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Performance Evaluation of a Passive Solar Crop Drying

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ABSTRACT: This paper presents the performance evaluation of a passive solar dryer. The Dryer was designed and constructed at the Mechanical Engineering Department of Caritas University, Amorji-Nike, and Enugu, Nigeria. The Dryer was constructed using locally sourced materials from Ogbete main market, Enugu. Experimentation was carried out using samples of 20mm and 40mm sliced cassava chips weighing 46g and 80g respectively in the month of November 2020.Temperature readings of the ambient air, the drying chamber and the collector chamber were recorded and tabulated for the hours of 10.00am to 5.00pm for the first day and 9.00am to 4.00pm for the second day. The moisture content and drying rates were evaluated for both samples using both dry and wet basis. Plots were made on the variation of temperature with time as well as moisture content with time for both dry and wet basis for the two days. Results show that the mass of the water removed were 112g and 105g for the first and second day respectively. Results also show the collector efficiency as 37.9% while the dryer efficiency was evaluated to be 37.6%. The moisture content of the 20mm samples of cassava slices were evaluated to be 53.03% and 38.8% for the first and second day respectively, while of the 40mm sample were evaluated as 112.9% and 64.6% respectively for the first and second day. The moisture loss or drying rate for the respective samples of 20mm and 40mm were evaluated to be 27.0g/hr and 34.0g/hr, showing percentage drying rates of 62.1% and 68% for the first and second day respectively. The equipment and the test therefrom have shown tremendous improvement on crop drying over the conventional open air-drying method used in the region/location under study. It also provided a veritable tool for training students on heat and mass transfer analysis.

KEYWORDS: Temperature, Moisture, Sun, Dryer, Drying Rates, Crop

1. INTRODUCTION

Solar drying of Agricultural produce has evolved in so many countries developed and developing countries. In Nigeria, many of the villages still make use of direct sun drying to dry their agricultural products, which has a greater risk of spoilage due to adverse climatic conditions like rain, wind, moist and dust, loss of produce to birds, insects, and rodents (pests), totally dependent on good weather and very slow drying rate with the danger of mold growth thereby causing deterioration and decomposition of the product and put consumers health at risk. Solar drying is the process of drying wet substances, especially agricultural produce using radiant energy from the sun. However, for drying operation in mixed mode solar dryer, the combined action process of solar radiation incident on the material to be dried and the air preheated in solar collector provides the heat required for drying operation (Chen, et al, 2009). Experiments have been carried out to evaluate the best drying method by using two drying states (mixed and indirect) from natural and forced convection (Chen, et al, 2009). Over-drying or under-drying of food materials and crops reduces quality and is very sensitive to dry conditions. Hence, the temperature is a key parameter in sun drying, which helps keep the texture, colour, etc in very good condition.

The absence of national grid connections and the high cost of fossil fuel in rural areas make agro-processing activities very difficult in Nigeria (Okonkwo and Okoye, 2005). Studies (Arinze, 1985) and (Adesuyi, 1991), showed that the use of solar energy in crop drying is possible. Solar energy is one of the most promising renewable energy sources in the world because of its abundance, inexhaustible and non-pollutant in nature compared with higher prices and shortages of fossil fuels (Rajkumar, 2007).

Solar dryers can be classified into two types, active and passive mode with passive dryers further divided into direct and indirect models. Passive dryers can be called natural convection in which the fluid motion is generated by density differences in fluid occurring due to temperature gradients. An active dryer requires external means such as fans or pumps. It is used for moving the heated air from the collector area to the drying chamber. Direct solar drying in passive mode typically consists of a drying chamber that is covered by a transparent cover made of glass or plastic. Hence, the glass cover reduces direct convective heat loss to the surroundings and increases the temperature inside the dryer. While in the mixed mode type of drying system, the heated air from the separate solar collector is passed through a drying chamber, and at the same time, the drying chamber will absorb solar energy directly through a transparent cover. The product is dried simultaneously by both radiations with the conduction of heat through the transparent cover and the convection of the heat from the solar air heater. (Moradi and Zomorodian, 2009), have developed a solar dryer that is suitable for drying the Cumin cymene grains. Experiments have been carried out to evaluate the best drying method by using two drying states (mixed and indirect) from natural and forced convection. The dryer was operated with a load of 70 to 80 grams of grains with a 43% average initial moisture content. They reported that the solar dryer is more efficient using the natural convention method for a mixed mode drying state compared to forced convection. After 90 min of 11 drying days, 43.5 % to 4.95 % of moisture contents were reduced using the passive mixed mode drying method. An indirect type natural convection solar dryer with integrated collector-storage solar and biomass backup heaters has been designed, constructed, and evaluated by (Mandhlopa and Ngwalo, 2007).

