Design and Fabrication of Small-Scale Maize Roaster

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***Abstract*: Nigeria local method of maize roasting is prone to high operating stress, uneven roasted maize, high greenhouse effect, low hygienic level and higher time per roast operation, this study was therefore design to explore modern method that can drastically reduce these challenges. From among alternatives considered a 2.976 kg roasted maize in fifteen minutes roasting machine was designed, fabricated using economically available local resources and evaluated. The machine consists majorly electric motor (2.5 rev/min to 3 rev/min) mounted on bearings, selected heating elements (2.07kW calculated based literature standard), transmission and drum shafts, perforated galvanized roasting drum and thermostat (200°C maximum temperature). The machine was tested empty at full chamber volume that took average of 51 minutes and 36 second to reach 200°C from ambient temperature. Other tests carried out helped to establish, the optimum roasting mass for the machine was 2 kg compared to design capacity value of 2.976 kg roasted maize in fifteen minutes. The roasting process was carried out faster with lesser stress, zero greenhouse gasses in a hygienic environment as calculated for.**

***Keywords*: maize, design, roasting machine, food processing.**

I. INTRODUCTION

Maize (Zea mays L.) is one of the world's three most important cereal crops, and it is an important source of food, feed, fuel and fibers (Tenaillon and Charcosset, 2011). Maize is a staple cereal after wheat and rice. It is an important source of carbohydrate, protein, iron, vitamin B and minerals for many poor people in the world (Hossain, A (ed.). 2020). It has the widest distribution of all the cereals, and it is primarily grown for its grain as food for human consumption (Tolera et al., 1998). Maize and other cereals are the major source of calories and protein to the diets of humans and livestock, and this is largely due to their adaptability, high yields, ease of harvest and storage, as well as their processing and eating properties (Lafiandra et. al., 2014).

The economic situation in most developing countries has left farmers and processors operating at small scale and under unhygienic environment (Sobowale et. al., 2020). Various roasting machines are developed for miscellaneous roasting purposes for home and industrial purposes. However, the development of roasting machines using locally available materials for the local people has not been researched as much (Deepika Pandey and Ratna Kumari, D. 2020)

Consumption of maize requires pre-treatments such as heat processing, which could confer some nutritional benefits, as well as alter the physicochemical contents and properties of its components (Deosthale, 1982; Siljestromet al., 1986). Roasting is regarded as a key procedure in the preparation of the maize beverage, due to the characteristic flavor produced during the roasting process. Also, Roasting is an important processing method in the food industry because it is use to improve food quality, to extend the shelf life of foods, and to improve the processing efficiency of subsequent treatment (Youn and Chung, 2012). Roasting is the process by which a product, basically agricultural products, is exposed to dry heat in an oven or over a fire for the purpose of removing moisture and cooking of the products to make it suitable for consumption, it involves the application of dry heat to legume seeds using a hot pan or dryer at a temperature of 150ºC to 200ºC for short time, depending on the legume or the recipe to be made (A. O. Atere, et. al., 2020).

In Nigeria, most maize traders resort into the use of local conventional roasters which are operated openly and are often powered with charcoal or sometimes with wood which results into low efficiency, high stress accumulated, poor quality, high time consumption, and unhygienic roasted produce due to unavailability of accurate temperature regulatory device, ununiformed roasting and the exposure of the maize to dust and other contaminants. Furthermore, economic situation in most developing countries have left farmers and processors operating at small scale, this indicates that the use of automated and electric power-driven equipment is limited to the few large-scale processors (Ilori et al., 2014).

