

## Development of an improved groundnut oil kneading machine for women processors

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### Abstract:

Groundnut oil extraction in Nigeria suffer a lot of drudgery, the locally produced product suffers among which are low extraction capacity, unhygienic and time wastage although, several effort has been made on development of ground nut kneading machine. This work was an improved design of groundnut kneading machine carried out. To remedy the challenges faced by the existing machine, the components designed include the oil kneading container, the scrappers and the shaft. Based on the power requirement and the factor of safety, the prime mover was selected. The groundnut kneading machine was constructed using readily available and appropriate materials including mild steel sheet, medium carbon grade steel, stainless steel sheet, stainless steel flat bar and angle iron. Performance test was carried out to evaluate the performance of developed machine. The highest mean machine output capacity 19.93 kg/h was obtained at the combination of 60 °C temperature, three fingers and a speed of 350 rpm. These results show a remarkable improvement on the performance indices over the existing kneader designs and hence it recommended for small-scale groundnut oil extractor for optimum production.

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### 1. Introduction

Groundnut (*Arachis hypogaea* L), which is generally known as peanut, though locally called *Gyada* in the Hausa language, *Epa* in the Yoruba language, and *Guzhia* in the Nupe language, is nowadays an essential oilseed and food crop [1]. It is an important oilseed crop with an excellent protein source for the production of oil, fuel, and food [2]. It contains between 38 – 47 percent oil content [3]. During the production of oil, a considerable amount of over 50 % by- product is produced in comparison with starting material being groundnut cake. Groundnuts have important qualities such as oil, protein, fatty acid, and amino acid composition [4, 5]. Due to its high smoke point, the oil is ideal for high-temperature cooking with no burning. It is recognized for having a pleasant flavor and a subtle nutty scent [6].

Groundnut kneading is an essential step in the process of groundnut oil extraction, which is a significant industry in many developing countries [7]. The traditional method of kneading groundnuts involves manual labour, which is time-consuming and labour intensive. As a result, there has been a growing interest in the development of mechanized groundnut kneaders [8]. Groundnut oil extraction is a vital industry in many developing countries, with groundnut kneading being an essential step in the process. Traditionally, the process involves manual labour,

which is time-consuming and labor-intensive [9, 10]. As a result, there has been an increasing interest in the development of mechanized groundnut kneaders to improve efficiency and reduce labour costs. The design and fabrication of groundnut oil kneaders have been the subject of numerous studies. For instance, Maduako, *et al.* [11] designed and fabricated a motorized groundnut kneading machine.

Further addressing the laboriousness of the manual process, test findings showed considerable and significant kneading time savings. The amount of time needed to knead was reduced by 80 %, and the machine's throughput capacity was found to be 46.3 kg/h. Ibrahim [12] also modified an existing kneader at the Department of Agricultural Engineering Bayero University, Kano and results revealed that the efficiency of the machine was in the range of 66.38% to 71.40%. Ravi, *et al.* [13] redesigned a Kneader at the Department of Agricultural Engineering at Bayero University, Kano, and reported the highest extraction efficiency of 78.59 % with the *Manipintar* groundnut seed variety. A study by Lawan, *et al.* [14] developed a motorized groundnut kneading machine that reduced the time required for kneading by 70 %. The authors reported that the machine's throughput was approximately 10 kg/h. Adeyanju, *et al.* [15] developed an

integrated groundnut oil extraction machine that was capable of producing a higher-quality of groundnut paste.

Similarly, Alonge, et al. [16] developed a semi-automatic groundnut kneading machine that uses a mechanical system to reduce the time and effort required for kneading. The machine was designed with a variable speed control and a mixing drum that ensures even mixing of the groundnut paste. Moreover, the machine's output capacity was approximately 15 kg/h of groundnut paste. Several studies have reported the development of the screw method of extraction [17 - 21]. But it was discovered that screw oil extraction had not been adopted by women processors since the by-product from screw extraction cannot be processed into a kind of a snack called 'Kulikuli' in Nigeria which is usually the main product and the processing of the groundnut oil only as part of the process. This necessitated the development of an improved kneading machine. Similarly, several studies reported on the kneading method of oil extraction machines [11, 13, 23].