A Simulation of a solar crop dryer for drying agricultural products was developed by (Habtamu, 2007). A thermal solar collector model was developed to determine the available useful energy for heating the ambient air with the available solar radiation. In the same vein, an indirect passive solar dryer was designed, constructed, and simulated using TRANSYS simulation software and Engineering Equation Solver (EES) (Musa, 2016). Assessing the drying rates of vegetables, tubers, and grain crops were accomplished by (Ajao and Adedeji, 2008). An indirect forced convection solar dryer combined with heat storage material for chili drying was designed and fabricated by (Mohanraj and Chandrasekar, 2009). The chili moisture content of 72.8% wb was reduced to 9.1 % and 9.8 % wb in the bottom and top trays respectively. The fresh chilies were loaded over the trays of the dryer chamber having about 90% perforation. The thermal efficiency of the solar dryer was found to be 21%. The extraction rate was found to be 0.87 kg/kWh. The design and construction of an indirect solar dryer with a heat storage chamber for drying maize seed was developed by (Lukman, 2010). The dryer was made up of a solar collector, a drying chamber, and a heat storage chamber (filled with gravel). The experimental test results gave a temperature above 45 °C in the drying chamber. 5 kg of maize at 30% initial moisture content was reduced to 13% in three days of 9hr each day of drying. Therefore, this study was carried out to help the students with the knowledge of mechanism of drying. This led to the designing of an improved design solar dryer that will improve the temperature in the south eastern Nigeria for better crop drying.

2. MATERIALS AND METHOD

Fig. 1. Pictorial View of Improved Design Solar Drier (IDSD)

The materials used for the construction of the passive solar dryer are cheap and easily obtainable in the local new Kenyatta market in Enugu state Nigeria. They are: solar collector (air heater), the drying cabinet and drying trays. The components of drying chamber are made of highly polished wood which consist of three drying iron tray nets. The wood material was chosen since it is a poor conductor of heat, and its surface finish and also heat loss by radiation are minimized. **Solar Collector is** an insulated box with transparent glazing constructed using galvanized iron sheet metal. One of the collectors houses the following -collector absorber, transparent covering (glazing), and heat storage materials. **Glazing-,** is a 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, and the material used for the cover plate is glass. **Absorber,** plate metal painted black and placed below the cover to absorb, the incident solar radiation transmitted by cover thereby heating the air between it and the cover, here aluminum is chosen because of its quick response in the absorption of solar radiation.

Insulation, fiberglass was used to insulate both the air heaters, and the door of the drying chamber. **Connecting Duct was made of g**alvanized steel sheet used to construct the air duct and it was well insulated to prevent heat loss to the surrounding which will result in a decrease in the pick-up efficiency of the dryer. The dryer is a passive type because it has no moving parts, sun rays entering through the transparent top cover are trapped, and the trapping of the rays is enhanced by the black painted absorber. The greenhouse effect achieved within the dryer drives the air current necessary for faster drying. The crop slices were put on trays inside the drying chamber. Air enters through the open bottom end of the collector and it is heated while it passes over the absorber with and without thermal storage. The warm air outlet of the collector was connected to a duct to aid the airflow and distribution, the hot air is then channeled and distributed into the drying chamber. The heated air is allowed to flow over the wet crop slices and provided the heat for moisture evaporation by convective heat transfer between the hot air and the wet crop slices. Drying takes place due to the difference in moisture concentration between the drying air and the air in the vicinity of the crop slices surfaces.

2.1. Design Considerations

The following information were considered during the design of the solar drier:

Collector angle of Inclination: The flat plate solar collector is always tilted and oriented in such a way that it receives maximum solar radiation during the desired season of use. The best stationary position is due north in the western hemisphere where the sun rays hit the solar collector and generate enough thermal energy (heat). This inclination also allows easy runoff of water and enhances air circulation. Table 1 below shows the average meteorological data for the design, this was obtained from the meteorological agency of Nigeria. (NIMET), with collector angle of inclination.