Few researchers have developed some improved maize roasters with different points of view; Ilori et al. (2014) fabricated a maize roasting machine that has a treadle drive mechanism which serves as a power transmission system. The machine basically consisted of a roasting chamber, a longitudinal main shaft which carried a circular disc and four charcoal trays with different pattern of air flow dust using traditional method, roasting of maize is done by placing the charcoal inside a tray and a metal grill is placed between the maize and charcoal. They used fan to blow air which support combustion. The faster the fan blows, the faster the air current, the faster the rate of combustion and the rate of heat transfer from the charcoal to the maize. The process becomes strenuous as the operator get tired out with time before the maize is completely roasted. Also, direct contact and exposure of the human body to direct heat emitted from the charcoal may have side effect on the human skin. Oke (2013) developed a multipurpose roasting machine made up of roasting chamber, heating chamber, two blowers, and driving (power transmission) mechanism. The roasting chamber houses ten food hangers, five on each side of the chamber. The food hanger is use to hold the food items and the hangers were subjected to continuous rotation for uniform and smooth roasting. The heating chamber is comprised of charcoal cabinet and ash collector rigidly joined together with a frame. The ash tray was designed to collect the ash from the burnt charcoal. The ash tray supports are rigidly joined together with charcoal chamber. This support was made to rest on adjusted mechanism to move both charcoal chamber and the ash tray to specific distance to the food item. The blowers that are on both side of the lower part of the machine supply continuous air to the heating chamber to maintain the heat intensity through continuous rotating fan that was channel toward heating chamber. Chain and sprocket mechanism is the mean of power transmission mechanism that was used to supply rotational motion to the fans and food hangers through the shafts in the machine. Awopetu and Aderibigbe (2017) developed a manually operated multi-purpose roasting machine with a sliding mechanism connected to the charcoal chamber which allows the regulation of temperature of the heat depending on the food items to be roasted. This machine operates in such a way that once the handle attached to the flywheel is rotating, flywheel undergoes rotatory motion. As the motion from the handle rotates the flywheel, it allows the chains and sprockets to rotate which has been incorporated with the flywheel. Food item holder and blower have been incorporated with chains and sprockets. Once the chains and sprockets rotate, the food item holder rotates likewise; the blower will generate air that has being channeled to the charcoal chamber. The developed machine is capable of roasting food items such as maize, plantain and yam depending on the choice of the operator.

Although, some research works have incorporated the design and fabrication of an effective small scale maize roasters that could improve the machine effectiveness, efficiency and quality of roasted maize. But it is important to come up with an alternative design for a maize roaster fabricated from locally available materials, which will give major solution for both maize consumers and maize roasters. Thus, the aim of this study is to design and fabricate (using locally source materials) a portable size substitute and improved maize roaster that eliminate or drastically reduce the deficiencies in local unscientific method of roasting which is often of low efficiency because of the stress involved, time consumed, varied roasting quality, unhygienic product, high energy loss, and non-environmentally friendly.

II. MATERIALS AND CONSIDERATIONS

The decision matrix used in selecting the best suitable materials for the machine was based on cost, availability, weight, operating condition, and functional requirements that best suit the design. Market survey was carried out on cost and availability. The maize roaster operates on electrical power source and the machine consists of the following major components: the frame, shafts, roasting drums, roasting chamber, bearings, electric motors, thermocouple, thermostat, heating elements and heat resistant glass.

2.1 Design Consideration

Physical and performance characteristics related to the machine design, environment, and the overall efficiency of the machine were considered. The following functions were critically considered before proceeding with the design;

(i) Heat requirement
(ii) Mass of maize to be roasted per cycle
(iii) Volume of the roasting chamber
(iv) Turning speed of the roasting chamber
(v) Friction and wears
(vi) Material selection
(vii) Cost of production

2.2 Design Analysis

These are the necessary design analysis used in calculating and selecting major components, parts and elements of the intended design of the maize roasting machine.

2.2.1 Heat Requirement

In any heating system, there is always a need for heat during the heating process. Specific heat is the quantity of heat that is gained or lost by a unit mass of product to accomplish a unit change in temperature, without a change in state. The quantity of heat or the amount of heat energy necessary for the complete roasting process is calculated using:

$$Q = mC_p(\Delta T) \quad \ldots\ldots (1)$$

$$\Delta T = T_f - T_i \quad \ldots\ldots (2)$$

$$\Delta T = 200^oC - 28^oC = 172^oC$$

Where, Q = the quantity of heat needed in joule(J)

m = mass of the food item at maximum loading capacity in grams (g)

C_p = the food item's specific heat capacity, and

ΔT = temperature difference

T_i = initial temperature (tropical ambient temperature assumed to be 28^oC)

T_f = the final temperature

The specific heat capacity C_p was calculated using a predictive comprehensive model of specific heat based on composition and temperature presented by (Choi and Okos, 1986).

$$C_p = \sum_{i=1}^{n} C_{p_i} X_i \quad \ldots\ldots (3)$$

Where, X_i = fraction of the i_{th} component

n = total number of components in a food

C_{pi} = specific heat of the i_{th} component

$C_p = 4.1766X_m + 2.0319X_p + 2.0177X_f + 1.5857X_h + 1.8807X_{fi} + 1.1289X_a$ …… (4)

Where X is the mass fraction of;

Subscripts h= carbohydrate
p=protein
f=fat
a= ash
m= moisture content
fi=fibre

The mass (m) for 20 freshly harvested maize was weighed and the average value was determined to be 186g on average per maize and for an average loading of 4 pieces of maize per roasting drum on 4 different columns. Thus,16 pieces of maize on average basis is equivalent to a total mass of 2976g. The specific heat capacity of maize was calculated using the gotten percentage proximate composition of freshly harvested yellow quality protein maize which is 3.49% of crude protein, 1.31% of crude fat, 73.86% of moisture content, 0.88% of ash, 1.05% of crude fibre, 18.96% of carbohydrate, and caloric value of 103.39(kcal/100g) (Omenna et al., 2016).