However, there are still reported limitations as regards groundnut oil kneading machines which includes the issue of the collection of extracted oil which can only be done after the batch operation in the existing designs. This increases the downtime and hence reduces the overall efficiency of the process. Also, the power transmission shaft and bevel arrangement in the existing designs involve longer link elements. Other studies have also investigated the use of different materials and design features to improve the efficiency and effectiveness of groundnut kneaders. Hence, the present work attempts to address the above-stated drawbacks in the existing designs by designing and fabricating an improved groundnut kneader by incorporating of new features and modifications that could enhance the performance and efficiency of the machine. This could increase productivity, and enhance the livelihoods of small-scale farmers and food processors in Nigeria and other developing countries. The aim of the study is to design and developed an improved ground nut kneading machine. Also to evaluate the performance of the developed machine and address the challenges of groundnut oil extraction faced among women processors in Nigeria.

## 2. Materials and method

### 2.1 Materials Selection

During material selection, availability, suitability of the materials for the working conditions, and cost were adequately considered. A stainless metal sheet was chosen for kneading cylinder construction because of its resistance to corrosion even under damp conditions. The angle iron that was used for the frame was selected because of its durability, availability, thermal conductivity, low cost, and strength to hold other components.

### 2.2 Design of the kneader components

Major components of the machine such as container capacity, thickness of the container, power requirement and shaft diameter were designed as follows:

#### 2.2.1 Design of oil extraction container

The container, which is a tapered cylindrical shape in form of a frustum houses the iron bars attached to a rotating shaft and the groundnut paste stock from which oil is extracted. The design of the kneading chamber was derived from Khurmi and Gupta [23] as in equation 1:

$$V = \frac{M}{\rho} \quad (1)$$

Where,  $V$  = volume of the chamber in  $m^3$ ,  $M$  = mass of the paste in kg and  $\rho$  = Density of the groundnut paste in  $kg/m^3$

To provide for clearance, avoid choking, avoid splashing, and effective mixing of the groundnut paste in the container during the extraction process, the volume of the container was made 2 times the volume of the groundnut paste.

$$V = 2 \times 0.23 = 0.046m^3$$

The diameter and length of the container were calculated from the equation for calculating the frustum of a cone as given in equation 2.

$$V = \frac{\pi h}{3} (R^2 + R_r r^2) \quad (2)$$

Thus, the height of the container was obtained from the volume of a frustum.

Where  $V$  = volume of the container ( $m^3$ ),  $h$  = container height (m),  $R$  = Radius of the upper side of the container (m) and  $r$  = radius of the lower side of the container (m)

#### 2.2.2 Design of container plate thickness

The container was assumed to be formed of a thin section in order to estimate the thickness of the container wall. The groundnut paste it contains and the agitation of the paste during the extraction process will cause pressure to build up inside the container.

The container cover is opened intermittently during operation to the atmosphere, the cylinder's maximum interior pressure  $P_{max}$  is indicated in equation 3:

$$P_{max} = P_{atm} + \rho g(h_1 - h_2) \quad (3)$$

Where  $P_{atm}$  is the atmospheric pressure and is equal to  $101325 \frac{N}{m^2}$ ,  $\rho = 1043.3 \text{ kg/m}^3$  [23],  $g$  is the acceleration due to gravity  $= 9.81 \frac{m}{s^2}$ ,  $h_1 - h_2$  is the height of the container  $= 0.1829m$

In order to account for the forces created by the iron bars' (fingers') squeezing action and the pressure produced by the paste's collision with the container's internal wall during oil extraction, a factor of safety of  $n = 4$  was chosen for the design. Thus, working stress of the hopper made of mild steel as given by Khurmi and Gupta [23] in equation 4:

$$\text{working stress, } \sigma_{ws} = \frac{\sigma_{yp}}{n} \quad (4)$$

Where  $\sigma_{yp}$  is the yield stress of mild steel  $= 250 \text{ MPa}$ ,  $\sigma_{ws}$  is the working stress in  $N/m^2$

