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Design and Fabrication of a Solar Powered Sawdust Briquette Machine for Okra Preservation

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Abstract
Storage of agricultural products is an ongoing problem in the agricultural sector with an all-round effect on the economy and other sectors. This research is aimed at reducing okra wastes due to lack of proper storage of the okra. The study focus is on how to improve the storage of okra by designing and fabricating a sawdust briquette powered cabinet dryer, capable of drying products at a regulated temperature and achieve efficient drying in lesser time with lesser contamination, while retaining the quality of the products after drying with solar powered Briquette machine. Sawdust was dried, carbonized and moulded to form briquette to serve as fuel for heating the dryer while a temperature regulator and a blower were incorporated in the design to aid the drying. The dryer has a capacity of 1.576 kg and results obtained from the performance evaluation carried out on the dryer showed that, it was able to dry okra to a desired moisture content of 10% within a period of 5 hours 30minutes. The efficiency of the dryer was based on input and output of heat which was 70% using 0.22kg of sawdust briquette in the dryer to dry the okra.

Keywords: *Dryer, okra evaluation, heat transfer, drying rate, fabrication.*

1.0 Introduction

The products from agriculture contribute significantly to the survival of human race and among these, the importance of fruits and vegetables cannot be overemphasized. Vegetables and fruits, have properties such as vitamins, and low-fat content, and are highly perishable after harvest if not properly preserved. This has been observed as a major problem in developing countries such as Nigeria with a high population with many consuming vegetables every day. Therefore, if the fruits and vegetables are not preserved, there is bound to be scarcity of the products in out of season period of the year. As a result of abundance of quantity of fruits and vegetable processed during the season of harvest, there are huge quantity of wastes encountered due to the lack of methods of preservation. This makes the prices of fruits and vegetables to be more expensive during the off-season or dry season. The popular traditional direct drying method has proven to be inefficient due to the limited time of sunlight available at day time, which means drying has to be undertaken for a number of days, thereby increasing the exposure to contamination, reduction in the quality of vitamins and nutrients of the products due to direct exposure to solar radiation. Also, there is no control over the rate of sun drying. To preserve perishable fruits and vegetables, it is therefore highly essential to remove water and moisture contents from the fruits and vegetables through drying within certain predetermined temperature to prevent decomposition. The moisture content of agricultural products determines the activities of micro-organism acting on it, as shown in Table 1.

Table 1: Moisture content of micro activities in agricultural products

Relative moisture content (%)	Growth of micro organisms
> 95	All organism can grow
75	All yeasts, moulds and most bacteria
60	All moulds and some yeasts and bacteria
40	All moulds and only Staphylococci
25	Most moulds
15	Some moulds
<10	No growth of micro organisms

Source: Dhumne *et al.* (2016)

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1.1 Okra

Okra (*Abelmoschus esculentus*) as shown in plate 1., is well known and well-utilized species of the family *Malvaceae* and an important economical vegetable crop grown in tropical and sub-tropical parts of the world. Okra has major health benefits such as heart health, promoting healthy pregnancy, treatment of digestive issues, promote healthy skin and blood, regulate the cholesterol level in the body, and stabilizing the blood sugar level in the body (Habtamu *et al.,* 2015).

Plate 1I: Okra
Source: Hongu *et al.* (2015)

Okra has some nutrition values and a large amount of fibre, and a unique profile of protein (McGuire and Beerman, 2012), as shown in Table 2. The values are based on one cup measure of raw, uncooked okra, a reasonable portion for someone to eat in one meal. For these facts, there is need to prolong the availability of Okra round the season for benefits of human consumption through a hygienic method of preservation using Solar powered Sawdust Briquette Machine.

Table 2: Okra nutrition facts (based on 1 cup raw)

Nutrients	Amount	% Daily Value
Calories	33	
Total Fat	0.2 g	
Carbohydrate	7.5 g	
Fibre	3.2 g	12.8%
Protein	1.9 g	
Sugar	1.5 g	
Calcium	82 mg	8.2%
Magnesium	57 mg	14.3%
Potassium	299 mg	8.5%
Sodium	7 mg	
Vitamin C	23 mg	38.3%
Thiamin	0.2 mg	13.3%
Vitamin B-6	0.2 mg	10.8%
Folate	60 micro- g	15%
Vitamin A	716 IU	14.3%
Vitamin K	31.3 mg	39.1%

Source: United States Department of Agriculture nutrition database (2015)

1.2 Operational System of the Solar Powered Machine

In order to improve the quality of dried fruits and vegetables, a Solar Powered Sawdust Briquette Machine was developed. A briquette is a block of flammable material formed from different types of agro-waste materials which can be utilized as fuel to ignite and maintain a fire (Olorunnisola, 1998). The Solar Powered Machine is a device designed and fabricated as shown in Figure 5, to use a Sawdust Briquette as a fuel when the machine received its energy from the sun which is converted into heat energy through the Solar Panel. With the aid of the battery powering the Briquette burner, the heat energy is extracted and sent into the Dryer chamber in order to reduce the water and moisture content of the Okra.

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2.0 Materials and Method

2.1 Material Selection

The materials used for the design and body fabrication of the Solar Powered Briquette machine include fibre glass, mild steel sheet, stainless steel sheet, square pipe, angle iron, rivet pins, screws, hinges, and others components such as D.C fan, thermostat, relay, battery, solar panel, and fuel. The crippling stress and the modulus of elasticity for mild steel are 320 N/mm^2 and 205,000 N/mm^2 respectively.

The materials selected for the construction of the dryer includes the following:

i. Stainless steel sheet was used for the combustion chamber and the tray, due to its properties such as: high strength to weight ratio, resistance to corrosion and ease of fabrication, ability to withstand heating of the sawdust briquette for a long period without rusting and its ability to conduct, conserve and preserve heat for effective drying and at the same time avoiding contamination with the product.
ii. A mild steel sheet was used for the construction of the body dryer because of its high weldability properties and ease of riveting.
iii. Squared pipes were used to forming the frame of the dryer.
iv. A mild steel Angle iron was used to form the support of the dryer to give rigidity.
v. DC fan to aid the transfer of heat through the heat exchanger space by creating a negative pressure gradient within the drying chamber thereby aiding the removal of a high rate of moisture content.
vi. Fibre glass was used as a lagging material to reduce thermal conductivity**.**

2.2 Design Analysis and Calculations

2.2.1 The amount of moisture to be removed is expressed as:

$MR = M(\frac{M1-M2}{1-M2})$ (Ehiem *et al., 2009)* (1)

where,
M_R is the amount of moisture to be removed (kg)
M is the dryer capacity per batch (kg)
M_1 is the initial moisture content of pepper 80% relative humidity
M_2 is the maximum dried final moisture content (10%) (Akpan, 2014)

2.2.2 The quantity of air required to effect drying is expressed as:

$Qa = \frac{M_R}{H_{R2}-H_{R1}}$ (Eheiem *et al.*, 2009) (2)

where,
Q_a is the quantity of air required to effect drying
H_{r1} is the initial humidity ratio of air 0.065 dry air at 50°C
H_{r2} is the final humidity ratio of air 0.087 dry air at 54°C