Substituting the values of maize proximate analysis into the equation (4), we have:

C_p = 3.51kJ/kgK

Recall, $Q = mC_p(\Delta T)$

Q = 2.976kg x 3.51kJ/kgK x 172K

Q = 1797kJ

If the roasting time is fixed for 15 minutes, the Power (P_{maize}) requirement will be:

$P_{maize} = Q / t$ …… (5)

P_{maize}= 1797kJ / 900sec = 1.997 kW

2.2.2 Heat losses through the walls

Due to convection through fluid and conduction through walls, there is always a need to checkmate the heat energy lost into the surrounding system. Heat will be transferred from one material to another when there is a difference in their temperature which is the driving force which establishes the rate of heat transfer. Conduction process occurs when heat is transferred between adjacent molecules and is mechanism of heat transfer in solids. According to Fourier's first law, the heat flux, in conduction heat transfer, is proportional to the temperature gradient as given below with assumptions that the heat loss happened at a steady state and the chamber was preheated to 200°C.

$$\frac{q}{A} = -k\frac{dT}{dx} \qquad …… (6)$$

Hence, $$q = -kA\frac{dT}{dx} \qquad …… (7)$$

Where q = the rate of heat flow

A = the cross-sectional area through which heat is transferred which is perpendicular to the direction of heat flow

dT/dx= the temperature gradient

k= the thermal conductivity

dT= the temperature difference

dx= the thickness

subscript "s" is for mild steel

subscript "f" is for the fibre insulation

subscript "in" for inside

subscript "out" for outside, and

subscript "loss" for loss

The derivation of Fourier's law for a mild steel sheet metal to fibre wool insulation to mild steel sheet metal conduction gives:

Recall: k_s = 45W/mK

k_f = 0.045W/mK

dx_s = 0.0015m

dx_f = 0.04m

A = 0.82m x 0.45m = 0.369m^2.

$$q_{loss} = \frac{T_{in} - T_{out}}{\left[\frac{dx_s}{k_s A} + \frac{dx_f}{k_f A} + \frac{dx_s}{k_s A}\right]} \qquad …… (8)$$

$$q_{loss} = \frac{200 - 28}{\left[\frac{0.0015}{45\times0.369} + \frac{0.04}{0.045\times0.369} + \frac{0.0015}{45\times0.369}\right]}$$

q_{loss}= 71.4 W = 0.0714 kW

Since the maize has maximum power requirement of 1.997kW, it will be used as the basis for this study, and the total energy requirement to checkmate the loss due to conduction is 0.0714kW, Hence Power required ($P_{required}$) to compensate for the maize and energy loss due to conduction is

$P_{required} = q_{loss} + P_{maize}$ …… (9)

$P_{required}$= 0.0714 + 1.997

Therefore, for Maize,

$P_{required}$= 2.07 kW

2.2.3 Roasting Drum

Analysis of roasting drum is done using the average measured maize with length of 170mm and diameter of 50mm to calculate a value with some tolerance which yielded a result of length = 200mm and diameter = 80mm which was used, and the door arclength was also calculated using the tolerance maize diameter, and the arclength of the door has been predetermined to be 90^0. For this project, a 400mm long with 170mm diameter cylindrical roasting drum was selected.

