Design of a Groundnut Kernel Roastmaster

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Abstract

Roasting in groundnut kernel processing provides a sustained value addition as heat instability during roasting results in low texture and crispy of roasted kernels. This however, makes roasting a difficult task without ready solution in groundnut kernel processing. The local groundnut vendors make use of small open sand-bath pan roasters to roast the kernels and these roasters are not very efficient. Apart from exposing the kernels to unhygienic conditions, they produce uneven roast due to uneven temperature distribution. It is a tedious process involving hand stirring and exposure to heat from most commonly used fuel such as wood, charcoal, kerosene and gas. Electrically powered groundnut roasters exist but most times in combination with extractor. This adds generally to the cost of the machines and thus, makes them unaffordable, sophisticated in operation for SMEs and street groundnut vendors. In view of the associated problems and difficulties, a groundnut kernel roastmaster is designed. The roaster has a percentage heat utilization of 0.83 with throughput of 56kg/hr.

Keywords: Design, Groundnut kernel, Roastmaster, Roasting, Percentage heat utilized

1. INTRODUCTION

Groundnuts, also called peanuts are stable plant food with proven sufficient quantity of carbohydrates, dietary protein, essential minerals, vitamins and healthy fats. In Nigeria, they are often roasted and eaten mixed with banana, garden egg, cucumber, roasted corn and, or as a dip-in, in the form of peanut butter with garden egg, bitter kola, coconut etc. In urban and sub-urban areas of Nigeria, roasted groundnuts vendors are a common sight. This is because roasted groundnuts are a popular snack and there is a good market. Accordingly, Adeyeye (2010), the nutty and agreeable flavour of roasted groundnut kernels make them particularly a suitable vegetable food. Lee and Resurreccion (2006); McDaniel (2012) emphasized that roasting provides sustained value addition to the groundnut kernels. Hence, proper roasting is critical to flavour and texture development as well as nutritional content of the kernels. Dry-roasted peanut kernels composed of sufficient levels of mono-unsaturated fatty acids and its consumption may help to lower bad cholesterol level in the blood thus preventing risk of coronary artery disease or stroke (MayoClinic .com). However, roasting reduces moisture content and modifies the internal microstructure of groundnut kernels to create the characteristic crunchy and crispy texture of roasted kernels, thereby causing a reduction in the level of aflatoxins-a poison produced by fungus in groundnut kernels (Ogunsanwo et al., 2004). Peanut kernels contain highly concentrations of poly-phenolic antioxidants and roasting releases these poly phenolic antioxidants primarily p-coumaric acid and hydroxybenzoic acid from their cellular matrix (Talcott et al., 2005; McDaniel, 2012). These compounds have been thought to reduce the risk of stomach cancer by limiting formations of carcinogenic nitrosamines in the stomach. Okegbile et al., (2014), maintained that a better oil extraction would be achieved if proper roasting is sustained, as heat instability results in low nutritional value of the roasted groundnut kernels, low quantity/quality of oil with oil colour changed to black in severe cases. This, however makes roasting a difficult task without ready solution in peanuts processing. The local groundnut processors make use of small open sand-bath pan roasters to roast the kernels. Accordingly, Olatunde (2014), these roasters are not very efficient. Apart from exposing the kernels to unhygienic conditions, they produce uneven roast due to uneven temperature distribution. It is a tedious process involving hand stirring and exposure to heat from most commonly used fuel such as wood, charcoal, kerosene and gas. Thus, electrically powered groundnut roasters exist but most times in combination with extractor as in Okegbile et al (2014). This adds generally to the cost of these machines and thus, makes them unaffordable, sophisticated in operation for street groundnut vendors as well as SMEs in roasted peanuts business. Therefore, this research work is devoted to the design of a groundnut kernel roastmaster that is efficient, user and cost friendly for SMEs.