2.2.3 The volume of air (m^3) to effect drying is expressed as:

$V_a = \frac{Q_a}{\rho_a}$ (Akpan, 2014) (3)

where,
Qa is the quantity of air in kg
ρ_a is the average density of air at 50°C

2.2.4 The heat transfer rate (Q_{ht}) is expressed as:

The heat transfer rate for a cylinder is given by the expression

$Q_{ht} = \frac{(KA(T_1-T_2))}{D}$ (Rajput, 2005) (4)

where,
Q_{ht} is the heat transfer rate
K is the thermal conductivity of stainless steel = 16.3 w/mK (Akpan 2014)
K is the thermal conductivity of mild steel = 43 w/mK
Assuming D is the diameter of heat exchanger = 0.2 m
A is the area of the heat exchanger = 0.25133 m^2
T_1 is the temperature of heated air at 70°C (343K) (Akpan 2014)
T_2 is the temperature of air in cabinet at 50°C (323K) (Akpan, 2014)
The quantity of heat that can be lost through the insulator is given by

$q_L = \frac{KAT_{be}}{\delta_x}$ (5)

k is the thermal conductivity of fibre glass = 0.04 w/mK
A is surface area

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T_{be} is the temperature difference between the hot air in the dryer and the environment.

2.2.5 Selection of Fan and its capacity

The fan is triggered to suck the heated air and moisture from the drying chamber when the temperature exceeds the required temperature of drying. The heat exchanger then circulates the heated air within the drying chamber. The mass transfer of the moisture away from the drying chamber is aided through the suction fan. The design equations are shown below;

M_R = 1.2259 kg

Quantity of heat required to remove moisture content

$$Q = M_a \times C_p \times \Delta T \quad (6)$$

Where,

C_p is the specific heat capacity of water at 4.182 Jkg/K^{-1}

ΔT is the temperature difference between the initial and final temperature (54°C – 50°C)

Taking a drying time of 4 hours

$Q = 1.2259 \times 4.182 \times 10^3 \times (4 + 273)$

= 1.4 MJ

$$\text{Power required for drying} = \frac{\text{quantity of heat}}{\text{drying time}} \quad (7)$$

$= \frac{1.4 \times 10^6}{4 \times 60 \times 60}$

= 98.62 W

C_{pa} is specific heat capacity of air at 1005 Jkg/K^{-1}

$$\text{Mass flow rate} = \frac{\text{power}}{C_{pa} \times \Delta T} \quad (8)$$

Mass flow rate $= \frac{98.62}{1005 \times 4}$

Mass flow rate = 0.00036 kg/s

$$\text{Suction} = \text{mass flow rate} \times \text{specific volume of air} \quad (9)$$

The average density of air at 50°C is 1.109 kg/m^3

$$\text{Specific volume of air} = \frac{1}{\rho_a} \quad (10)$$

$= \frac{1}{1.109} = 0.9017\ m^3/kg$

Suction = 0.00036 × 0.9017

Suction = 0.00032 m^3/s

$$\text{The velocity of air through the drying chamber} = \frac{\text{suction}}{\text{area}} \quad (11)$$

The velocity of air through the drying chamber $= \frac{0.00032}{0.24 \times 0.14}$

= 0.00951 m/s

2.2.6 The insulation of the drying chamber is expressed as:

$$\text{Heat power loss} = \frac{K \times A \times (T_2 - T_1)}{d} \quad \text{(Rajput, 2005)} \quad (12)$$

K is the thermal conductivity of fibre glass 0.04 w/mK

A is Area

$T_2 - T_1$ is temperature change

d is Thickness = 0.02 m

2.2.7 Support frame

A structural steel was selected as the material for building the supports of the machine because of its high strength to weight ratio, and ease of fabrication. The crippling stress and the modulus of elasticity for mild steel are 320 N/mm² and 205,000 N/mm² respectively (Akpan, 2014).

$$W = \frac{S_c A}{1 + a(\frac{L}{K})^2} \quad (13)$$

but W = S A

$$Therefore\ S = \frac{S_c}{1 + a(\frac{L_m}{K})^2} \quad (14)$$

where,

L_m is length member

K is least radius of gyration

S_c is cripping stress (320 N/mm²)

S is working stress

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A is Rankine –Gordon's constant for the material $(\frac{1}{7500})$
L/k = 200
W is weight
A is area

$$W = mg = \rho At \quad (15)$$

where t is thickness

2.2.8 The thermal efficiency of the dryer is expressed as: H

Efficiency based on latent heat of vaporization = $\frac{Hr}{Ha}$

Heat to evaporate moisture only (H_r) = ($M_a \times C_p \times \Delta T$) + ($M_m \times L$) from Heat in hot air being supplied = Ha

The dryer efficiency based on the heat input and output in drying air:

$$\eta = \frac{T_1 - T_2}{T_1 - T_a} \quad (16)$$

where
T_1 is inlet temperature to the dryer (°C)
T_2 is the outlet temperature from the dryer (°C)
T_a is the ambient temperature (°C)

2.3 Fabrication of the Dryer

The dryer is composed of four (4) structural units which consist of a combustion chamber, heat exchanger, drying chamber, and suction unit, these were fabricated and connected together as a single unit in a rectangular form as shown in Plate 2. The major operation used in the fabrication of the dryer includes cutting, welding, filing, bending, painting and riveting.

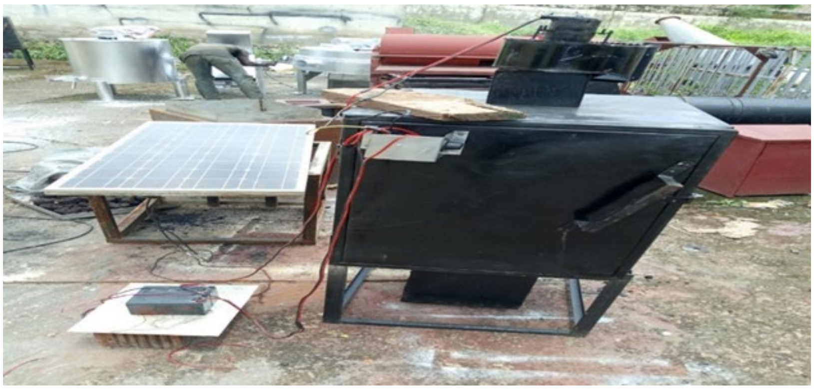

Plate 2: Dryer

2.3.1 Fabrication of the combustion chamber

The combustion chamber was fabricated as a square container with a dimension of 23 × 23 × 23 cm where heat energy is generated and it has a riser tube that directs the heat to the heat exchanger. It was made from stainless steel and also contains a trolley which was fabricated for loading of briquette at various intervals when the briquette burns off shown in Plate 3. The combustion chamber makes use of free space insulation for the reduction in loss of heat is attached to a metal container which is used to attach the combustion chamber to the body of the dryer. Various working drawings for the machine components are as shown in Figures 1 - 4.

