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DESIGN ANALYSIS OF A CASSAVA MASH ROASTER

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Abstract

This paper highlights the design concept of a cassava mash roaster with the objectives of obtaining minimal power requirement and optimum heat energy conservation. The designed roaster consists a roasting chamber, rotating paddles, heat source, frame, electric motor, belt drive and a planetary gear mechanism. In designing the machine, factors such as ease of use, portability, heat energy conservation, and quality of gari were considered. Design results obtained such as volumetric capacity, heat energy requirement, power requirement, operating speed, estimated time of frying, and machine throughput are $0.1208m^3$, 20.961kW, 3.16Hp, 11.48rpm, 2hours and 91.14kg/h *respectively. An approximate value of 5.15kg of charcoal was also calculated to roast 182.28kg of cassava mash for 2 hours. Compared with existing gari roasters, it was found that the designed roaster has a higher throughput, smaller roasting time and smaller heat energy requirement.*

Keywords: Design, Cassava Mash, Roaster.

Introduction

Nigeria is the largest producer of cassava in the world. Cassava plays a particularly important role in the agriculture of developing countries, especially in sub-Saharan Africa. It is a food security crop which serves both as subsistence and cash crop to poor resource farmers. Cassava tubers and the various products hold an important position in Nigerian economy and also in its gross domestic product. The Food and Agriculture Organization (FAO) estimated as at year 2000 that cassava production was approximately 34 million (FAO, 2004).

Cassava roots can be processed into several different products, which include gari, flour, bread and starch. Processing provides smallholder cassava producers with additional market opportunities, beyond simply selling the fresh roots. Once they have invested in suitable equipment, processing enables smallholders to increase their incomes, since they can demand a higher price for the value-added processed products (James et al, 2012).

In terms of number of consumers, the most important and by far, the most common processed foods from cassava are farinha de mandioca originated in Brazil and gari in West and Central Africa. Gari as well as farinha has a scale of processing that ranges from 0.2 to 5 metric tons of roots per day for individual family units and small-to-medium-scale village processors to 50 to 100 metric tons per day for large industrial processors (Odigboh and Ahmed, 1984).

In many developing countries of the world, cassava’s toasted granules (Gari), has become an important staple food for many households. In Nigeria, Gari processing firms occupy a substantial portion of small and medium enterprises (SMEs) that has contributed significantly to national economic growth (Oluleye et al, 2007).

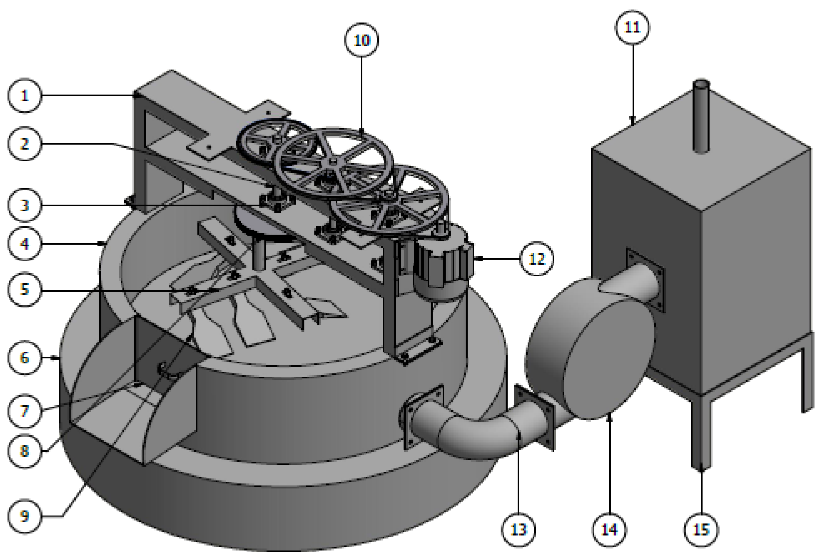
Despite some impressive technological achievements through development of new machinery and equipment, cassava processing still continue to present daunting challenges because the production level of these processors are either cottage or small-scale. This level is characterized by low level of technology use and poor management leading to low productivity. Notwithstanding the various improvements so far recorded in terms of technology, processing cassava into *gari* is still carried out using traditional methods carried out mostly by women (Taiwo and Fasoyiro, 2015; Adenuga and John, 2014).