Table 1: Design Parameters and Values

Specific Parameters	Optimum values
Location and Latitude	Enugu (Latitude 6.5°)
Crop	cassava(design)
Design Capacity	7.0 kg (design)
Bulk density	660kg/m^3
Initial moisture content	60-112% (d. b)
Final moisture content	9.65 -17% (d.b)
Average Crop Slice Thickness	40mm
Drying time per day (sunshine hours)	5 hours average
Drying Period	November
Wind speed	5.47 m/s
Ambient temperature	29.8° Average for November
Incident Solar Radiation (H)	14.12 MJ/m^2/day
Collector type	Flat metal Plate
Collector tilt angle	16.5°
Collector Efficiency	30-50%
Maximum Collector Temperature	62.5°
Thickness of Insulation	0.05 m (Design)
Vertical Distance between adjacent trays	0.32 m (Design)

In the design, we assumed the collector operates under steady-state conditions. The glazing cover material is thin. There is a one-dimensional heat flow through the cover. The effect of dust and dirt on the collector is negligible. All empirical equations used are valid for the design

Solar Collector Design

Requires **e**nergy balance obtained by equating the total heat gained to the total heat lost by the absorber of the solar collector (Bukola and Ayoola, 2008). Therefore,

$$IA_C = Q_u + Q_{cond} + Q_{conv} + Q_{rad} + Q_p \qquad (1)$$

Where, I is total radiation incident on the absorber's surface (W/m^2), Ac is the collector area (m^2), Q_u is the rate of useful energy collected by the air (W) and Q_{cond} is the rate of conductive losses from the absorber (W), followed Q_{conv} rate of convective losses from the absorber (W), Q_{rad} rate of long wave re-radiation from the absorber (W) and Q_p is the rate of reflection losses from the absorber (W). Denoting the three loss terms: conduction convection and radiation as Q_L

From (Bukola and Ayoola, 2008)

$$IA_c = \tau l_T A_c \quad (2)$$

Where τ is the Transmittance of the top glazing and, l_T is the total radiation incident on the top surface of the collector. The reflected energy from the absorber is given by the expression.

$$Q_p = \rho \tau l_T A_c \qquad (3)$$

ρ Denotes the reflection coefficient of the absorber.

Substituting equations (2), (3), in equation (1) and for an absorber, 1-ρ =α (Duffie and Beckmann, 1991) where α is solar absorbance. The loss terms become

$$Q_L = U_L A_C (T_C - T_\alpha) \qquad (4)$$

U_L is the overall heat transfer coefficient of the absorber (W/m^{2}k), T_c the temperature of the collector's absorber (K) with T_α being the temperature of ambient air (k)

If the heated air leaving the collector is at collector temperature, heat gained by the air is given

$$Q_a = \dot{m}_a C_p (T_0 - T_a) \qquad (5)$$

Here $\dot{m}_a$ is the mass flow rate of air leaving the collector per unit area (kg/s) and T_0 is the temperature of air ta the collector outlet (k). The collector heat removal factor F_R is the quantity that relates to the actual useful energy gained by the collector.

$$F_R = \frac{\dot{m}_a C_P (T_0 - T_a)}{A_c[(\alpha\tau)l_T - U_L(T_C - T_a)]} \qquad (6)$$

From equation 6;

$$Q_a = A_c F_R [(\alpha\tau)l_T - U_L(T_C - T_a)] \qquad (7)$$

Solar Collector Area

In solar drying system design, one of the methods of sizing the collector is based on meteorological and crop parameters. The required surface area of the transparent cover for crop drying depends primarily on the heat load of the drying system. (Kamble, et al, 2013) and it obtained by

$$A_c = \frac{Q_{load}}{\eta l_T t_d} \qquad (8)$$

Where, t_d is drying time (hrs) and l_T is given from (Alamu, et al, 2010) as

$$l_T = H \; X \; R \qquad (9)$$

H = horizontal radiation (W/m^2), R = ratio of solar energy on a tilted surface to that on the horizontal, (dimensionless), and η = efficiency of the collector which is between 30 – 50% as given by (Tonui, et al, 2014)