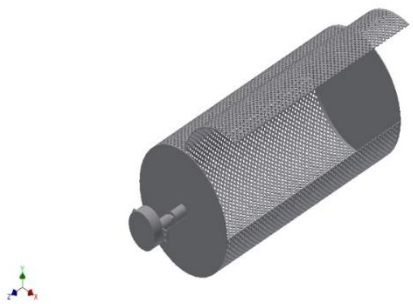

Figure 2a: AutoCAD of the roasting drum

The volume "V" of the roasting drum was derived from:

$$V = \frac{\pi D^2 L}{4} \quad \text{………..… (10)}$$

Where, V = Volume of the roasting drum

D = diameter of the roasting drum

L = length of the roasting drum

The number "n" of holes of holes on the sheet metal that was perforated is obtained as:

$$n = \frac{\pi DL}{0.0004} \quad \text{………..… (11)}$$

The volume "v" of each hole is determined using:

$$v = \frac{\pi d^2 t}{4} \quad \text{………..… (12)}$$

Where, v = volume of holes on sheet metal

d = diameter of holes

t = thickness of sheet metal

Hence, the total volume of the holes;

$$v_h = n \text{ x } v \quad \text{………..… (13)}$$

The volume of the sheet metal to be used before the perforation is obtained as:

$$V_s = \pi \text{x } D \text{ x } t \quad \text{………..… (14)}$$

After the perforation was done on the sheet metal, the new volume of the sheet metal can be determined as:

$$V_n = V_s - v_h \quad \text{………..… (15)}$$

2.2.4 *Transmission Shaft*

Since the expected shaft is subjected to twisting moment (torque) only, the diameter of the shaft only needs to be obtained. According to Khurmi and Gupta, (2005), the diameter of a solid shaft meant to transmit only torsional moment is calculated:

$$d^3 = \frac{16T}{\pi\tau} \quad \text{………..… (16)}$$

Where T= Twisting moment (or torque) acting upon the shaft in Nm

τ = Torsional shear stress

r = distance from neutral axis to the outer most fiber

= $d/2$; where d is the diameter of the shaft $(d_0)^4$

Also,

$$P_{transmitted} = \frac{2\pi nT}{60} \quad \text{………..… (17)}$$

Where: $P_{transmitted}$= power transmitted in watts

n = shaft speed in rev/min.

From the existing design of electric motor used, the maximum power that can be transmitted through the shaft is 4W at a speed of 3 rev/min. The shaft was made from mild steel with allowance for keyways and the allowable shear stress taken as 42 MPa = 42 N/mm^2, substituting these values into equation (17) gives:

$$T = \frac{4\text{x } 60}{2\pi \text{ x } 3} \quad \text{………..… (18)}$$

= 12.73 Nm = 12732 Nmm

Also, substituting the value gotten from equation (18), equation (16) becomes;

$$d^3 = \frac{16 \text{ x } 12732}{\pi \text{ x } 42}$$

d^3 = 1543.89

Therefore: d = 11.56 mm

However, the shaft will be shaped to a polygonal section at both ends or throughout the length so as to be able to transmit torsional strength from the electric motor to the drum shaft which in turn rotates the roasting drum alongside with the food items.

Using the Pythagoras theorem, taking the hypotenuse as the shaft diameter and the other two sides as cross-sectional lengths of the square shaft, hence;

$d^2 = l^2 \text{ x } l^2$

therefore $(11.56)^2 = (l \text{ x } l)^2$

l^2 = 11.56

l = 3.4 mm

hence, let's have l = 10 mm and d = 14.14 let's say 15 mm which is 30% higher in value with factor of safety as 1.3

2.2.5 *Drum Shaft*

Since ease of assembling and disassembling is a major criterion of a good machine which is to allow maintenance and repairs to be carried out on the machine easily. The transmission shaft is separated from the roasting drum by an inclusion of a drum shaft, this drum shaft is meant to carry the drum load while it transmits the torsional moment from transmission shaft to the roasting drum and in turn to the food items. The drum shaft will be welded to the roasting drum horizontally, the shaft is subjected to bending moment and torsional moment, also, the shaft will be made hollow to allow the key coupling of the square shaft into its square hollow socket.

2.2.6 Assuming a Steady Load

According to maximum shear stress theory

$$d^3 = \frac{16(M^2+T^2)^{\frac{1}{2}}}{\pi\tau} \quad \text{………… (19)}$$

Where: M = bending moment

Maximum bending occurs at the bearing support point and calculated as follows:

B.M = W x L = (mass x acc. due to gravity) x perpendicular distance

= (3 x 9.81) x 210

= 6180.3 Nmm

Also, bending moment at the point of support = 0

Substituting the value of $d^3$and 42 Mpa as the maximum permissible working stress for shafts with allowance for keyways into equation (19) we have:

$$d^3 = \frac{16(6180.3^2+12732^2)^{\frac{1}{2}}}{\pi \text{ x } 42}$$

d^3 = 1716.17

d = 11.97 mm

however, the transmission shaft diameter to be used is bigger than the drum shaft, we use the value for transmission shaft while we assume k = 0.7