2. METHODOLOGY

2.1 Machine Description

The groundnut kernel roastmaster consists of the following components: reducer gear electric motor, V-belt, solid shaft, pulleys, collar bearing, roasting cylinder, heater shell, and structural stand. The input speed, gear ratio and power of the reducer gear electric motor are 1440rpm, 10:1 and 1.5hp respectively. The solid shaft is made from a stainless steel rod of diameter 30mm, length 300mm with a pulley of 200mm diameter attached to it. Note, the choice for the shaft length is informed by the need to minimize heat transfer by conduction to its bearing and pulley. The roasting cylinder inclined at 35^o (angle greater than the dynamic angle of repose of groundnut kernel on steel sheet) is made from 1.5mm thick stainless sheet whereas the heater shell consists of a double wall cylinder made from a 2mm mild steel sheet. The silicone heater tape of 20W (approx.) is wound eccentrically round the inner linings of a cylinder to form the heater shell. The supporting frame is made from a 40mm * 40mm angle iron. See the isometric view of groundnut kernel roastmaster as shown in Fig. 1 and 2 respectively.

2.2 Design Consideration

Since this research work was devoted to the design of a groundnut kernel roastmaster that is efficient, user and cost friendly for SMEs, therefore, local, durable but affordable materials were considered in its design.

2.3 Design Analysis

The major designs were on the roasting cylinder, power requirement, pulleys, heater capacity, belt drive, and collar bearing.

2.3.1 Roasting Cylinder

The groundnut kernel roastmaster is expected to have a targeted throughput capacity of 56kg/hr (14kg per batch). In calculating for the volume occupied by the groundnuts in the roasting cylinder, we use the true density of groundnuts as 937.70kg/m^3 at 8% dry basis moisture content as recorded by Firouzi et al.(2009)

Groundnuts occupied volume, $V_{goc} = \frac{W_{tg}}{\rho_{tg}}$ ------------------ (1)

Where V_{goc} = groundnuts occupied volume (m^3), W_{tg} = batch output (kg) and ρ_{tg} = true density (kg/m^3). Hence,

Groundnuts occupied volume = $\frac{14}{937.7}$ = **0.01493m^3**

Assume volume of air space = 10%V_{goc}

Thus, Volume of the roasting cylinder, V_{rc} = 0.01493 + (0.10 * 0.01493) = **0.01642m³**

2.3.2 Length of the Roasting Cylinder

Based on the cylindrical nature of the roasting unit, its length is determined with the empirical relation given below:

Volume of the roasting cylinder, $V_{rc} = \pi\frac{d_{rc}^2 h_{rc}}{4}$ ------- (2)

Thus, $h_{rc} = \frac{4V_{rc}}{\pi d_{rc}^2}$ = -- (3)

Where h_{rc} = length of the roasting cylinder (m), d_{rc} = diameter of the roasting cylinder (m) and V_{rc} = volume of the roasting cylinder (m³)

Let, d_{rc} = 0.45m; $h_{rc} = \frac{4 * 0.01642}{\pi * 0.45^2}$ = **0.103m**

2.3.3 Thickness of the Roasting Cylinder

The roasting cylinder is classified as an open end vessel with only the circumferential or hoop stress induced by the stirring/rotating action of the shaft. This circumferential or hoop stress acts in a direction tangential to the circumference of the roasting cylinder and its thickness is determined using Barlow's equation (Lingaiah, 1994)

$t = \frac{p \times d}{2\sigma}$ -- (4)

Where t = thickness of the roasting cylinder (m), p = the shaft induced pressure = stirring/internal pressure of the roasting cylinder (Mpa), d = internal diameter of the roasting cylinder (m), and σ = circumferential or hoop stress on the area of the roasting cylinder wall.

Let, p = 0.0015Mpa, d = 0.45m, σ = 0.3Mpa

$t = \frac{0.0015 * 0.45}{2 * 0.3}$ = **0.001125m** and 1.5mm thick stainless steel plate is selected for the fabrication of roasting cylinder

2.3.4 Torque Developed

The torque (T_s) which is developed due to shaft induced pressure on the roasting cylinder is approximated by the empirical equation below:

$T_s = \frac{\pi P_s d^3}{8}$ -- (5)

Where T_s = torque developed by the driven shaft (Nm), P_s= the shaft induced pressure = stirring/internal pressure of the roasting cylinder (Mpa), d = internal diameter of the roasting cylinder (m).

Let, P_s = 0.0015Mpa, d = 0.45m

$T_s = \frac{\pi * 0.0015 * 10^6 * 0.45^3}{8}$ = **54Nm**

Note, from circular motion, this torque developed by the driven shaft is also approximated by the equation given below:

$T_s = \frac{M\omega^2 d^2}{4}$ -- (6)

Where T_s = torque developed by the driven shaft (Nm), M = the resultant weight (kg), ω = angular speed of the roasting cylinder (rad/s), d = internal diameter of the roasting cylinder (m).