Absorber Surface Area

The absorber surface area A_{ab} is approximately equal to the area of the collector A_C. The recommended collector length to width ratio is in the range of 1-2 Therefore, in this work Collector length to width ratio is taken as 1.5. (Tonui, et al, 2014), gives the area as

$$A_{ab} = A_C = L_c \; x \; w \qquad (10)$$

Determination of the Base Insulator Thickness for the Collector. For the design, the thickness of the insulator was taken as 5 cm. The insulating material is made of wood and black painted gravels. The loss through the side of the collector will be considered negligible.

Angle of Tilt (β) of Solar Collector/Air Heater. The angle of tilt (β) of the solar collector is given by the formula below: (Alamu, et al, 2010)

$$\beta = 10° + \text{lat } \phi \qquad (11)$$

Where lat ϕ is the latitude of the collector location, the latitude of Enugu where the dryer was designed is 6.5°N.

Hence, the suitable value of β use for the collector IS 16.5°

Drying Chamber Design

The total energy required for drying a given quantity of food items can be estimated using the basic energy balance equation for the evaporation of water (Bolaji, 2005)

$$m_w L_v = m_a C_P (T_d - T_i) \qquad (12)$$

Where, L_v is latent heat of vaporization of water from the crop (kJ/kg) and m_w is mass of water evaporated from the crop (kg), T_d the temperature of outgoing air from the drying chamber (°C) while T_i is the ambient air temperature (°C)

Drying Heat Load

The heat load is determined by the amount of crop to be dried. Its initial and final moisture contents and the time required to complete the drying operation (Kamble, et al, 2013)

$$Q_{load} = m_w L_v \qquad (13)$$

Where m_w is the mass of water evaporated from the crop (kg) and L_v is the latent heat of vaporization of water from the crop (kJ/kg)

Chimney Design

To determine the height of the hot air column (chimney), it's necessary to determine the pressure drop through the drying bed. The resistance of air flow through the packed bed of agricultural produce is expressed in the form given by (Forson, et al, 2007).

Chimney height is given by;

$$H_{ch} = \left[\frac{\Delta P_T R}{g\left(\frac{1}{T_{amb}} - \frac{1}{T_{dryer}}\right)P_a}\right] \qquad (14)$$

ΔP_T = the total pressure drop in the dryer in pa, R = the gas constant = 0.287 kPa m^3/kgK

T_{dryer} = the temperarure of air in the dryer in kelvin, T_{amb} = the temperature of ambient air in Kelvin

g = the gravitational acceleration in m/s ^{2}, P_a is the atmospheric pressure = 101.3kPa

2.2. Drying Chamber Capacity and Other Dimensions

The width of the collector (W) was considered equal to the width of the drying chamber (B).The volume of crop slices per tray can be obtained from equations given by (Adzimah and Seckley, 2009)as:

$$V_Y = W_T L_T Y_I \qquad (15)$$

Total volume of the crop slices on the trays in the drying chamber can be obtained as;

$$V_T = nV_Y = W_T L_T Y_I \qquad (16)$$

Where, Y_I the thickness of the crop slices in the drying chamber, with W_T width of the tray which is equal to the width of the drying chamber (m) and L_T length of tray (m)

Performance Evaluation of the Crop Dryers The performance of the drying system was evaluated using the solar collector efficiency, moisture content, moisture loss, and drying efficiency of the dryer.

Solar Collector Efficiency

The ratio of heat gained by the air leaving the collector to the incident solar energy over a particular time period. The steady state thermal efficiency of the solar collector is given by Hottel- Whillier- Bliss equation in (Forson, et al, 2007) as:

$$\eta_c = \frac{\dot{m}_a C_p (T_0 - T_a)}{A_c I_T} \qquad (17)$$

2.3. Moisture Content, M.C

The moisture content is given by (Ezeokoye and Enebe, 2006) as:

$$\%\boldsymbol{Moisture\ content} = \frac{loss\ in\ mositure}{initial\ weight\ of\ sample} x100 \quad (18)$$

$$\boldsymbol{M_w}(wet\ basis) = \frac{mi - mf}{mi} x100 \qquad (19)$$

$$\boldsymbol{M_d}(dry\ basis) = \frac{mi - mf}{mf} x100 \qquad (20)$$

Where, Mi = initial mass of sample before drying and M_f = final mass of sample after drying.

