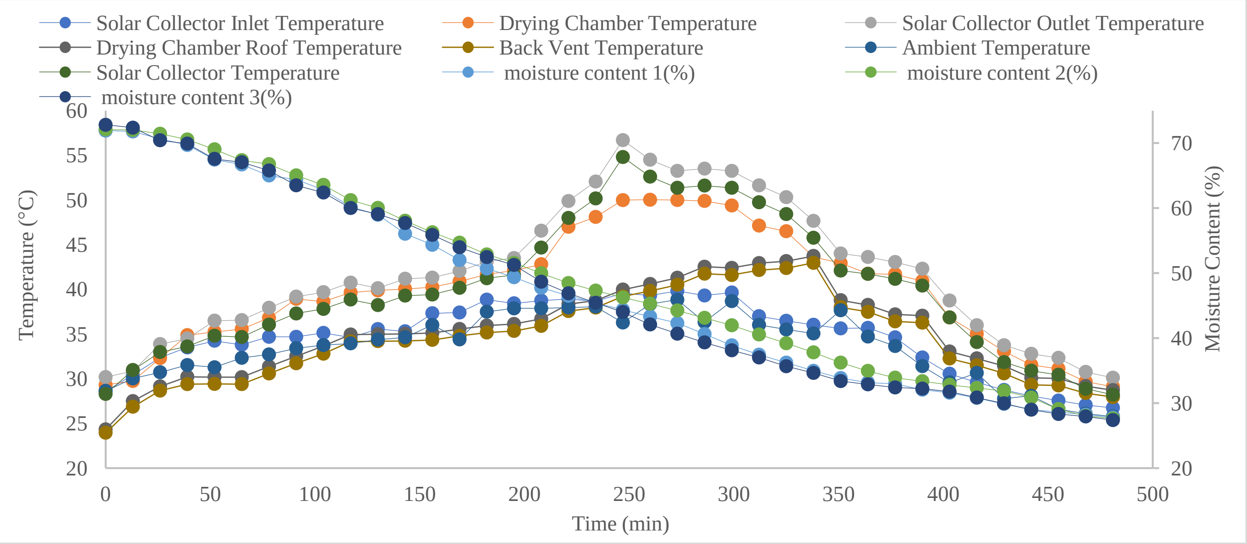

Figure 6: Variability of weather condition, moisture content with respect to time during load test for indirect solar dryer

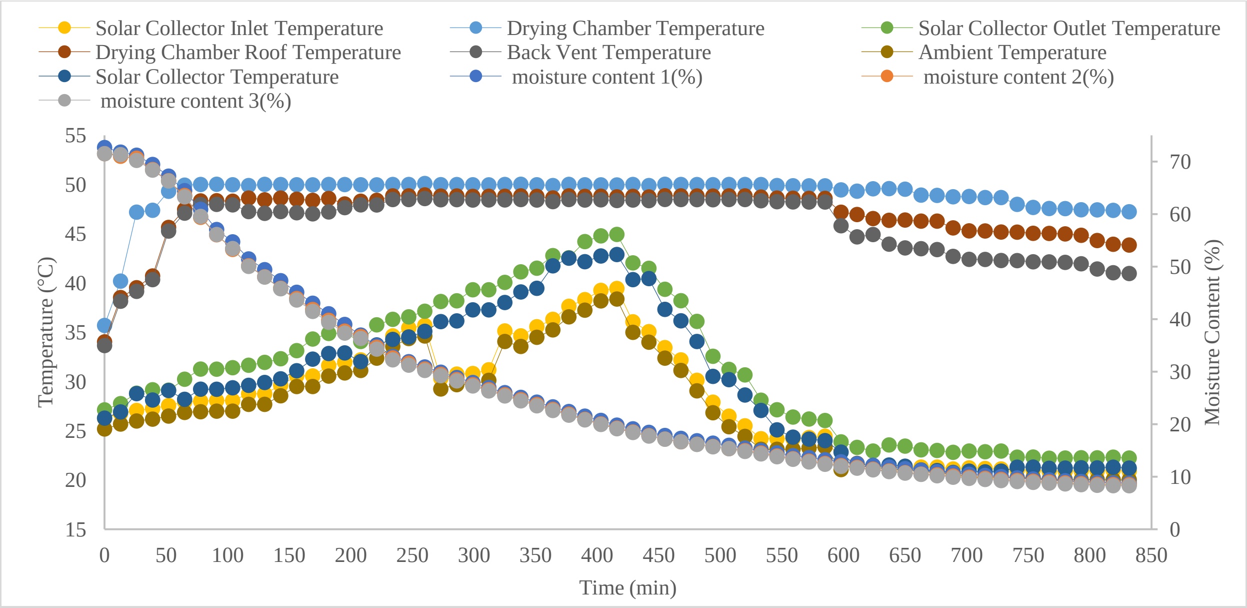

Figure 7: Variability of weather condition, moisture content with respect to time during load test for SPHSD at 50 °C

4. CONCLUSION

The main drudgery militating the used on solar dryer during harsh weather condition and night period is environmental factors and electricity instability. Time taken in drying agricultural materials during harsh weather condition and in drying commodities with high moisture content take so long leading to poor product and spoilage in some situation. Solar dryer with the aid of solar power with DC heater and fan was developed and tested to remove the drudgery in order to aid fast drying rate and eradicate bacterial growth. SPHSD was observed to give a faster drying rate and stability compared with indirect solar dryer. The effect was established when tested with white yam slices. For indirect solar dryer, 3 mm white yam was dried for 481 minutes (between 0910 hrs to 1713 hrs) reducing the moisture from 71.91 %, 72.1 % and 72.8 % to 27.95 %, 25.78 % and 28.23 % for MC_1, MC_2 and MC_3 respectively where 832 minutes (between 0901 hrs to 2257 hrs) reduced the moisture content of white yam slices of 7 mm thickness from initial moisture content levels of 72.66 %, 71.48 % and 71.48 % to 13.47 %, 12.53 % and 12.54 % for MC_1, MC_2 and MC_3 respectively in SPHSD.

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