Recall that: $k = d_i / d_o$……….(20)

Where d_o = inside diameter of the shaft

d_i = outside diameter of the shaft

k = ratio of inside and outside diameter of the shaft

0.7 = 14.14 / d_o ………… (21)

d_o = 20.2 mm, we take 20 mm

2.2.7 Assuming a Fluctuating Load

In actual practice, the shafts are subjected to fluctuating torque and bending moment, according to Khurmi and Gupta (2005), diameter of a hollow shaft under fluctuating load is:

$$d^3 = \frac{16T_e}{\pi\tau} \quad \text{………… (22)}$$

Where, T_e is the equivalent twisting moment

$T_e = [(K_m \text{ x } M)^2 + (K_t \text{ x } T)^2]^{1/2}$………… (23)

Where, K_m = Combined shock and fatigue factor for bending,

K_t = Combined shock and fatigue factor for torsion

According to Khurmi and Gupta, (2005), for a rotating shaft with suddenly applied load with minor shock, value taken are, K_m = 2 and K_t = 2. Also, substituting these values into equation (23), we have:

$T_e = [(2 \text{ x } 12360.6)^2 + (2 \text{ x } 12732)^2]^{1/2}$

T_e = 35490.18 Nmm

Hence, d^3 = 4303.57

d = 16.27 mm

Recall that $d^3 = d_o^3 (1-k^4)$

$4303.57 = d_o^3 (1-0.24)$

d = 17.82 mm, we say 20 mm

2.2.8 Torsional Rigidity of the Shaft

The torsional rigidity of every shaft is based on permissible angle of twist. The amount of twist permissible depends upon the particular application of the shaft and varies from 0.3 degree/m for a machine tools shaft to about 3 degree/m for line shafting. According to Hall et. al., (1988) angle of twist between bearings is given as;

$$\theta = \frac{584\,ML}{Gd^4} \quad \text{………… (24)}$$

Where θ = angle of twist (^{0})

M = torsional moment (Nm)

L = shaft length (m)

G = torsional modulus of rigidity (Nm^2)

d = shaft diameter (m)

According to Harrison and Nettleton (1994), torsional modulus of elasticity of the shaft material (Mild steel) is 80 GN/m^2.Also, According to Khurmi and Gupta (2005), the approximate rating (or service) life or dynamic load rating for ball or rolling contact bearing under variable loads is based on:

$$L = \left(\frac{C}{W}\right)^k \text{x}10^6 \text{ revs} \quad \text{………… (25)}$$

Where; L = rating life

C = basic dynamic load rating

W = equivalent dynamic load

k = 3, for ball bearings and (10/3) for roller bearings

Also According to Khurmi and Gupta (2005),

$C = \frac{2M}{d}$ ………..… (26)

Where, M = torsional moment on the shaft

d = shaft diameter

Therefore, $C = \frac{2 \text{ x } 12360.6}{20}$

= 1236.06 N

The dynamic equivalent load (W) is the load at different instant of speed. The effect of load on bearing life is that, if the load is doubled it reduces the life of the bearing to one tenth. Increasing the load by 20% approximately halves the life (Khurmi and Gupta, 2005)

In essence if the load is doubled then new load rating C_1 is obtained as:

C_1 = 2 x C ………..… (27)

= 2 x 1236.06

= 2472.12 N

However, if the load is increased by 20% then the new load rating C_2 is obtained as:

C_2 = C + (20% x C) ………..… (28)

= 1236.06 + (1236.06/0.2)

= 1483.27 N

Hence, equivalent dynamic loading "W" is calculated as follows:

W = (C + C_1 + C_2)/3 ………..… (29)

= (1236.06 + 2472.12 + 1483.27) / 3

= 1730.48 N

We can now say that the rated life is:

$L = \left(\frac{C}{W}\right)^k \text{x}10^6$ revs

$= \left(\frac{1236.06}{1730.48}\right)^3 \text{x}10^6$ revs

= 364434.01 revs

Angular twist between bearings

$\frac{T}{J} = \frac{G \text{ x } \theta}{L}$ ………..… (30)

Where θ = angular twist between bearings in radians

J = polar moment of inertia

J = (*pi* x d^4) / 32 ………..… (31)

2.2.9 Linear Velocity

To get the linear velocity (V_{linear}), taking the maximum diameter of food items to be 120 mm and the food items to be rotated at 2 rev/min, is:

V_{linear} = 2 x 376.99= 753.98 mm/min = 0.75 m/min

2.2.10 Power Required

According to Khurmi and Gupta, (2005), the energy required to rotate a mass of 6 kg at a linear velocity of 0.75 m/min is:

E = W x V_{linear} ………..… (32)

= 58.86 x 0.75

= 44.145 Nm/min

Taking the maximum mechanical efficiency as 0.67, therefore power of the driving motor:

E = 44.145 / 0.67

= 66 Nm/min

Power required (P_{rotate}) by the drum per minute

P_{rotate}= E / 60 ………..… (33)

= 66 / 60= 1.1 W

2.2.11 Torque Required

According to Khurmi and Gupta, (2005), the torque needed by the drum shaft to rotate a mass of 6 kg through a radius of 100 mm is given as:

T = W x R ………..… (34)

Where T = required torque

W = total roasting weight

R = drum radius

Therefore: T = (6 x 9.81) x 100

= 5886 Nmm

2.2.12 Required Motor Speed

Angular speed of the roasting drum is given as:

ω = linear speed / drum radius ………..…(35)

= 0.63 / 0.1

= 6.3 rad/min

With no or 1:1 speed reduction of the gear, the angular speed of the electric motor is:

w = 6.3

$N = \frac{w}{2\pi} = \frac{6.3}{2\pi}$ ………..… (36)

= 1 rev/min

Base on existing design, and closest available motor in the market with such specification, an electric motor with speed of 2.5 to 3 rev/min and power of 4 W is selected in fabrication.

2.2.13 Chassis/Frame

According to (Khurmi and Gupta, 2005) the polar moment of area of the square cross section shown above can be obtained as follows:

$I_{XX} = \frac{1}{12}(L^4 - l^4)$ .... (37)

Where, L = outer length = 40 mm

l = inner length = 36 mm

t = thickness = 2 mm

$Ixx = (40^4 - 36^4) / 12$

$= 73365.33\ mm^4$

Also, $I_{YY} = \frac{1}{12}(L^4 - l^4)$ ....(38)

$= (40^4 - 36^4) / 12$

$= 73365.33\ mm^4$

Since $I_{XX} = I_{YY}$ therefore the section will tend to buckle along the X-X axis and Y-Y axis. Thus, we shall take $I = I_{YY} = I_{XX}$ which is 73365.33 mm^4 (Khurmi and Gupta, 2005)

The area of the column is obtained from:

$A = L^2 - l^2$ .... (39)

$= 40^2 - 36^2 = 304\ mm^2$

Also, $k = \sqrt{\frac{I}{A}}$ .... (40)

Where; I = polar moment of area

Hence, k can be obtained as follows:

$= \sqrt{\frac{73365.33}{304}}$

= 15.53 mm

According to Khurmi and Gupta, (2005), slenderness ratio is:

$\left(\frac{l}{k}\right)^2 = \left(\frac{450}{15.53}\right)^2$ .... (41)

$l/k = 28.98 < 80$,

Also, L/k = (450/2) / 15.53 = 14.49 <140 hence, it is a short beam

2.3 Materials Selection

Table 1 shows the breakdown of the selected material for this machine. The selection of suitable material used after careful analysis and design consideration is based on various properties of engineering material such as strength, hardness ductility machinability and dimensional stability at high temperature, also the cost and availability were considered.

Table 1: Material selected

Machine components	Criteria for selection	Material selected	Remarks
Frame	Strong, affordable, less massive, rigidity and robustness	Square iron bar made of mild steel	ability to maintain stability and rigidity without twist
Casing	to provide covering and resistance to corrosion	Galvanized steel sheet metal	Availability, corrosion resistance and low cost
Insulator	low thermal conductivity	Bulk fibre roll	good insulation
Motor	perfect operation with low electricity consumption	Low speed high torque electric motor	transmitting the required power at lower speed
Thermostat	to control the roasting temperature	Digital thermostat	Suitability
Door	Transparent and high thermal capability	Heat resistant glass	see through ability with high safety standard
Shaft	Ability to withstand high torsional stress	Mild steel shaft	Ability to withstand high torsional stress
Roasting drum	to allow maximum exposure of food items to heat at high hygienic level	Perforated galvanized drum	Light in weight and high thermal capability
Heating element	to generate thermal energy	Induction coil heating element	ability to release heat generated at a faster rate
Ball bearings	to allow ease while the shaft rotates	Carbon bearing	Suitable for operation at high temperature