The most critical unit operation that determines the quality of the final product in gari production is the roasting operation. Gari is produced by roasting the cassava mash in a heated pan or trough with continuous mixing of the mash until they are cooked and dried. It has been quite difficult to mechanize this operation correctly and rightly because this operation was not well understood by many designers and manufacturers (Igbeka, 1995). Most existing cassava mash roasters or fryers use horizontal shaft drive mechanism with rotating paddles for turning the cassava mash while frying. They also use electric heating source for frying. This method has not been energy efficient and also results in higher cost of gari production incurred through electric power supply. This study was aimed at designing a cassava mash or gari roaster using a planetary gear drive and minimal heat energy to produce gari at a minimal cost.

2.0 Methodology

2.1 Conceptual Drawing and Components of the Machine

The engineering drawing of the cassava mash roaster was developed using Autodesk Inventor 2015. Figs. 1 and 2 show the isometric and exploded views of the machine.



PARTS LIST		
ITEM	QTY	PART NUMBER
1	1	UPPER FRAME
2	1	POWER TRANSMISSION SHAFT
3	6	FLANGE BEARING
4	1	ROASTING CHAMBER
5	3	ROTATING PADDLES CARRIER
6	1	FIRE RESISTANT CLAY BASE
7	1	DISCHARGE CONTROL GATE
8	1	PLANETARY GEAR
9	6	ROTATING PADDLES
10	3	GROOVED PULLEY
11	1	CHARCOAL BOX
12	1	ELECTRIC MOTOR
13	1	HOT AIR CONDUIT PIPE
14	1	SUCTION FAN
15	1	CHARCOAL BOX FRAME

Fig. 1: Isometric view of the cassava mash roaster

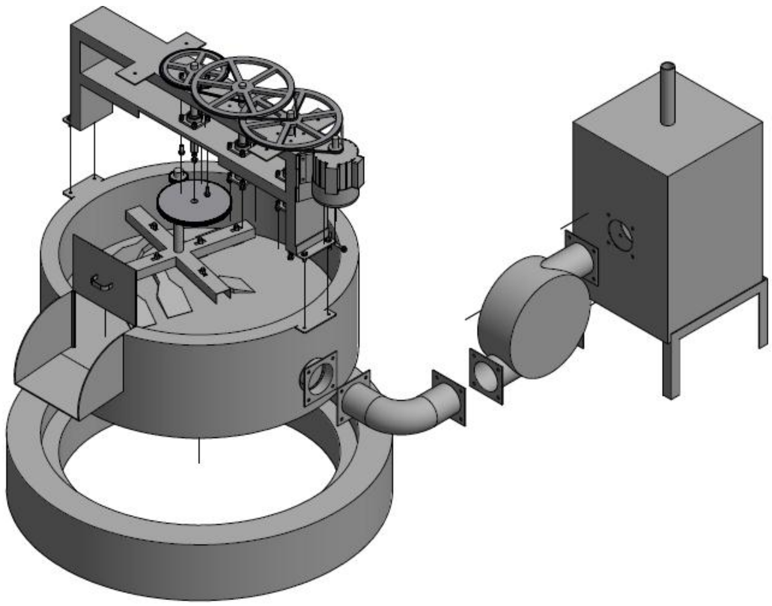


Fig. 2: Exploded view of the cassava mash roaster

The component parts of the machine are described as follows:

1. Frame: It provides support for the major components such as transmission shafts, belt and gear drives, paddles and electric motor.
2. Power Transmission Shaft: There are three power transmission shafts which transmit power from electric motor to the rotating paddles.
3. Flange Bearing: There are six flange bearings which provide support for the three transmission shafts.
4. Roasting Chamber: This is where roasting of cassava mash is done. The chamber, made of stainless steel, is double-walled with lagging material in between to prevent heat loss. Heat is applied to the base of the chamber while the rotating paddles on the chamber turn and mix the mash during roasting. The chamber is mounted on a heat resistant clay base.
5. Rotating Paddles Carrier: The carrier is welded to the main drive shaft and it also supports the rotating paddles
6. Heat Resistant Clay Base: This is made of heat resistant material (lateritic clay) for storing the hot air sucked from the heat source (charcoal box). The roasting chamber is mounted on the clay base.