Hence, from Eq. (6) above,

$\omega = \sqrt{\frac{4T_s}{Md^2}}$ -- (7)

With T_s = 54Nm, d = 0.45m, M = the resultant weight (kg) = weight of the roasting cylinder (kg) + weight of the batch output groundnut kernel (kg).

The computational equation for theoretical weight of stainless steel sheet is given by SMC (2013) as:

Weight (kg) = Thickness (mm) * Width (m) * Length (m) * Density ---------------------------- (8)

By rearrangement of Eq. (8) above, bearing in mind that the product Width (m) * Length (m) is equal to area (m²), we have:

$\frac{\text{Weight (kg)}}{\text{Width (m)} * \text{Length (m)}} = \text{Wt. kg/m}^2$ = Thickness (mm) * Density -- (9)

Table-1: Weight Table of Stainless Steel Sheet

Thickness (mm)	Wt. kg/m²
0.50	4.0
0.70	5.6
0.90	7.2
1.00	8
1.20	10
1.50	12
2.00	16

Hence, from weight table of stainless steel sheet (SMC, 2013) presented above, the density of stainless steel sheet is calculated thus, the density of stainless steel sheet = $\frac{12}{0.0015}$ = **8000kg/m³**

Now, weight of the roasting cylinder (Wt_{rc}) is approximated by the empirical equation below:

$Wt_{rc} = \frac{A_{rc}\rho V_{rc}}{A_{ss}}$ -- (10)

Where Wt_{rc} = weight of the roasting cylinder (kg), A_{rc} = area of the roasting cylinder (m²), ρ = density of stainless steel sheet (kg/m³), V_{rc} = volume of the roasting cylinder (m³), A_{ss} = area of stainless steel sheet (m²).

With $A_{rc} = 2\pi r h_{rc} = 2\pi*(\frac{0.45}{2})*0.103 = 0.1456\text{m}^2$, ρ = 8000kg/m³, V_{rc} = 0.01642m³, A_{ss} (for 304, 430 grade) = (4' * 8') = (1.219 * 2.438) = 2.9719m²

$Wt_{rc} = \frac{0.1456*8000*0.01642}{2.9719}$ = **6.436kg**

Thus, the resultant weight (M) = 6.436 +14 = **20.436kg**

And from Eq. (7), $\omega = \sqrt{\frac{4*54}{20.436*0.45^2}}$ = **7.22 rad/s**

2.3.5 Power Requirement

The power developed by the driven shaft which is connected to the roasting cylinder is given by the relationship below:

$P_{ws} = \omega T_s$ -- (11)

Where P_{ws} = power developed by the driven shaft (watts), ω = angular speed of the roasting cylinder (rad/s), T_s = torque developed by the driven shaft (Nm).

With ω = 7.22 rad/s, T_s = 54Nm and from Eq. (11), P_{ws} = 389.88 **(0.39kW)**

Hence, the power developed by the geared electric motor at constant torque (T_s) is obtained from the relationship below:

$\frac{P_{ws}}{P_{wm}} = \frac{D_2}{D_1}$ --- (12)

Where P_{ws} = power developed by the driven shaft (kW), P_{wm} = power developed by the driver shaft (kW), D_2 =

driver pulley diameter (mm), D_1= driven pulley diameter (mm)

Let, P_{ws} = 0.39kW, D_2 = 100mm, D_1 = 200mm and from Eq. (12) P_{wm} = **0.78kW**

2.3.6 Geared Electric Motor Selection

For moderate shaft induced pressure under intermittent roasting operation per day (i.e. a batch roasting), a 1.25 service factor is selected (Fenner, 2012).

Hence, the designed power for geared electric motor = 1.25 x 0.78kW = **0.975kW** (1.3hp). Thus, a **1.5hp** geared electric motor with gear ratio **10:1**is ideal for this design.