For a thin-walled cylindrical vessel, the tangential stress (working stress) was given by Khurmi and Gupta [23] as in equation 5:

$$\text{Tangential stress, } \sigma_{ws} = \frac{P_{max} \times d}{2t} \quad (5a)$$

Where  $\sigma_{ws}$  = is also the working stress = maximum built up pressure inside cylinder in  $N/m^2$

$$\sigma_{ws} = \frac{N}{m^2 P_{max}} \quad (5b)$$

Also  $d$  is the diameter of the base of the container and  $t$  = thickness of the wall of container (mm)

Hence, a mild steel plate of 2 mm thickness was considered adequate for the fabrication of the container.

### 2.2.3 Design of vertical scrappers

Three vertical scrappers were made with 50 mm angle iron of 4 mm thickness and mounted inside around the hopper's wall, spaced uniformly apart. They function as scrappers. The relationship between a circle's circumference and the distance between the scrappers was used to calculate this distance as in equation 6:

$$\text{Circumference } C = \pi D \quad (6)$$

$D$  = diameter of the top container, If  $D = 410mm$  (from existing groundnut kneader), i. e  $C = \pi \times 410 \approx 1288mm$ , Number of vertical scrappers,  $N_b = 3$ , position of vertical scrappers from another =  $\frac{C}{N_b}$ , Vertical scrappers position from one another =  $\frac{1288}{3} = 429.33mm$ .

As a result, the vertical scrappers were positioned circumferentially around the inner wall of the container at a distance of about 430 mm from one another. Hence, this is meant to help in breaking of groundnut paste lumps during operation.

### 2.2.4 Total power for the kneader

The power requirement was calculated according to Khurmi and Gupta [23] presented in equation 7:

$$P = \frac{2\pi NT}{60} \quad (7)$$

Where  $P$  = Power required to drive the shaft (W),  $N$  = Operating speed (rpm) and  $T$  = Torque (Nm)

### 2.2.5 Power requirement without load

There are four number of fingers (maximum number of fingers) always acting on the shaft even without load, hence;

$$F_f = m_g = V_f \times \rho_s \times g \quad (8)$$

Where  $F_f$  = is the weight of the finger,  $V_f$  = volume of the finger in  $m^3$  as in equation 9,  $\rho_s$  = density of mild steel and  $g$  = acceleration due to gravity

$$V_f = l \times b \times t \quad (9)$$

Where  $l$  = length in m,  $b$  = breadth in m, and  $t$  = thickness in m.

Note:  $F_o$  is the total weight exerted by the fingers on the shaft (No load). From Ibrahim [12] presented in equation 10;

$$T_o = F_o \times r_f \quad (10)$$

### 2.2.6 Power requirement with load

To determine the power required to rotate the shaft with load, a relationship given by Khurmi and Gupta [23] as presented in equation 14 was used.

$$F_l = w \quad (11)$$

Where  $F_l$  = the total load on the shaft,  $w$  = maximum weight of groundnut paste that can be processed at a time. This is given as 24kg [13].

From;

$$P_L = \frac{2\pi NT}{60} \quad (12)$$

Where  $P_L$  is the power required to rotate the shaft with load.

### 2.2.7 Horizontal shaft power requirement

The vertical shaft connected with horizontal shaft through bevel gear, and the relationship between power acting on both vertical shaft and horizontal shaft is given by Karwa [25] as presented in equation 13:

$$P_H = \frac{P_v}{\cos \theta} \quad (13)$$

Where  $P_H$  = the power required to power horizontal shaft (watt),  $P_v$  = the power required to power vertical shaft (watt),  $\theta$  = the pressure angle of bevel gears and According to Karwa [25],  $\theta$  is  $20^\circ$  for bevel gears.