7. Discharge Control Gate: This controls the discharge of the roasted gari from the roasting chamber
8. Planetary Gear Drive: The gear mechanism consists of a small pinion gear which is in mesh with a larger gear directly coupled to the third power transmission shaft. The pinion gear shaft drives the paddle and paddle carrier assembly in a planetary motion along the circumference of the roasting chamber.
9. Rotating Paddles: There are six inclined rotating paddles made of aluminum which do the work of sweeping, turning and mixing the cassava mash during roasting.
10. Grooved Pulley: Three large and three small pulleys were used to step down the speed from the electric motor to the main drive shaft which carries the rotating paddles.
11. Charcoal Box: It is the heat source for roasting. The heat generated from the charcoal box is sucked by a fan through a conduit pipe into the roasting chamber.

2.2 Design Considerations

In designing the machine, the following factors were considered:

i. Size and portability: The size of the machine was chosen such that it can be moved from one place to another and not be too bulky. Thus the diameter of the frying chamber was designed to be 800mm

ii. Heat energy conservation: In order to reduce heat loss and minimize the exposure of the machine operator to heat emission, the body of the machine was designed to be double-walled with lagging material in between

iii. Speed: Too high speed will result in dried but not well cooked gari while too low speed will result in burnt and caked gari. The speed at which gari is turned in traditional gari roasters was carefully studied and used in designing optimum speed for roasting.

iv. Power requirement: The power requirement by the machine was considered so as to get the optimum power that will drive the rotating paddles and prevent power wastage.

2.3 Design Calculation

A. Determination of the Volumetric Capacity of the Roasting Chamber

The volume of the roasting chamber is given as:

$$V = \pi r^2 h \qquad \text{……………………….. (1)}$$

Where V = Volume of the chamber, r = radius and h = depth of the roasting chamber

r = 620mm = 0.62m, h = 300mm = 0.3m

$$V = \frac{22}{7} \times 0.62^2 \times 0.3$$

$$V = 0.3624m^3$$

The effective capacity will be one third of the volume of the cylinder since the loading of the roasting chamber should not be more than height of the rotating paddle. Therefore

Effective Capacity, $V_e = \frac{1}{3} \times 0.3624 = 0.1208m^3$

B. Determination of Power Requirement

Power Required = $\frac{2\pi NT}{60}$ ……………………………….. (2)

Where N = speed of rotating paddles, T = Torque required

$$T = W_T \times r \qquad \text{………………………………..(3)}$$

Where W_T = Total rotating weight, and r = radius of the roasting chamber

$$W_T = W_p + W_s + W_c \qquad \text{………………………………..(4)}$$

Where W_p = weight of the paddles, W_s = Weight of shaft, W_c = Weight of cassava mash

Weight of 1 paddle made of stainless steel = ρVg ………………………………..(5)

Where $\rho =$ density of aluminum = 2700kg/m^3 (Kissell and Ferry, 2002), V= volume of paddle material = 0.0000974m^3 (based on dimensions from design drawing), g = acceleration due to gravity = 10m/s^2

Weight of 1 paddle = $2700 \times 0.0000974 \times 10$ = 2.63N

W_p = 2.63 x 6 paddles = 15.78N

Working with a shaft of diameter 30mm (0.03m), length 450mm made of stainless steel of density 8000kg/m^3

Weight of shaft, W_s = ρVg = $8000 \times \frac{22}{7} \times 0.03^2 \times 0.450 \times 10$ = 101.83N

Weight of Cassava Mash, W_c = ρVg ………………………………..(6)

Where $\rho =$ density of cassava mash = 1509kg/m^3 (Gevaudan et al, 1989), V = effective volume of roasting chamber = $0.1208m^3$ and g = 10m/s^2

W_c = 1509 x 0.1208 x 10 = 1822.872N

Total rotating weight, W_T = 15.78 + 101.83+ 1822.87 = 1822.87N

From equation (3), torque required, $T = W_T \times r$ = 1822.87 x 0.62

T = 1130.179Nm

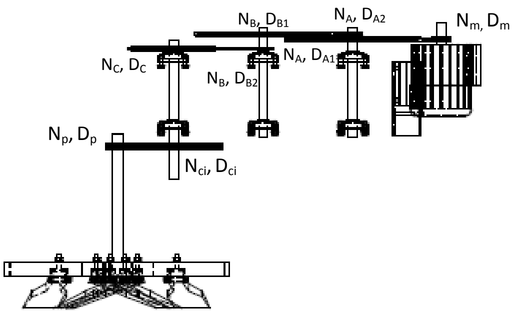
From equation (2), Power Requirement, P = $\frac{2\pi NT}{60}$