Plate 3: Combustion chamber

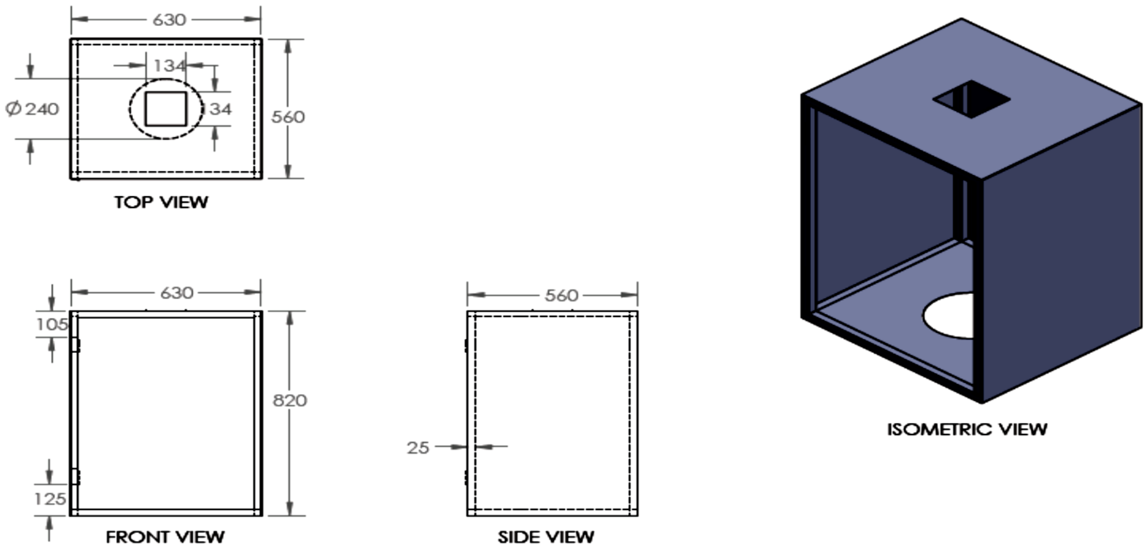

Figure A: The drying chamber

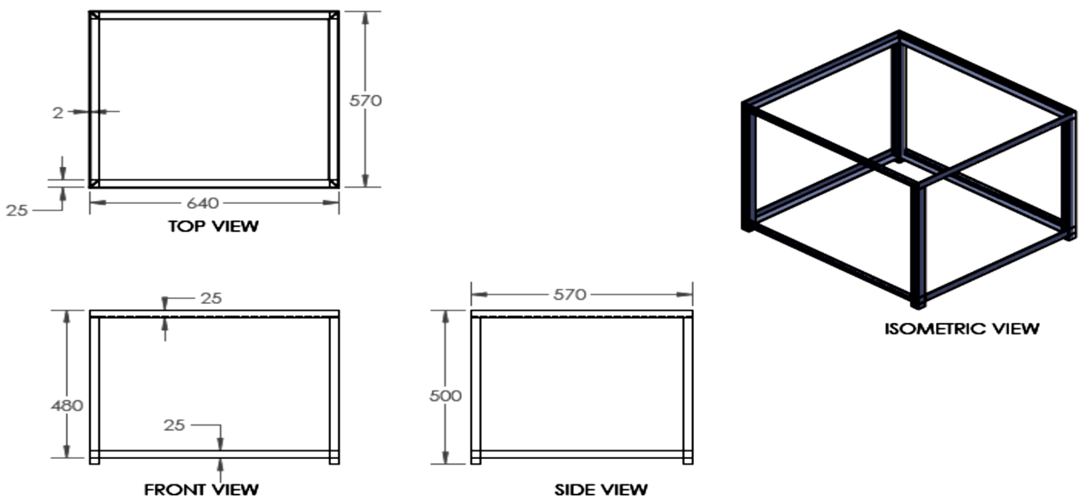

Figure 1: Dryer base stand

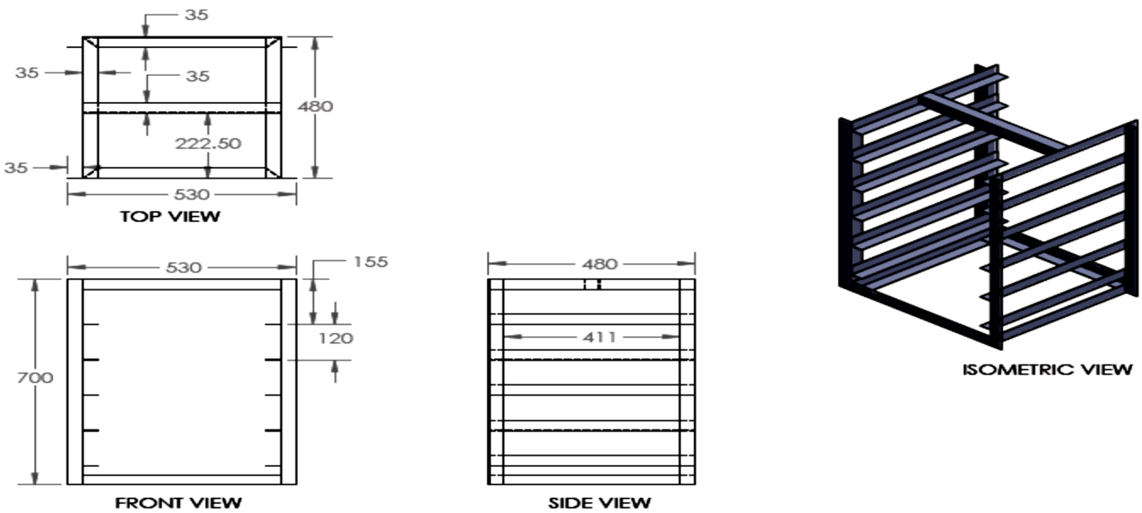

Figure 2: Dryer tray trolley

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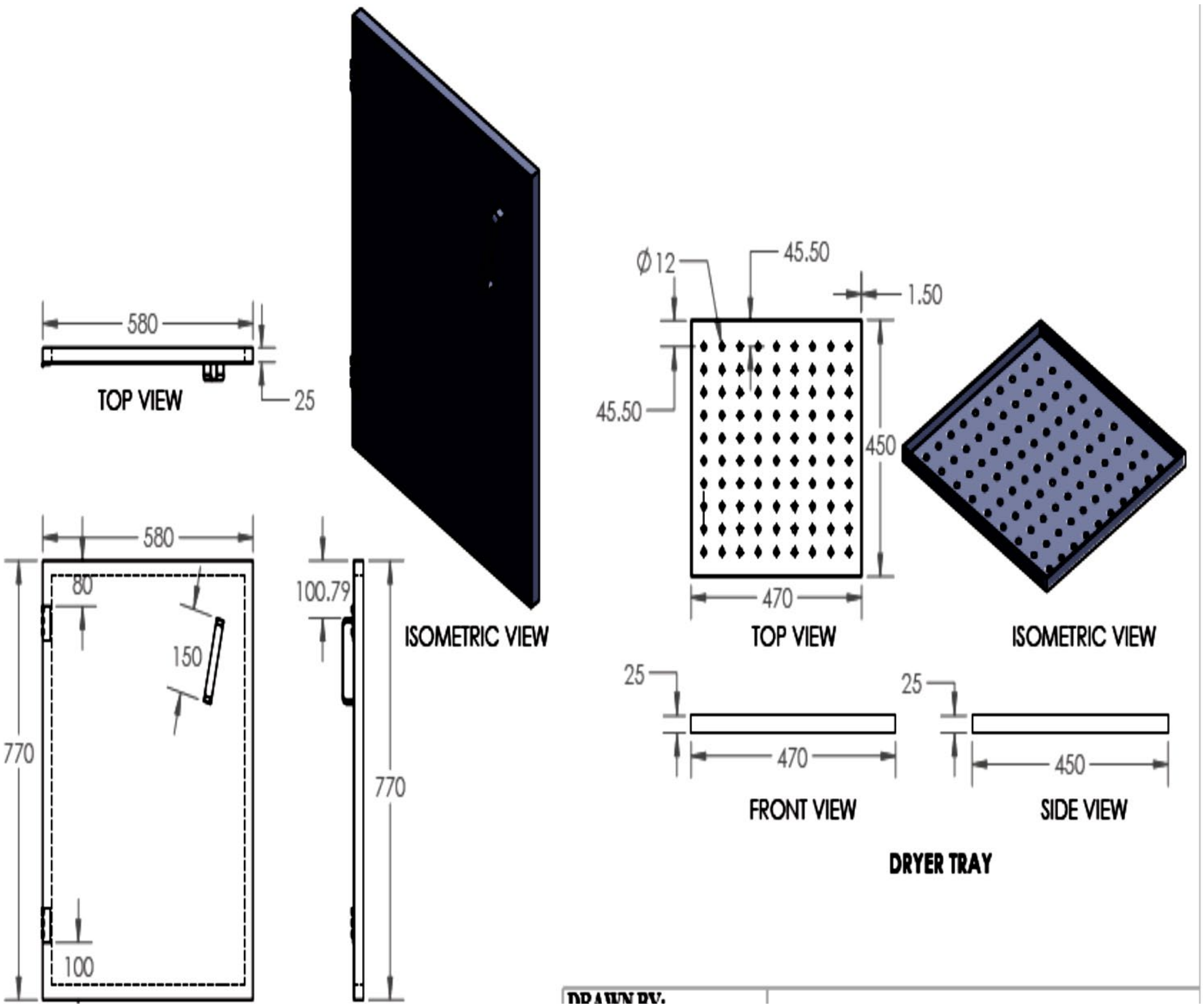


Figure 3: Dryer door and dryer tray

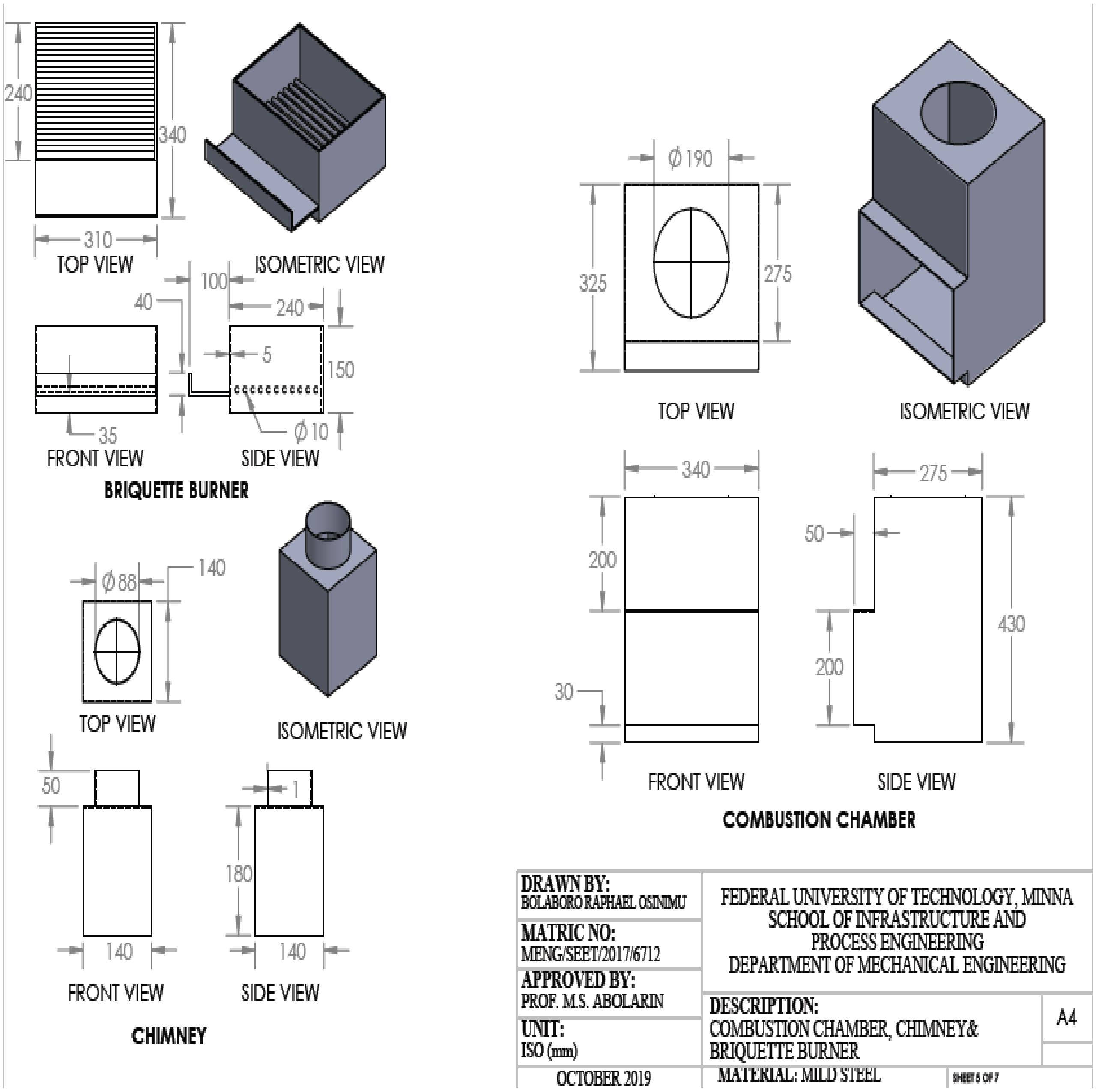


Figure 4: Combustion chamber, chimney and briquette burner

2.3.2 Fabrication of the heat exchanger

The heat exchanger is the space between the insulated body and the drying chamber and is connected to the chimney. The heat exchanger was fabricated in a "U" like hollow to conserve and preserve the heated air before being transferred to the drying chamber and it also serves as a channel in the removal of smoke through the chimney.