### 2.2.8 Power due to belt tension.

The power due to belt tension was calculated by Karwa [25] from relationship in equation 14:

$$P_b = b_p \times b_s \quad (14)$$

Where,  $(P_b)$  = required power,  $b_p$  = belt pull (N) and  $b_s$  = belt speed (rpm)

### 2.2.9 Determination of shaft diameter

According to ASME [26], design code for ductile material (mild steel) was used to design the rotating shaft based on strength. Since the shaft was subjected to bending and torsional stress, the diameter was determined using the expression given by Khurmi and Gupta [23] in equation 15:

$$D^3 = \frac{16 \sqrt{(K_b M_b)^2 + (K_t M_t)^2}}{\pi S_s} \quad (15)$$

Where  $D$  = shaft diameter (m);  $M_b$  = resultant bending moment;  $M_t$  = twisting/torsional moment,  $K_t$  = combined shock and fatigue factor applied to bending moment;  $K_b$  = combined shock and fatigue factor applied to torsional moment;  $S_s$  = allowable shear stress in shaft. From ASME design shafting code,  $K_b$  and  $K_t$  for rotating shaft

experiencing minor shock equals 1.5 to 2.0 and 1.0 to 1.5 respectively.

### 2.2.10 Torsional moment of shaft

Torsional moment of the shaft expression was given by Khurmi and Gupta [23] as in equation 16:

$$M_t = \frac{60P}{2\pi N} \quad (16)$$

Where  $M_t$  = torsional moment (Nm) and  $N$  = Speed (rpm)

### 2.2.11 Determination of belt speed

Belt speed was estimated using the expression given by Khurmi and Gupta [23] as in equation 17:

$$V = \frac{\pi \times D_1 \times n_1}{60} \quad (17)$$

Where,  $V$  = Belt speed (m/s),  $n_1$  = operating speed = 450 rev/min, selected based on literature,  $D_1$  = Diameter of driven pulley (m) = 0.257m (from existing pulley).

To determine the value of  $T_1$  and  $T_2$  and  $W$ , the following expressions were used in Khurmi and Gupta [23] as in equation 18;

$$\frac{T_1}{T_2} = e^{\mu\theta} \quad (18)$$

Where  $T_1$  = Carrying side of belt tension (N),  $T_2$  = Return side of belt tension (N),  $\theta$  = Angle of contact between the pulley and belt ( $^\circ$ ) = 101.45 $^\circ$ ,  $\mu$  = Coefficient of friction between drive pulley and belt = 0.25.

$$\frac{T_1}{T_2} = e^{0.25 \times 101.45} \quad (19)$$

According to Khurmi and Gupta [23],  $T_1 = 1.035 T_2$

Similarly, belt tension can also be calculated using power transmission relation in equation 20 and 21:

$$P = (T_1 - T_2) \times V \quad (20)$$

$P$  = Conveying power = 3kW,  $V$  = Belt speed = 6.06m/s putting the values in the equation above:

$$3 = (T_1 - T_2) \times 6.06$$

$$\frac{3}{6.06} = (T_1 - T_2)$$

$$T_1 = T_2 + 0.5 \quad (21)$$

Weight of the pulley was obtained using equation 22

$$W = mg \quad (22)$$

Where  $m$  (mass (kg) of pulley – existing pulley (cast aluminum)) = 1.6 kg,  $g$  = acceleration due to gravity (9.81 m/s)

Resultant bending moment  $M_b$  will be obtained using equation given by Khurmi and Gupta [23] as in equation 23:

$$M_b = \sqrt{(M_v)^2 + (M_h)^2} \quad (23)$$

$M_v$  = Maximum vertical bending moment = 73.64 Nm and  $M_h$  = Maximum horizontal bending moment = 73.64 Nm

### 2.2.12 Determination of shaft diameter

Shaft diameter was determined using the expression given by Khurmi and Gupta [23] as in equation 25:

$$d = \sqrt[3]{\frac{16}{\pi\tau} (\sqrt{(K_b M_b)^2 + (K_t M_t)^2}} \quad (25)$$