Where N = assumed paddle rotating speed = 20 rpm (considering the range of speed recommended for gari roasting from previous works of Olagoke et al (2014) and Odigbo and Ahmed (1984).

$$= \frac{2 \times \frac{22}{7} \times 20 \times 1130.179}{60}$$

= 2367.994W ≈ 2.37kW ≈ 3.16Hp

C. Determination of Operating Speed



N_m = Input speed of electric motor
D_m = Diameter of electric motor pulley
N_A = input speed of transmission shaft A
D_{A1} = Input pulley diameter of transmission shaft A
D_{A2} = Output pulley diameter of transmission shaft A
N_B = input speed of transmission shaft B
D_{B1} = Input pulley diameter of transmission shaft B
D_{B2} = Output pulley diameter of transmission shaft B
N_C = Input speed of transmission shaft C
D_C = Input pulley diameter of transmission shaft C
N_{Ci} = Output pulley diameter of transmission shaft C
D_{Ci} = Pitch diameter of input gear on transmission shaft C
N_p = Final speed of gear on paddle shaft
D_p = Pitch diameter of gear on paddle shaft

D_m = 80mm = 0.08m, D_{A1} = 250mm = 0.25m, D_{A2} = 80mm = 0.08m, D_{B1} = 250mm = 0.25m, D_{B2} = 80mm = 0.08m, D_C = 250mm = 0.25m, D_i = 60mm = 0.06m, D_o = 250mm = 0.25m.

N_m = speed of electric motor (for 3hp motor, speed = 1460rpm), D_m = 80mm = 0.08m, D_A = 250mm = 0.25m

$$N_A = \frac{N_m D_m}{D_{A1}} = \frac{1460 \times 0.08}{0.25} = 467.2\text{rpm}$$

$$N_B = \frac{N_A D_{A2}}{D_{B1}} = \frac{390 \times 0.08}{0.25} = 150\text{rpm}$$

$$N_C = \frac{N_B D_{B2}}{D_C} = \frac{150 \times 0.08}{0.25} = 47.84\text{rpm}$$

$$N_o = \frac{N_i D_i}{D_o} = \frac{47.84 \times 0.06}{0.25} = 11.48\text{rpm}$$

D. Determination of Heat Energy Required for Roasting

The heat energy required for roasting cassava mash within range of temperature of 60^0C is given as:

$$Q = mc\Delta T \qquad \text{..................................(7)}$$

Where m = mass of cassava mash in the roasting chamber = 182.287kg (from calculation above), c = specific heat capacity of cassava mash = 1.45KJ/kg^{0}C (Nwabanne, 2009), and ΔT = temperature range for roasting = 60^0C

$Q = mc\Delta T = 182.287 \times 1.45 \times 60 = 15858.969$KJ

E. Estimation of Time required for Roasting

Time required for roasting, t can be obtained from the equation:

$$\frac{\Delta Q}{\Delta t} = \frac{KA\Delta T}{L} \quad \text{.................................(8)}$$

Where $\frac{\Delta Q}{\Delta t}$ = Heat Energy Transfer Rate, K = thermal conductivity of cassava mash = 0.24W/mK (Oyerinde and Olalusi, 2011), ΔT = temperature range = 60^0C = 333K, L = thickness of cassava mash in the roasting chamber = 1/3 of depth of roasting chamber = 0.1m and A = total surface area of the cassava mash in the roasting chamber, $\Delta t =$ roasting time

A = $2\pi rh + 2\pi r^2$ ....(9)

Where r = radius of roasting chamber = 0.62m, h = total depth covered by cassava mash = 0.1m

A = $2 \times \frac{22}{7} \times 0.62 \times 0.1 + 2 \times \frac{22}{7} \times 0.62^2$ = 0.389 + 2.2628 = 2.657m^2

$$\frac{\Delta Q}{\Delta t} = \frac{0.24 \times 2.657 \times 333}{0.1} = 2123.4744\text{J/s}$$

$$\Delta t = \frac{\Delta Q}{2123.4744} = \frac{1.5858 \times 10^7}{2123.4744} = 7467.9497s = 2.0244\text{hr} \approx 2\text{hours}$$