2.3.3 Fabrication of the drying chamber

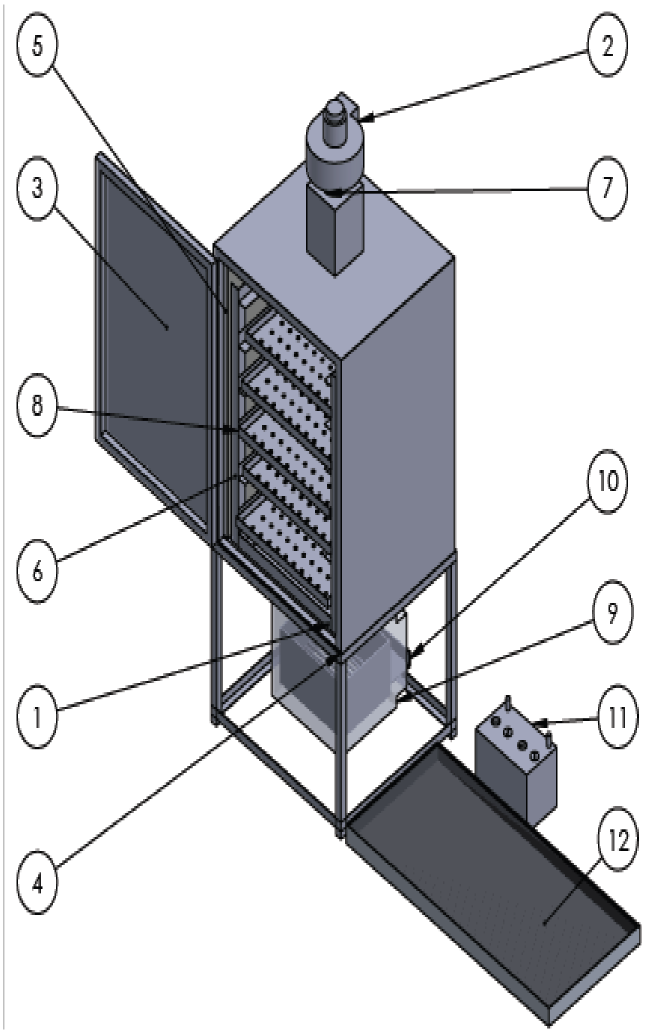
The drying chamber is the third layer from the body of the dryer. The first layer is the insulating layer containing a sandwich of fibre glass between two metal plates with a thickness of 50 mm. The second layer is the space (heat exchanger) between the insulating layer and the drying chamber insulated cabinet. The drying chamber is made up of five shelves of trays where the products are spread for drying. The drying cabinet measures 59 cm long, 52 cm wide, and 78 cm high (with the external dimension of 63 cm x 56 cm x 82 cm) consisting of five sets of trays spaced 12 cm from one another.

2.3.4 Installation of the suction unit

The impeller fan of 0.5 hp was installed and connected to the battery and thermostat for sucking the heated air from the combustion chamber through the heat exchanger and distributes it to the drying chamber. It also sucks out the moisture content from the drying chamber out through the chimney.

2.3.5 Assembling Process

The joining processes for the construction of the dryer were electric arc welding, riveting, folding, bending, bolt, and nuts. The components were all assembled following the processes outline in Table 2. The fabricated dryer is shown in Plate III.



ITEM NO.	PART NUMBER	QTY.
1	DRYER BASE	1
2	Extractor Fan 1	1
3	DRYER DOOR	1
4	DRYING CHAMBER	1
5	FIBRE GLASS INSULATION	1
6	DRYER TRAY TROLLEY	1
7	CHIMNEY	1
8	DRYER TRAY	5
9	COMBUSTION CHAMBER	1
10	BRIQUETTE BURNER	1
11	12V Battery	1
12	Solar Panel	1

Figure 5: Fabricated dryer

2.2.7 Experimental Procedure

The dryer was heated up, okras were packed in the machine chambers for drying. The okra used was sourced from Minna, Niger State with an average moisture content of 86.9% after initial test. Fresh samples were washed, air-dried for 30 minutes and weighed. The weight was recorded as the initial (wet) weight. They were chopped to smaller pieces and dried at a temperature of 54°C for 4 hours to attain a constant weight (the dry weight). The difference between the wet and dried samples was considered as the moisture content. Okra was weighed and spread inside the tray before they were packed into the dryer. The product in each tray was weighed at every interval of 30 minutes for 4 hours. This was done by rapidly removing the trays from the trolleys, weighing them on an electronic scale, and returning them to the dryer. The moisture content at each interval was calculated from the initial weight of the products in each tray. At the end of drying, when the moisture content of the product has reached 10 % or less the trays were removed from the trolley one at a time to determine the differences in drying rate. This was done repeatedly and all weights were measured and recorded to determine their moisture content.

The Okra constant rate occurred at a two-time interval between 300 to 330 minutes. The drying rate is expressed as:

$$Rc = \frac{M_d(M_1-M_2)}{A_s t} \quad (17)$$

where,

R_c is the drying rate

M_d is the total weight of the dried product in kg

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A_S is the surface area of the tray containing dried okra
M_1 and M_2 is the initial and final moisture contents
t is drying time

3.0 Results and Analysis

The summary of the design calculations and result is shown in Table 3.

Table 3. Summary of Design Calculations and Results

Initial Data	Calculation and Sketches	Results
Latent heat of vapourization of water at 50°C = 2381.6 kJ/kg Specific heat capacity of pepper = 3.81 kJ/kg°C 1.2258 kg of wet matter must lose at least 1.218 kg of moisture to achieve a 10% dryness ratio	**Amount of heat required to effect drying (H_r)** Heat energy to raise it temperature from 50°C to 54°C + Latent heat to remove water $H_r = (M_a \times C_p \times \Delta T) + (M_m \times L)$ $H_r = (1.576\ kg \times (54^oC - 50^oC) \times 3.81 \times 10^3) + (1.218 \times 2381.6 \times 10^3)$ $H_r = 4.6 \times 10^6$ J = 4.6 MJ	H_r = 4.6 MJ
Mass of moisture = 1.218 kg	**Actual heat required to effect drying (H_D)** $H_D = \frac{H_r}{1.218\ kg}$ $H_D = \frac{4.6\ MJ}{1.218\ kg}$ = 3.8 MJ/kg	H_D = 3.8 MJ/kg
K of stainless steel = 16.3 w/mK K mild steel steel = 43 w/mK D = 0.2 m A = 0.25133 m² T_1 = 70°C (343K) T_2 = at 50°C (323K) k of fibre glass = 0.04 w/mK A = 16.11 m² T_{be} = 20°C(293K) $\delta_x = 0.02\ m$	**Heat transfer rate (Q_{ht})** $Q_{ht} = \frac{(KA(T_1\text{-}T_2))}{D}$ $Q_{ht} = \frac{16.3 \times 0.25133 \times (343-323)}{0.2} + \frac{43 \times 16.11 \times (343-323)}{0.024}$ Q_{ht} = 409.6637 J + 577275 J = 577.684664 KJ $q_L = \frac{KAT_{be}}{\delta_x}$ $q_L = \frac{0.04 \times 16.11 \times 293}{0.02\ m}$ = 9.44046 KJ Hence net heat transfer $Q_{ht} - q_L$ = 577.684664KJ – 9.44046 KJ Net heat transfer = 568.244204 KJ	Q_{ht} = 577.6846 KJ q_L = 9.44046 KJ
M_a = 1.2259 kg C_p of water = 4.182 Jkg/K^{-1} ΔT = (54°C – 50°C) T = 4 hours C_{pa} of air = 1005 Jkg/K^{-1} ρ_a at 50°C =1.109 kg/m³	**Fan design and capacity** $Q = M_a \times C_p \times \Delta T$ $Q = 1.2259 \times 4.182 \times 10^3 \times (4 + 273)$ = 1.4 MJ Power required for drying = $\frac{\text{quantity of heat}}{\text{drying time}}$ $= \frac{1.4 \times 10^6}{4 \times 60 \times 60}$ = 98.62 W Mass flow rate = $\frac{\text{power}}{C_{pa} \times \Delta T}$ Mass flow rate = $\frac{98.62}{1005 \times 4}$ = 0.00036 kg/s Suction = mass flow rate × specific volume of air specific volume of air = $\frac{1}{\rho_a}$ $= \frac{1}{1.109}$ = 0.9017 m³/kg Suction = 0.00036 × 0.9017 = 0.00032 m³/s	Q = 1.4 MJ Power = 98.62 W Mass flow rate = 0.00036 kg/s Suction = 0.00032m³/s