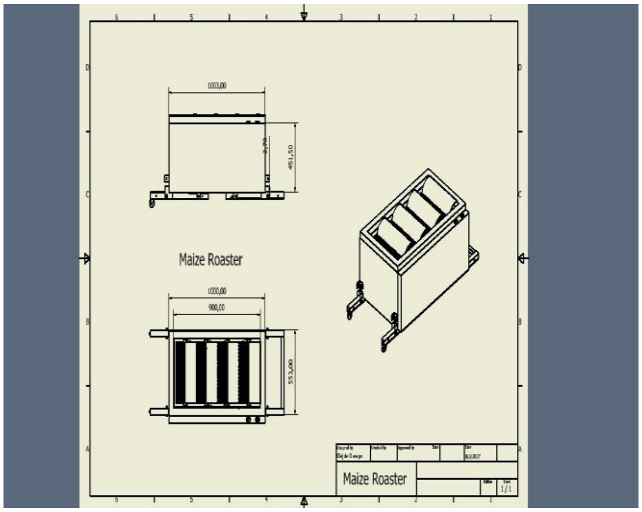

Figure 2b: AutoCAD of the maize roaster in wire sketch

Figure 2c: AutoCAD of the maize roaster with legs collapsed

Figure 2d: AutoCAD of the maize roaster with legs unfolded

III. MACHINE OPERATION AND PERFORMANCE

3.1 Machine description

Figure 3a: The Fabricated maize roaster

The machine works as an intermittent process. The heating is done with the aid of heating element set to a predefined temperature. The lower part of the roaster has an electric heater attached to its inner base while the roasting drum is attached to the inner middle part of the chamber. A shaft is attached to each cylindrical roasting drum and connected to electric motors to effect turning operations. Attached to each end of the drums is bearing to ease the free turning of each drum and to reduce friction between two surfaces moving relative to each other which eventually aids even roasting effect on food items and prevents burnt roast. To maintain the maize at a specified temperature, a thermostat device was also incorporated.

Figure 3b: Fabricated roasting drum

The machine parts are breakdown below:

(i) Machine size = (90 x 53 x 36) cm
(ii) Sheet metal thickness = 1.2mm (galvanized)
(iii) Roasting drum = (40 x 17) cm
(iv) Sheet metal thickness = 1.5 mm (perforated and galvanized)
(v) Fibre insulation = 4cm
(vi) Legs = (65 x 90 x 53) cm
(vii) Heating element capacity = 2200W

(viii) Motor ratings = 4W, 2.5 to 3 rev/min, 125^{o}C

Table 3: Bill of material and total cost estimate used to produce the machine

S/N	Description	Quantity	Rate (₦)	Amount (₦)
1	40x40x2mm, 5486.4mm long square hollow pipe (Mild Steel)	2.5	1800	4500
2	25 x 25 x 2mm, 5486.4mm long square hollow pipe (Mild Steel)	1	1100	1100
3	1219.2 x 2438.4 x 1.5mm Galvanized steel sheet metal	1.5	14000	21000
4	Mild steel electrodes	$^{1}/_{2}$ pack	2000	1000
5	Fibre insulation	1 bag	2300	2300
6	1100W heating element	2	2500	5000
7	Thermostat assembly	1	8500	8500
8	1000 x 1000mm galvanized sheet (perforated)	$^{1}/_{2}$ sheet	10000	5000
9	Double gang switch	1	1100	1100
10	Tempered glass door 525 x 850mm	2	5000	10000
11	Inches	3	150	450
12	13Amps plug	1	500	500
13	High wattage wire cable	6 yards	500	3000
14	Bearing	8	250	2000
15	Shaft	4	200	800
16	Slot keys	2 pairs	500	1000
17	Clips	8	100	800
18	Electric motor	4	2000	8000
19	Tire	2	500	500
	Subtotal			**76550**
	Workmanship, Transport, Miscellaneous			13000
	Total			**89550**

3.2 Performance Evaluation

The performance of the machine was carried out by altering the amount of maize (kg) loaded while observing the time (s) response in relation to the rate of change in temperature (^{o}C). The loaded maize was varied between 1kg and 3kg with an interval of 1kg. The time taken to alter the temperature of food items by 1^{o}C was recorded using a stop-watch, also the temperature was recorded too so as to get the most effective parameters for optimum roasting conditions.

The machine was first tested empty and it takes 51mins and 36 secs to reach 200^{o}C, it was later test run with 20 pieces of maize of 3.7kg and the result roasted incomplete that took 67mins to reach 153^{o}C where temperature drag was noticed. This leads to a modification of the machine by partitioning the roasting chamber into two. With the same heating capacity, the machine was tested and evaluated by altering the mass from 1kg to 3kg with an interval of 1kg. On each variation, temperature and time were noted.