Moisture loss, M.L

The Moisture Loss is given by (Ezeokoye and Enebe, 2006)as:

$$Ml = (mi - mf) \qquad (21)$$

Dryer Efficiency

Thermal performance or drying rates of the products are the key factors used for the evaluation of the solar drying system efficiency (Leon, et al, 2002). For natural convection solar dryer, the system efficiency can be expressed as given by (Forson, et al, 2007) and (Drew, 2011):

$$\eta_{dryer} = \frac{M_w L_v}{I_t A_c t} \qquad (22)$$

Where, M_w is the mass of water evaporated (kg), L_v is the latent heat of vaporization of water (kj/kg), I_t the total solar radiation incident on the top surface (w/m^2). A_c is the collector area (m^2) and t is the drying time (hr).

2.4. Design Calculations

Table 2 gives the calculated results of the dimensions of the solar drying system, obtained using equations established above

Table 2. Parametric Design Calculations of the Solar Dryer

M_w(kg)	L_v(kj/kg)	%	H(MJ)	t_d(hrs)	R	I_T (MJ/m^2/day)	Q_{load}(MJ)	A_c(m^2)
5.31	2320	50	14.12	8	1.0035	14.169	12.32	0.217

Table 3. Summary of the Dimensions of the Designed Dryer

S/No	Parameters	Dryer Dimensions
1	**Solar Collector**	
	Length (L_c)	0.70m
	Width (W)	0.50m
	Area of the Collector (A_c)	0.217m^2
2	**Drying Chamber**	
	Length(L)	0.80m
	Width (B)	0.50m
3	**Chimney Height(H_{ch})**	0.50m

2.5. Testing the Solar Dryer

Testing of the solar dryer was done in the month of November at Caritas University, Amorji-Nike Emene, Enugu State Nigeria. The dryer was placed outside with the collector facing the sun. The collector has been rigidly fixed to the dryer at an angle of 16.5° to the horizontal to absorb perpendicular beams of sun rays. The drying chamber was loaded with cassava chips weighing averagely 46g and 81g of 20mm and 40mm thickness respectively. This crops were used to test the drier. The temperature of the heated air inside the dryer, the collector chamber and the ambient air was recorded every one hour interval, starting from 10am to 5pm, on the first day and 9am to 4pm, on the second day using a thermometer and in the absent of hygrometer two thermometers were used to measure the relative humidity, where one of the thermometer has its sensor whirled with the wick touching water in a beaker to get the wet bulb temperature and the other thermometer provided the normal temperature which gives the dry bulb temperature. The wet bulb and dry bulb temperature were used to obtain the relative humidity on the psychometric chart; this was done every one-hour interval, starting from 10am to 5pm for day 1 and 9am to 4pm for day 2.

3. RESULTS AND DISCUSSION

3.1. Hourly Variation of Temperature and Relative Humidity in the Solar Dryer

The initial analysis was for the comparative analysis of the temperatures of ambient and the dryer sun collector. This help us initially to ascertain if te improved design can raise the ambient temperature higher.