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Initial Data	Calculation and Sketches	Results
	Velocity of air through the drying chamber = $\frac{\text{suction}}{\text{area}}$ = $\frac{0.00032}{0.24 \times 0.14}$ = 0.00951 m/s	Velocity = 0.00951 m/s
M_c = 0.083 kg/m³s A_T = 0.851 m² H_{r1} = 0.065 kg/kg dry air H_{r2} = 0.087 kg/kg dry air q_2 = 0.0018 m³/s	**Rate of mass transfer** (Q_{mtr}) $Q_{mtr} = M_c\, A_T(H_{r2} - H_{r1}) \times q_2$ $(H_{r2} - H_{r1})$ = (0.087 – 0.065) = 0.022 kg/kg dry air q_2 is air flow rate = 0.0018 m³/s Q_{mtr}= 0.083 × 0.851 × 0.022 × 0.0018 = 2.798 ×10⁻⁶ kg/s	Q_{mtr} = 2.798 ×10^{-6} kg/s
M_d = 0.3502 kg A_S = 0.1702 m² M_1 = 80% M_2 = 10% t = 4 hours	**Drying rate** $R_c = \frac{M_d(M_1\text{-}M_2)}{A_S t}$ $R_c = \frac{0.3502(80\text{-}10)}{0.1702\times 4}$ = 0.36 kg/mol	R_c= 0.36 kg/mol
K of fibre glass = 0.04 w/mK A = 16.11 cm² T_1 = 70 T_2 = 120 d = 0.02 m	**Insulation of drying chamber** Heat power loss = $\frac{K\times A \times (T_2\text{-}T_1)}{d}$ Heat power loss = $\frac{0.04 \times 16.11(393\text{-}343)}{0.02}$ = 1.611 KJ	Heat power loss = 1.611KJ
L_m = length member K = least radius of gyration S_c = 320 N/mm² S = working stress (N/mm²) g = 9.8 m/s² A = $(\frac{1}{7500})$ L/k = 200 A_0 = 53144 mm² A_i = 30345 mm²	**Support frame** $W = \frac{S_c A}{1+a(\frac{L}{K})^2}$ W = S A Therefore $S = \frac{S_c}{1+a(\frac{L_m}{K})^2}$ W = mg = ρAt ∑W for mild steel sheet = 7850 kg/m³ x 53.144 m² x 0.02 m x 9.81 m/s² = 81850.795 N $= \frac{320}{1+\frac{1}{7500}(200)^2}$ = 50.53 N/mm² The total area of member $A_t = \frac{\sum W}{S}$ Therefore, area of a single member $A_t = \frac{\sum W}{4S}$ $A_t = \frac{81850.795}{4 \times 50.53}$ = 404.96 mm² Let Area, A = $A_0 - A_i$ A = 53144 – 30345 = 22799 mm² $A > A_t$	∑W = 81850.795 N S = 50.53 N/mm² A_t = 404.96 mm² A= 22799 mm²
Mass of briquette used = 1 kg Caloric value of briquette = 16.31 MJ T_1 = 110ºC T_2 = 54ºC T_a = 30ºC	**Thermal efficiency of the dryer** For 10% moisture content or less; Efficiency based on latent heat of vaporisation = $\frac{\text{Heat to evapourate moisture only}}{\text{heat in hot air being supplied}}$ Heat to evaporate moisture only (H_r) = (M_a × C_p × ΔT) + (M_m× L) from (3.6) H_r = (1.576 kg × (54ºC- 50ºC) ×3.81 × 10³) + (1.218 × 2381.6× 10³) H_r = 4.6 x 10⁶ J = 4.6 MJ Efficiency = $\frac{4.6\text{ MJ}}{16.31\text{ MJ} \times 1\text{ kg}}$ = 0.27 kg The dryer efficiency based on the heat input and output in drying air: $\eta = \frac{T_1\text{-}T_2}{T_1\text{-}T_a}$	

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Initial Data	Calculation and Sketches	Results
	$\eta = \frac{110 - 54}{110 - 30}$ η = 70% 1 kg of briquette will generate 21. 1 MJ of energy Therefore H_r (4.6MJ) will require $\frac{4.6}{21.1}$ = 0.22 kg of briquette But 1 kg of briquette was used for the drying operation efficiency in generating energy from briquette is therefore $\frac{0.22}{1}$ × 100 = 22%	

The design condition and assumptions are shown in Table 4.

Table 4: Design Conditions and assumptions

Items	Conditions and assumptions
Products	Okra
Density	1.004 2 g/cm^3
Slices	1.75 mm thick
Initial moisture content	86.9 %
Final moisture content	<10%
Drying time	4 hours
Loading technique	Batch process
Loading rate	300 g per tray of fresh products
Ambient temperature	30^{o}C
Ambient relative humidity	23%
Maximum allowable temperature	60 ^{o}C
Heat source	Briquette
Energy density of briquette	16.31 MJ
The vertical distance between two trays	120 mm

After fabricating the dryer, the efficiency of the dryer based on input and output of heat was 70% and the dryer needed 22% out of 1kg of the briquette to dry the product. Okra was dried during the test period with 0.3 kg on each tray. Okra took 5 hours 30 minutes to dry. A weight of 0.3 kg of okra sample was arranged in the tray for drying and the final weight was 0.1442 kg. The results are shown from Table 5.