2.3.7 Determination of Pulley Speeds and Centre Distance

The driver pulley diameter, speed and that of the driven are related as shown below:

$$\frac{\omega_1}{\omega_2} = \frac{D_2}{D_1} \text{ -- (13)}$$

Where ω_1= angular speed of the driven (rad/s), ω_2 = angular speed of the driver (rad/s), D_2 = driver pulley diameter (mm), D_1= driven pulley diameter (mm)

With ω_1 = 7.22rad/s, D_1 = 200mm, D_2 = 100mm, and from Eq. (13), ω_2 = **14.44rad/s => N_2 = 137.87rpm**

Also, the centre distance (c) between two adjacent pulleys is determined using the relation given by Khurmi and Gupta (2005)

$$c = \frac{d_1+d_2}{2} + d_1 \text{ -- (14)}$$

$$c = \frac{100+200}{2} + 100 = \mathbf{250mm}$$

2.3.8 Heater Capacity

The heating unit consists of silicon tape heater wound round the inner linings of a cylinder to form the heating shell. To determine the heat transfer rate from the heating shell and that required to roast the groundnut kernels, the equations below adapted from Iloeje (2005) and Eastop and McConkey (1993) are respectively applied:

$$\dot{Q} = \frac{T_R - T_r}{R_t} \text{ --- (15)}$$

$$Q^{\cdot}_{gk} = \frac{W_{tg} C_{gk} (T_r - T_a)}{t_r} \text{ --- (16)}$$

$$R_t = R_{air\,film} + R_{Silicone\ heater\ tape} = \frac{1}{2\pi tLh} + \frac{\ln(r_o/r_i)}{2\pi kL} \text{ --- (17)}$$

Where $\dot{Q}$= heat transfer rate of the heater shell (W), $Q^{\cdot}_{gk}$ = heat required to roast groundnut kernel (W), T_R = temperature of the heater shell (°C), T_r = the roasting temperature/inside temperature of the roasting cylinder (°C), T_a = room temperature (°C), C_{gk} = specific heat capacity of groundnut kernel (kj/kg°k), R_t = the total thermal resistance to heat flow (°K/W), W_{tg} = weight of the target output of groundnut kernel (kg), t_r = roasting time (s), r_o= radius of the heater shell (m), r_i = radius of the roasting cylinder (m), t = thickness of the air gap, L = length of the cylinder (m), h = heat transfer coefficient of air (W/m² °K), k = thermal conductivity of silicone heater tape (W/m °K)

Note, from equation 15 and 16 above, the energy balance of the system becomes

$$\dot{Q} = Q^{\cdot}_{gk} + Q^{\cdot}_{loss} \text{ --- (18)}$$

With, T_R = 250 °C, T_r = 180 °C, T_a = 30 °C, C_{gk} = 1.9 kj/kg°C (Bitra et al, 2010), W_{tg} = 14 kg, t_r = 15 minutes, t = 0.03m, r_o = 0.245 m, r_i = 0.225 m, L = 0.103 m, h = 15 W/m² °K, k = 1.30 W/m °K

R_t = **3.58 °K/W**, $\dot{Q}$ = **19.55W**, $Q^{\cdot}_{gk}$ = **16.24W**, $Q^{\cdot}_{loss}$ = **3.31W**

2.3.9 Belt Drive

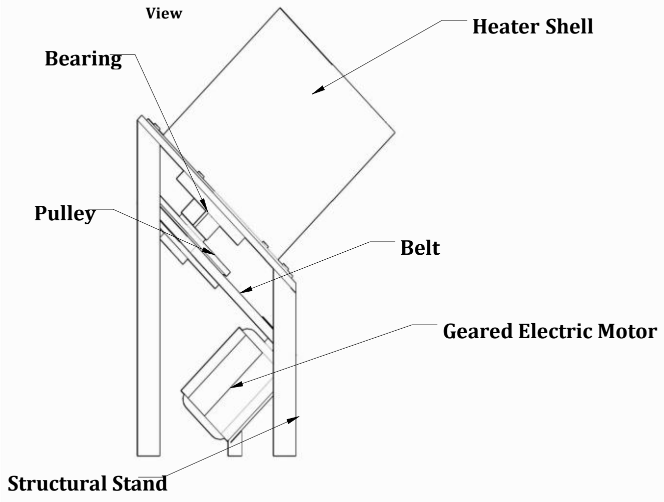

Fig. 1 Side View

Belt length (L) is determined using the expression given by Khurmi and Gupta (2005)

$$L = \frac{\pi(d_1+d_2)}{2} + 2c + \frac{(d_1-d_2)^2}{4c} \text{ ---------------------------------- } (19)$$

$$L = \frac{\pi(100+200)}{2} + 2(250) + \frac{(100-200)^2}{4(250)} = \mathbf{961mm}$$