F. Determination of Total Heat Energy Requirement

Total Heat energy requirement, $Q_T = Q_1 + Q_2 + Q_3$ ....(10)

Where Q_1 = heat loss by conduction through conduit pipe = $\frac{K_p A_p \Delta T}{L_p}$ ....(11)

Q_2 = convective heat loss through air flow = $hA_p \Delta T$ ....(12)

Q_3 = heat required for roasting = 2123.4744W

Where K_p = thermal conductivity of conduit pipe (mild steel) = 50W/mK (Long and Sayma, 2009), L_p= Length of conduit pipe = 1001mm ≈ 1m, A_p = surface area of the conduit pipe = $2\pi r L_p = 2\times\frac{22}{7}\times 0.15\times 1 = 0.943m^2$,

h = convective heat loss by air = 10W/m^{2}K (Engineers Edge, 2016), K_s = thermal conductivity of roasting chamber (stainless steel) = 14W/mK (Long and Sayma, 2009), A_s = surface area of the roasting chamber = $2\pi rh+\pi r^2$= $2\times\frac{22}{7}\times 0.62\times 0.3+\frac{22}{7}\times 0.3^2$ = 4.402m^2, Ls = thickness of the roasting chamber plate = 5mm= 0.005m,

$$Q_1 = \frac{K_p A_p \Delta T}{L_p} = \frac{50\times 0.943\times 333}{1} = 15698W$$

$Q_2 = hA_p\Delta T$ = 10 x 0.943 x 333 = 3140.19W

Total heat energy, Q_T = (15698 + 3140.19 +2123.4744)W

= 20961.6644W = 20.961KW

G. Determination of Quantity of Charcoal Needed for Roasting

Total Energy (in Watts) required by the system = 20.961KW. For 2 hour operation, energy required in Joules = 20.961 x 10^3 x 2 x 3600 = 150.923MJ

The energy present in 1kg of charcoal is 29.3MJ (Hulscher, 2016). Therefore, if 29.3MJ of energy can be obtained from 1kg of coal, then 150.923MJ of energy can be obtained from

$$\frac{1\times 150.923}{29.3}kg$$

$$\frac{1\times 0.145}{29.3}kg \approx 5.15\text{kg}$$

H. Estimation of Expected Throughput of the Machine

Machine throughput = $\frac{Quantity\ of\ cassava\ mash\ roasted\ (kg)}{Total\ time\ taken\ (hr)}$ ……………………….(13)

$= \frac{182.28}{2}$ = 91.14kg/hr

3.0 Result and Discussion

The cassava mash roaster was designed using belt and planetary gear mechanism. The size of the component parts were chosen by considering the portability, size and ergonomic factors. The results of the design calculations shows that the machine has a volumetric capacity of 0.1208m^3 which can accommodate 182.28kg of cassava mash. From the design calculation, the speed of operation obtained was 11.48rpm with input from a 3hp, 1460rpm electric motor. Though this speed is less than the speed range of 20 - 40rpm recommended for roasting as reported by Olagoke et al (2014) and Odigbo and Ahmed (1984), the diameter of the grooved pulleys can be adjusted to attain optimum speed. A high throughput of 91.14kg/hr was obtained. This value is higher compared to that obtained by Akinnuli et al (2015) and Ikechukwu and Maduabum (2012). The estimated time of roasting 182.28kg of cassava mash was calculated to be approximately 2 hours. This time is far less than that obtained by Olagoke et al (2014). The design results also showed the machine will be economical as it requires only 5.15kg of charcoal to roast 182.28kg (approximately 4bags) of cassava mash.

4.0 Conclusion

A cassava mash roaster was designed. The roaster uses planetary gear mechanism together with belt drives for speed reduction. Design results obtained such as volumetric capacity, heat energy requirement, power requirement, operating speed, estimated time of frying, and machine throughput are $0.1208m^3$, 20.961kW, 3.16Hp, 11.48rpm, 2hours and 91.14kg/hr respectively. Compared with existing gari roasters, it was found that the designed roaster has a higher throughput, smaller roasting time and smaller heat energy requirement.

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