Table 5: Drying rate for okra

Time (minutes)	Tray 1 (g/min/cm2)	Tray 2 (g/min/cm2)	Tray 3 (g/min/cm2)	Tray 4 (g/min/cm2)	Tray 5 (g/min/cm2)
30	0.000257	0.00029	0.00017	0.00019	0.000353
60	0.0000559	0.000063	0.00008	0.000063	0.00007
90	0.000177	0.000185	0.00017	0.00018	0.000181
120	0.00006	0.000057	0.000055	0.00006	0.000065
150	0.000093	0.000097	0.000065	0.00007	0.00012
180	0.000056	0.00005	0.000057	0.00007	0.00004
210	0.000015	0.000017	0.000026	0.00002	0.000023
240	0.000014	0.000023	0.000026	0.00002	0.00002
270	0.000064	0.00007	0.0000068	0.000073	0.000068
300	0.000019	0.000011	0.00003	0.000014	0.000000041
330	0.000008	0.000008	0.000016	0.000013	0.00000001

The pattern of the materials in each tray and how their masses reduced with time is shown in Figure 6. The weight of the samples continued to decrease consistently due to the evaporation or loss of moisture from the okra samples. From Figure 6, it was seen that the okra attained critical moisture content at 330 minutes.

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At 300 to 330 mins, it becomes very difficult for further extraction of moisture without causing damages to the product. This was also observed by Mohammed, (2013).

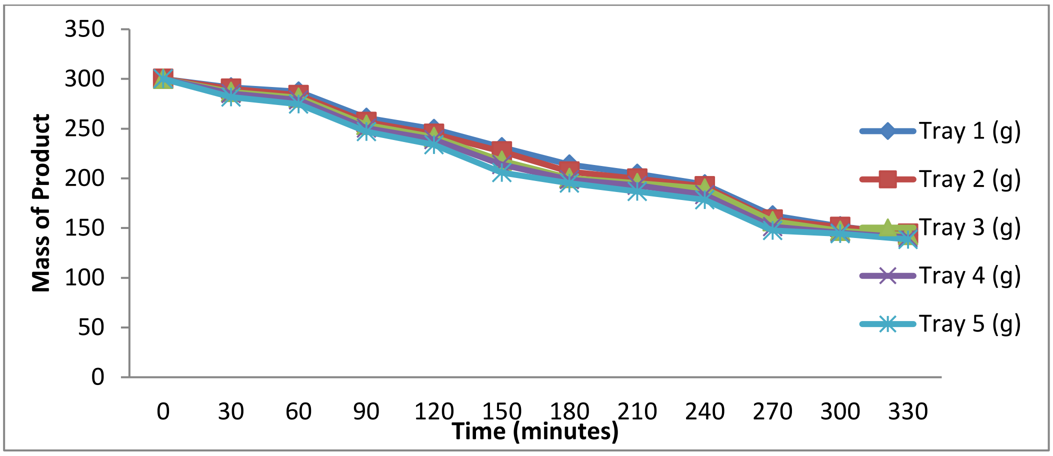

Figure 6: Variation of mass content of okra against time

Figure 7 shows a variation of moisture content of okra against time, it decreases in a non-linear fashion. This may be attributed to the availability and bonding of water molecules in the food sample. Initially, heat is taken from the source of heat by the sample and only a few portions of the free moisture are evaporated and as the drying advances, the moisture moves out by diffusion. The heat penetrates inside and knocks moisture out leaving a product with a decreased water content which agrees with the discovery made by Banout (2011).

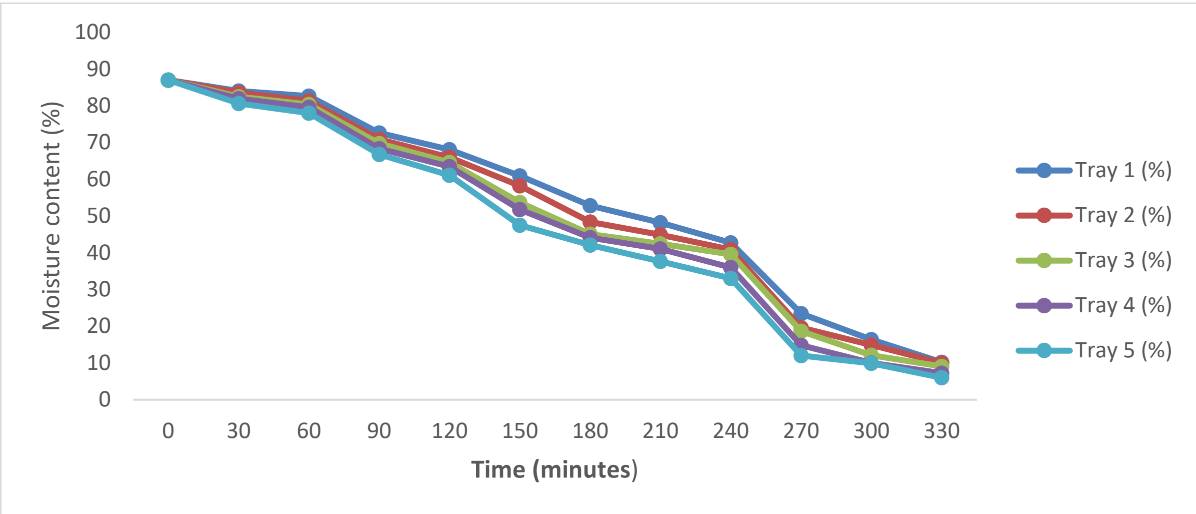

Figure 7: Variation of moisture content of okra against time

In the beginning, the drying rate increases owing to the availability of free moisture shown in Figure 8. As the water content decreases, due to evaporation, more and more moisture moves out to the surface by diffusion, and thereby further decreasing the amount of water to be evaporated which leads to the decline in the drying rate. Similar findings have been reported by Yahya (2016).

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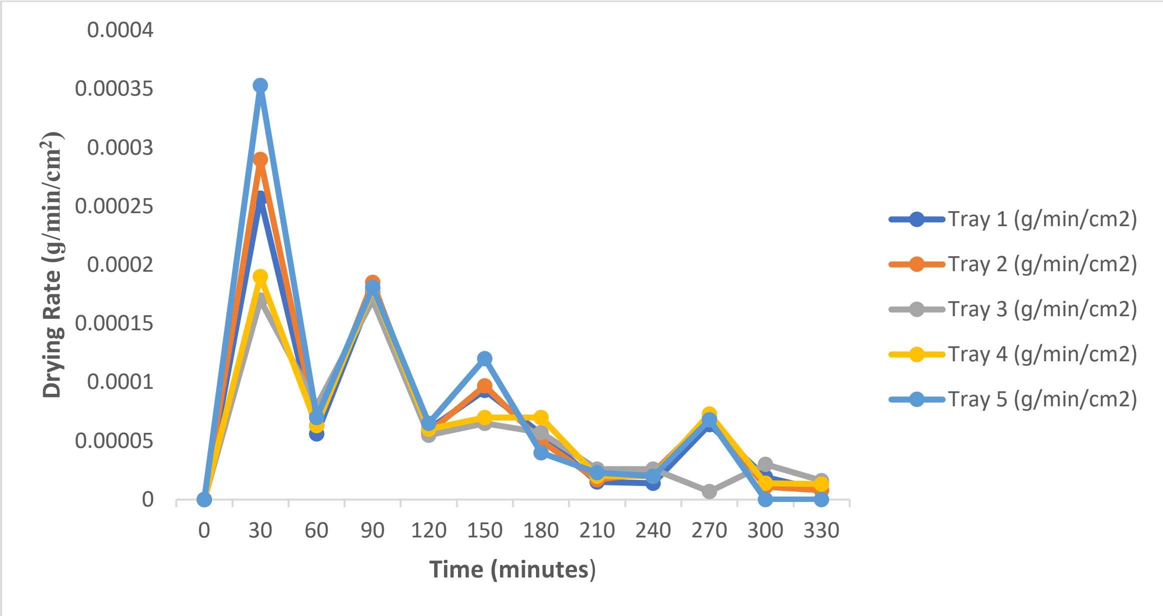