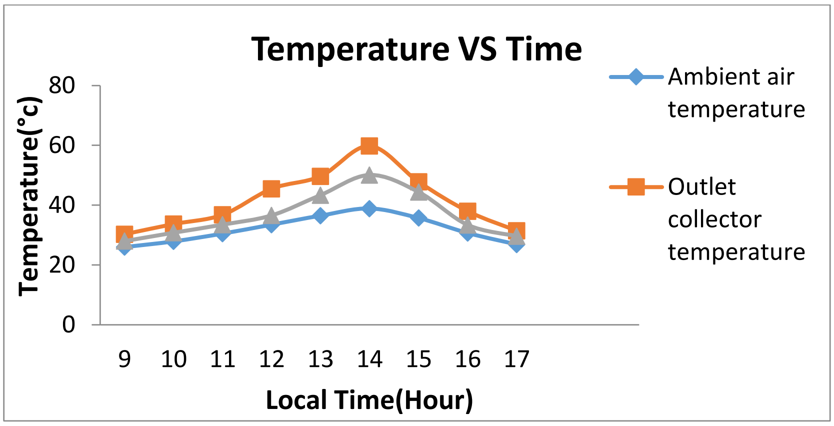

Fig. 2. Temperature Time Variation on the 26 day of November, 2020

Fig. 2 shows typical days results of the hourly variation of temperatures in the solar collector of the improved design and the drying cabinet compared to the ambient temperature. The dryer is hottest between 12.00hr and 15.00hr and begins to go down for the three temperatures. The temperatures inside the dryer outlet collector was about 50 – 60°C and the solar collector between 40 – 45°C while the ambient temperature was 30 -35°C. The temperature rises inside drying cabinet for about three hours indicates prospect for better performance than open-air sun drying.

3.2. Drying behavior of cassava in the Improved Design Solar Dryer

Moisture content of the cassava slices during the wet and dry times are plotted below for day 1 and day 2 on 26th November, 2020 and 27th November, 2020 respectively.

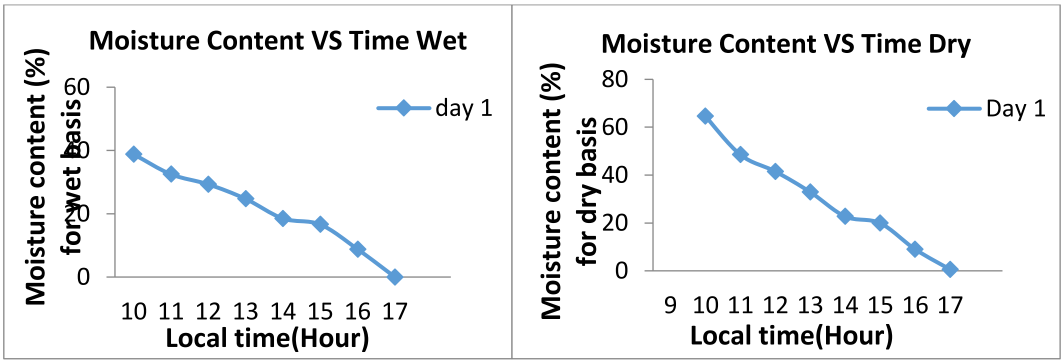

Fig. 3. Drying Curve on Day 1 Wet and Dry Basis (26/11/2020)

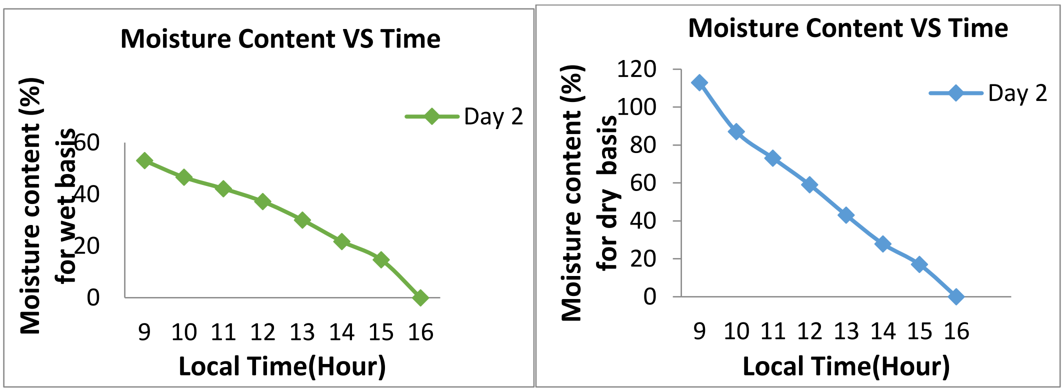

Fig. 4. Drying Curve on Day 2 Wet and Dry Basis (27/11/2020)

Fig 3, and 4 shows the drying curve for Cassava slices in the solar dryer for day 1 and day 2 wet and dry bases respectively. It was observed that the drying rate increased due to increase in temperatures between 10.00h and 14.00h but decreased thereafter. The moisture content of the cassava slices decreased with increase in temperature caused by change in time. The mass of water removed from cassava are 112g and 105g from wet and dry basis respectively. The collector efficiency of the improved design solar dryer during the test period was found to be 37.9%.