The angle of contact of belt on the motor pulley (θ)

$$\theta = (180 - 2\alpha)\frac{\pi}{180} \text{ --- } (20)$$

Where, sine$\alpha = \frac{d_2-d_1}{c} = \frac{200-100}{250} = 0.4$

Hence, $\alpha = 23.58^o$

Thus, $\theta = \{180 - 2(23.58)\}\frac{\pi}{180} =$ **2.32 rad**

Now, based on the rotating speed of geared motor (137.87rpm), design power (1.5hp = 1.12kw) and minimal pulley diameter (100mm) respectively, from standard graph (Sanok, 2012) type A (V-belt) is selected.

2.3.10 Collar Bearing

In designing collar bearings, it is assumed that the pressure is distributed uniformly over the bearing surface.

The outer diameter of the collar is usually taken as 1.4 to 1.8 times the inner diameter of the collar i.e. diameter of the shaft (Khurmi and Gupta, 2005)

Hence, the bearing pressure (p_b) $= \frac{W}{A}$ -------------------- (21)

And the expression for total frictional torque (T) is given by Khurmi and Gupta (2005)

$$T = \frac{2\mu W}{3}\left(\frac{R^3-r^3}{R^2-r^2}\right) \text{ --- } (22)$$

Where, p_b = bearing pressure, W = load transmitted over the bearing surface, A = cross-sectional area of the bearing surface, R = outer radius of the collar, r = inner radius of the collar, μ = coefficient of friction, n = number of collars.

Let, W = 20.436 * 9.81 = 200.477N, p_b = 1.5 x 10^3N/m^2, T = 2.0Nm, μ = 0.5 and R = 1.6r

Then, from equation (22), r = **0.0151m** (15mm), R = **0.024m** (24mm), and also from equation (21), A = 0.13365m^2 = $n\pi 100\,(R^2 - r^2)$

Hence, n = **1.22 ~2**

2.3.11 Roaster Efficiency

The efficiency of the groundnut kernel roastmaster is measured in terms of energy utilized in roasting. Hence, from the energy balance equation, the percentage heat utilized by the groundnut kernel roastmaster is given by the equation below:

$$PHU = \frac{\text{useful output heat}}{\text{Input heat}} = \frac{\dot{Q}_{gk}}{\dot{Q}} \text{ ---------------------------------- } (23)$$

With $\dot{Q}_{gk}$ = 16.24, $\dot{Q}$ = 19.55, PHU $= \frac{16.24}{19.55} =$ **0.83**

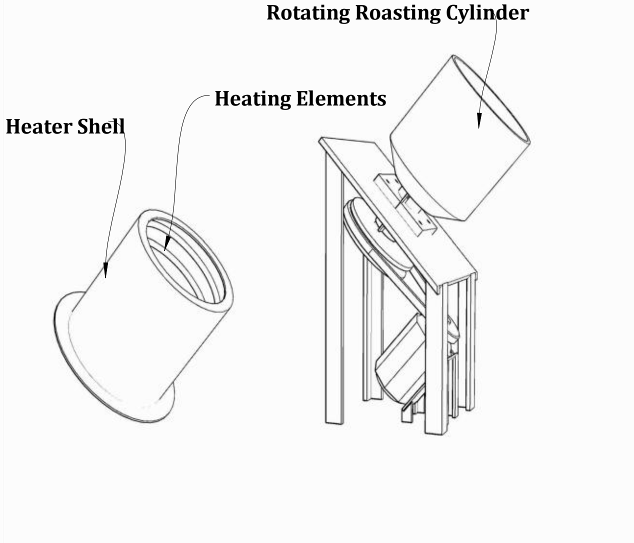

Fig.2 Isometric View

3. CONCLUSION

Groundnuts are an excellent and affordable source of vital nutrients to the human body such as proteins, carbohydrates, lipids, vitamins, minerals and fiber. Roasting of groundnut kernels seemed to be a difficult task. Manually operated method such as open sand-bath pan roasting has been adjudged unhygienic, tedious and inefficient. To culminate this associated problems and difficulties in the manual method, groundnut kernel roastmaster was designed. The choice of material, the power requirement and overall cost would be simply enough to encourage mass production; it is, therefore, recommended for both small and medium scale groundnut vendors.

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