Figure 8: Drying rate of okra with time

In Figure 9, half of the total moisture present was removed during the first hour of the drying process. The okra samples had total moisture content in the range of 87%. As drying proceeds, a gradual decrease in the water content occurs due to the evaporation of water molecules from the sample. Initially, more than 25% of the moisture content was removed in all samples in the first two hours and more than 53% during the first four hours of drying. The effect of increasing temperature on the drying of samples is quite evident from the result, as it clearly shows an increase in temperature decreases the time duration of drying. Drying rate as a function of the water content also exhibits non-linear behaviour. In this study, the drying rate was observed to decrease with decreasing moisture content in Figure 4 which is in agreement with the results of previous research conducted on the effect of temperature and relative humidity on the drying rates and drying times of green bell peppers by Sigge *et al*, (2007), which reported that drying rate decreased with decreasing moisture content. The overall, drying curves follow the general trends of drying curves, in agreement with the theory of the drying process (Akpan, 2014). This results in a reduction of weight or moisture loss of the pepper. The moisture content of pepper was reduced from 87% (w.b.) to 10.0 % (w.b.) or 0.3 kg H_2O/kg solids (d.b.) to 0.143 kg H_2O/kg solids (d.b) within five hours thirty minutes.

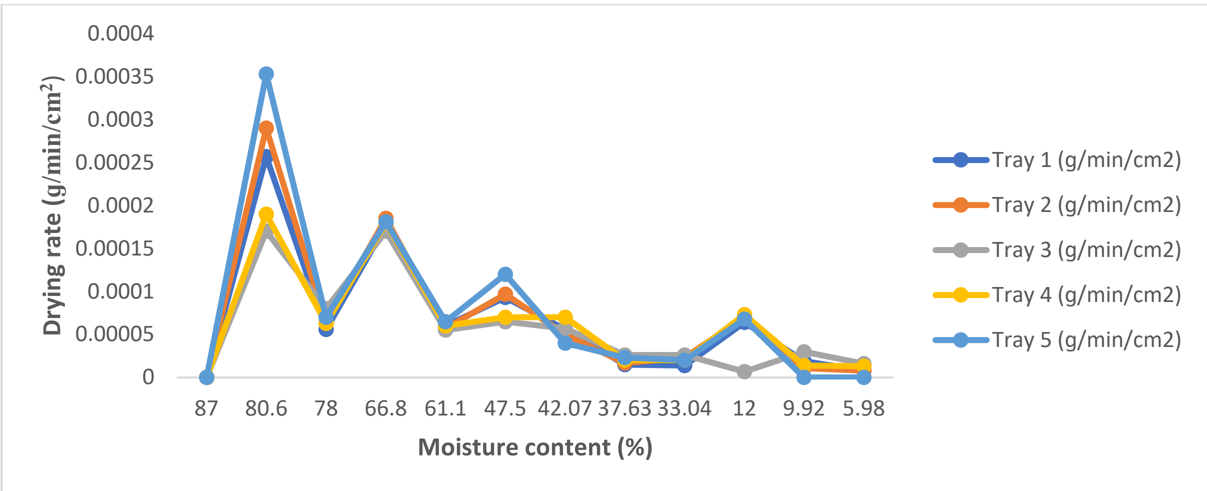

Figure 9: Drying rate of okra with moisture content

Figure 10 shows that the dryer was able to reduce the moisture content up to 30%. From the experiment, it was found that the humidity in the drying chamber reduced with the increase in drying time. Upon 240 minutes of drying operation, the air humidity in the drying chamber successfully reduced significantly from 70% to 32%. The humidity was constant at a level for few times before it dropped again when it was reaching 330 minutes of the drying period. Similar findings were reported by Bharadwaz *et al,* (2017).

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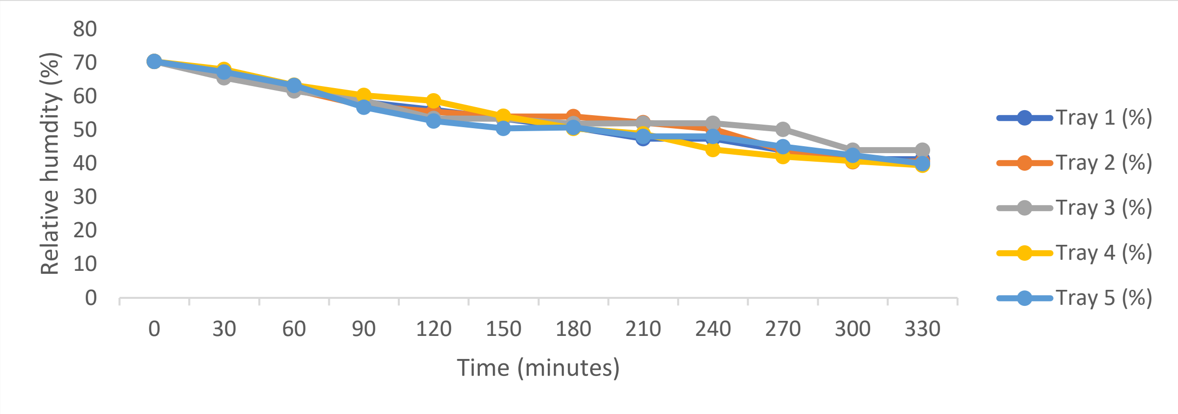

Figure 10: Variation of relative humidity with time

4.0 Conclusion

The development of the dryer for this research is important as it shows improvements over existing ones. The incorporation of a chimney into the design helps in the quick remover of moisture from the system. The temperature regulator helps to retain the product colour, taste, nutrients, and aroma. The simplicity and integration of various units into a single system makes it easier for transportation and reproduction.

The following conclusions were drawn:

i. the cabinet dryer was successfully designed and fabricated using locally sourced materials in accordance to specifications.
ii. the test carried out showed that the dryer having a capacity of 1.576 kg/batch was able to dry okra for 5 hours 30minutes. Test also showed steady progressive reduction in mass and moisture of the products which suggest a fairly even drying rate to attain 10% moisture content. The efficiency of the dryer based on input and output of heat was 70% and the dryer needed 0.22 kg of the briquette to dry the product.

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