3.3. Hourly Moisture Loss and Moisture Content of Cassava

Table 4 shows the masses of five samples of cassava slices considered for the first day and their average masses when calculated, which was used to determine the average moisture loss in grams of the samples from 10.00am when they were placed in the dryer to 17.00pm, and the hourly average percentage moisture content (dry basis) of the cassava.

Table 5 shows the masses of five samples of cassava sliced considered for the second day and their average masses when calculated, which was used to determine the average moisture loss in grams of the samples from 9.00am when they were placed in the dryer to 16.00pm, and the hourly average percentage moisture content (dry basis) of the cassava.

The percentage moisture content (dry basis) and (wet basis) of the cassava slices are shown in Table 4 and Table 5 and also giving the drying curves for cassava slices.

Table 4. Hourly Moisture content and Moisture loss for Cassava on day 1

Time Hr	M1 (g)	M2 (g)	M3 (g)	M4 (g)	M5 (g)	M_{AV} (g)	M_C (%) w.b	M_C (%)d.b	M_L (%)	Temp c°
10:00	46	61	53	78	50	57.6	38.8	64.6	-	32.5
11:00	43	55	49	68	46	52.2	32.5	48.5	27	37.5
12:00	41	52	47	66	43	49.8	29.3	41.5	39	45.7
13:00	39	49	44	62	40	46.8	24.7	32.9	54	48.3
14:00	37	47	42	60	38	44.8	18.5	22.7	72	58.5
15:00	34	44	40	58	35	42.2	16.6	19.9	77	47.5
16:00	31	40	38	54	30	38.6	8.8	9.65	95	39.4
17:00	28	38	35	49	26	35.2	-	-	112	35.3

Table 5. Hourly Moisture content and Moisture loss for cassava on day 2

Time Hr	M1 (g)	M2 (g)	M3 (g)	M4 (g)	M5 (g)	M_{AV} (g)	M_C (%)w.b	M_C (%)d.b	M_L	Temp c°
09:00	36	46	44	30	42	39.6	53.03	112.9	-	29.8
10:00	29	41	39	28	37	34.8	46.6	87.1	24	38.7
11:00	25	38	36	26	36	32.2	42.2	73.1	37	46.6
12:00	23	36	33	23	33	29.6	37.2	59.1	50	49.8
13:00	20	33	30	20	30	26.6	30,1	43.0	65	57.5
14:00	18	30	27	17	27	23.8	21.8	27.9	79	46.5
15:00	17	28	24	15	25	21.8	14.7	17	89	37.4
16:00	15	23	21	12	22	18.6	-	-	105	34.5

Where, M_1 to M_5 is the mass of the specimen cassava slices, M_c the moisture content, M_{av} is the average mass of the 5 specimen M_l is moisture loss recorded per hour for each of the mass.