IV. RESULT

Figure 4a present the variation in temperature and time for the unloaded machine to reach the maximum temperature of 200^{o}C, and figure 4b presents the variation in temperature and time for machine to completely roast maize of 1kg, 2kg, 3kg. The machine was evaluated and tested with respect to its roasting capacity (kg), operating temperature (^{o}C) and operating time (s) by varying the mass of loaded maize from 1kg to 3kg with an interval of 1kg to ascertain the optimum roasting conditions. The machine was tested empty at full chamber volume which takes 51mins and 36sec to reach 200^{o}C. Also, it was tested at half chamber volume after which some results were gotten: when empty; operation time was 18.6mins; initial temperature was 22^{o}C; final temperature was 200^{o}C and average time of increment in time per 5^{o}C increment in temperature was 31s, when mass was 1kg; operation time was 18.3mins; initial temperature was 201^{o}C; minimum temperature was 189^{o}C; final temperature was 193^{o}C and average time of increment in time per 1^{o}C alteration in temperature was 55.9s, when mass was 2kg; operation time was 21.4mins; initial temperature was 200^{o}C; minimum temperature was 189^{o}C; final temperature was 193^{o}C and average time of increment in time per 1^{o}C alteration in temperature was 61.2s, and finally when mass was 3kg; operation time was 26.6mins; initial temperature was 205^{o}C; minimum temperature was 188^{o}C; final temperature was 193^{o}C and average time of increment in time per 1^{o}C alteration in temperature was 49.8s. Hence, the optimum roasting mass for the designed machine was gotten to be 2kg.

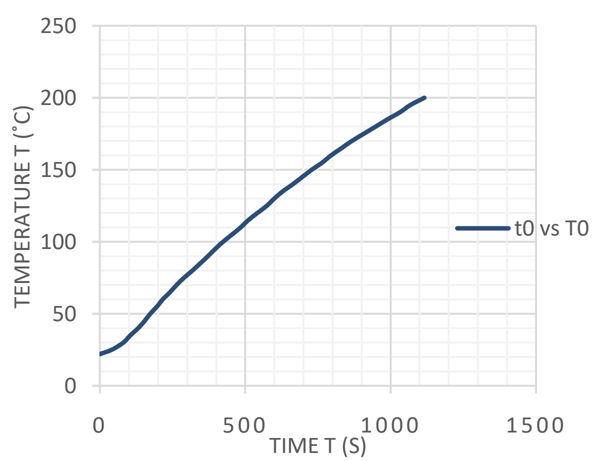

Figure 4a: graph of temperature versus time when empty

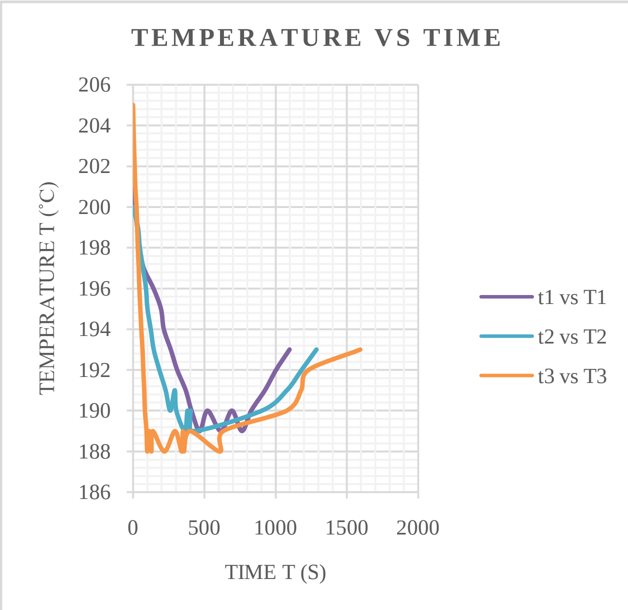

Figure 4b: Graph of temperature versus time for the three iterations

V. CONCLUSION

A roasting machine was designed, developed and fabricated. The machine has shown to be a simple to operate and maintained without the need for special training, thus, the operation and maintenance of the machine performance and compactness will make it acceptable and adaptable to the small and medium scale industry for roasting operations. Also, the roasting machine was efficient and cost worthy considering the reduced stress, fast roasting time, hygienic condition and environmentally friendliness among others.

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