Where  $\tau$  = Allow shear stress = (0.60 $\tau_{ut}$ ),  $K_b$  = 1.5; (Fatigue factor as applied to Bending moment),  $K_t$  = 1; (Combine shock factor as applied to Torsional Moment), Ultimate tensile strength ( $\tau_{ut}$ ) = 700 N/mm

### 2.2.13 Bearing Selection

Bearing catalogue was used to select standard bearings base on their load carrying capacity, life expectancy and reliability. The relationships between the basic rating life, the basic dynamic load rating,  $C$  and bearing load,  $P$  that are as given below was used by Karwa [25] in equation 26 and 27:

$$C = (L_{10})^{\frac{1}{k}} \times P \quad (26)$$

$$L_{10} = \frac{60n}{10^6} \times L_H \quad (27)$$

Where  $L_{10}$  = rating life of bearing for 90% survival at one million revolutions,  $L_H$  = required life of bearing in million revolutions,  $k$  = exponential for life equation of bearing ( $k = 3$  for ball bearing),  $n$  = bearing rotational speed (rpm);  $n = 450$  rpm,  $L_H = 8000$  hrs, [23].

### 2.3 Mode of machine operation

For the machine to begin operating, a known weight of paste is poured into the container, and it is then set up. Once the engine is running, the V-belt and connecting shaft provide rotary power to the kneading shaft. The centrifugal force of the rotating fingers acts on the oil molecules in the paste to knead it, and warm, clean water is gradually added as the process goes along until it is finished.

### 2.4 Performance tests

*Maibargo* variety of groundnut was used to evaluate the machine and it was collected from the open market Dawanau grain market, Kano State. The performance indices used were extraction efficiency, Output capacity, and oil yield. The equations used to determine the oil extraction efficiency, output capacity, and oil yield as expressed by ASME [26] are given in equation 28 and 29;

$$OEE = \frac{OY}{AEO} \times 100\% \quad (28)$$

Where  $OEE$  = oil extraction efficiency,  $OY$  = oil yield (%) and  $AEO$  = amount of oil expected (%) (% Oil content x Mass of seeds processed (kg).

$$OC = \frac{M_P}{T_E} \quad (29)$$

Where  $OC$  = output capacity (kg/h),  $M_P$  = mass of oil produced (kg),  $T_E$  = effective time taken (h)

$$OY = \frac{W_O}{W_{PK}} \times 100\% \quad (30)$$



Where OY = oil yield (%),  $W_o$  = weight of oil obtained (kg),  $W_{PK}$  = weight of groundnut paste kneaded (kg)

Since the speed of the machine, finger numbers and water temperature of the groundnut paste are the major variables that could influence the overall performance oil kneading machine [12, 20, 22, 28].