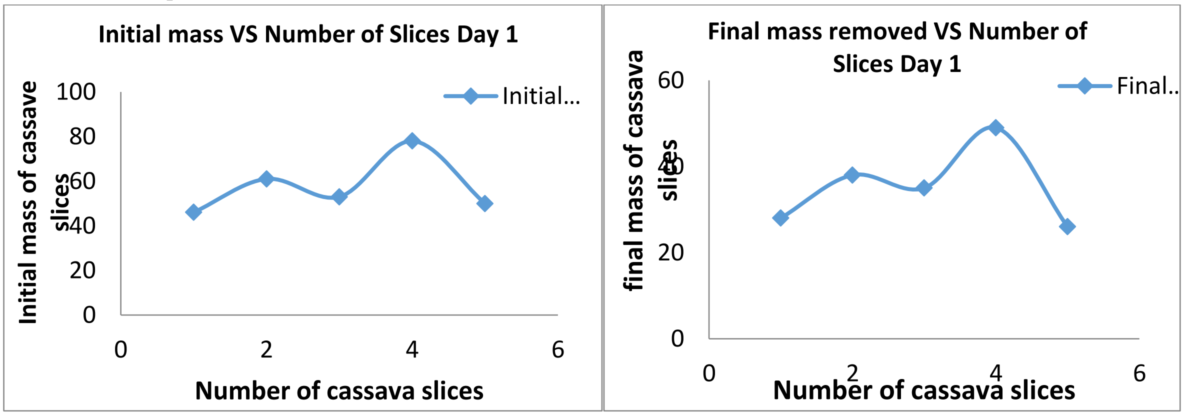

Fig. 5. Initial mass and final mass of water removed cassava on day 1 26/11/2020

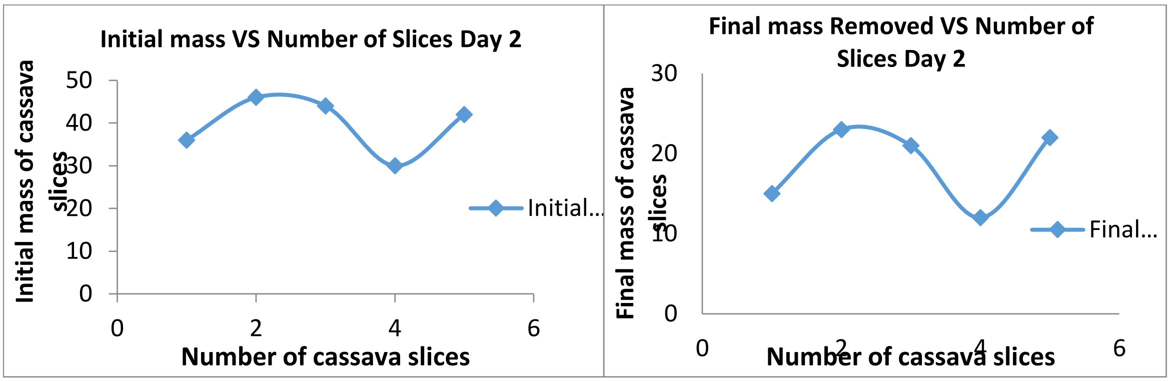

Fig. 6. Initial mass and final mass of water removed from cassava on day 2 27/11/2020

Fig. 5 and 6 shows the comparative analysis of initial and final masses of the slice cassava in day 1 and day 2. From the final mass of the cassava slices in both days, it depicts the reduction in mass. In day 1 the initial mass decreased from 42 gram to about 23gram number 1 cassava slice while day 2 decreased from about 35gram to about 15 grams for number 1 cassava slice. This was further confirmed by the curve pattern for the two days. This was further tabulated blow in tables 6.

From the table 6 the total initial mass was 288g and the final mass was 176g and mass of water removed was 112g for the first day. Likewise, second day mass of water removed was 105g

Table 6. Variation of mass of water removed in the solar dryer.

Cassava First day		Cassava Second day	
Initial mass (g)	**Final mass (g)**	**Initial mass (g)**	**Final mass (g)**
46	28	36	15
61	38	46	23
53	35	44	21
78	49	30	12
50	26	42	22

Table 7 below showed evaluated parameters of the solar dryer such as Isolation on the collector surface area, dryer and collector efficiency, volume and area of the dryer, collector slope and declination which were calculated in chapter three, and also moisture loss and moisture content determined when the indirect drying method was used.

Table 7. Result of Evaluated Dryer Parameters

Parameter	Values obtained
Isolation on the Collector Surface Area	163.42 W/m
Moisture content (M.C)	2cm and 4cm thickness of cassava had moisture content of 53.03% and 38.8% for wet basis and 112.9% and 64.6% and for dry basis
Moisture loss (ML)	2cm and 4cm thickness of cassava had moisture loss of 27.0g/hr and 24.0g/hr
Dryer efficiency η_{dryer}	37.6% (per day)
Volume of Dryer chamber(V)	0.1575m^3
Collector Area (A)	0.35m^2
Collector Efficiency $\eta_{collector}$	32.1% (average)
Declination (θ)	10^o
Collector slope (β)	16.5^o

4. CONCULSION

Improved design solar drier designed and constructed from its study, its performance was evaluated using slices of cassava. It was shown that the solar dryer raised the ambient temperature to a considerable high value for increase drying rate of agricultural products. The improved designed solar dryer eliminated all the shortcomings associated with open drying in Rain forest region of Nigeria. Having successfully dried cassava slices, this mechanism of solar dryer can be employed in drying other agricultural products. With the collector showing improved average efficiency of 37.9%, the water removal rate from the slices of cassava in day one and two showed 62.1% and 68% respectively.

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