### 3. Results and discussion

#### 3.1 Dimensions of components

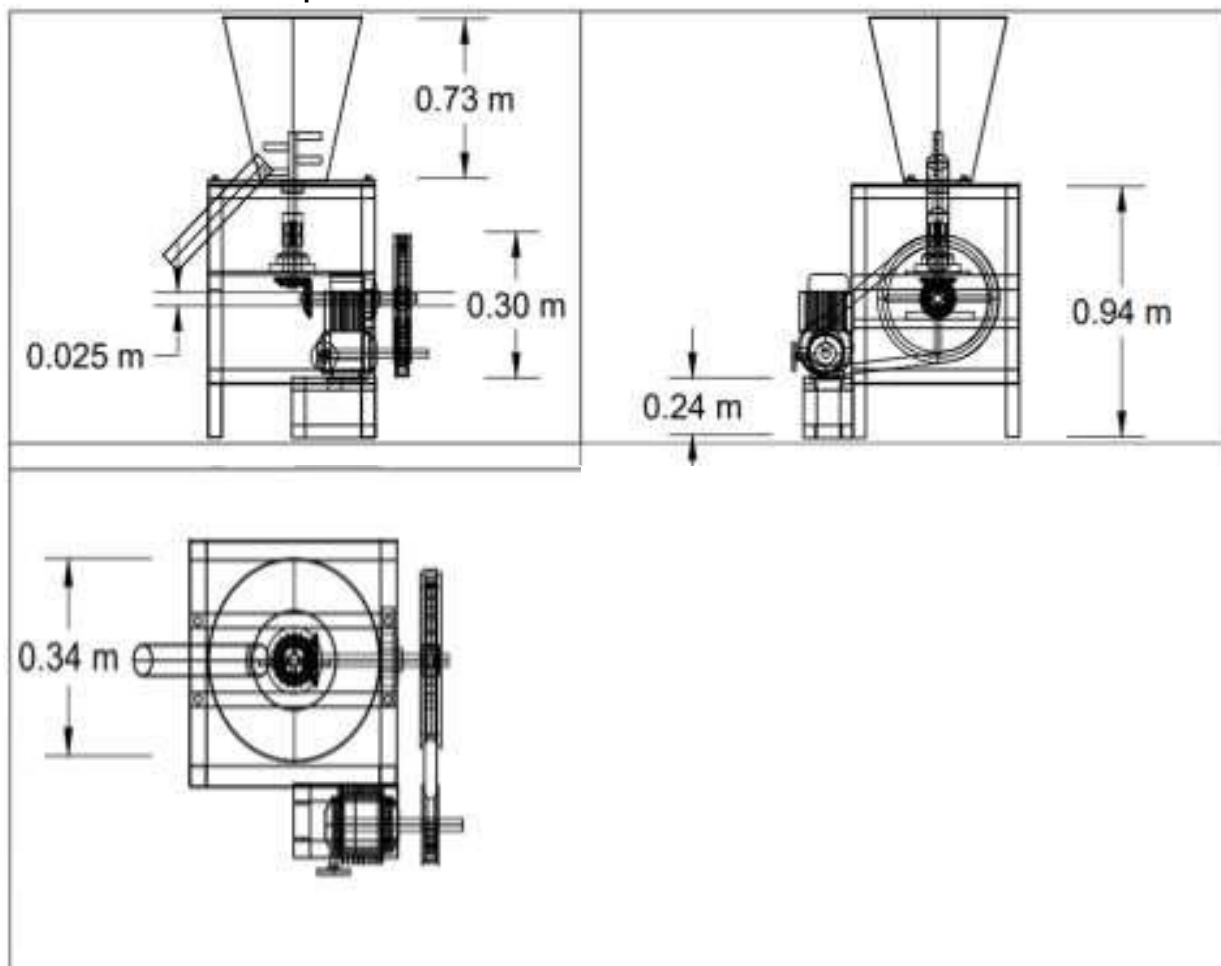


Figure 1: Orthographic view of the designed Kneader

#### 3.1.2 Vertical Scrappers

Three vertical scrappers were made with 50 mm angle iron of 4 mm thickness and mounted inside the hopper's wall, spaced uniformly apart.

#### 3.1.3 Extraction fingers

Length, breadth and thickness of the fingers were selected based on the existing kneader designs available to the smallholder women processors which are 0.225 m, 0.029 m and 0.005 m respectively.

Plate thickness for the hopper was determined as 3.7 mm but standard value of 5 mm was selected.

#### 3.1.4 Power requirement:

#### 3.1.1 Hopper dimensions

The volume of the container was made 2 times the volume of the groundnut paste.

$$V = 2 \times 0.023 = 0.046$$

Based on existing kneader designs,  $R = 0.17$  m; and  $r = 0.11$  m were selected, height of the container,  $h=0.73$  was calculated. Hence a height of 0.75 was used in the design.

- Power required to rotate the shaft with no load,  $P_o$  was determined as 0.0167 kW
- Power required to rotate the shaft with load,  $P_L = 2.5$  kW
- Power due to belt tension,  $P_b = 0.15$  kW
- Total power requirement  $P_T = 2.75$  kW
- Considering a factor of safety, a 3 kW electric prime mover was selected.
- Shaft diameter calculated based on torsion and bending = 25 mm; Std size of 30 mm was selected

#### 3.2 Performance Results

The highest mean machine efficiency (81.83 %) was obtained at combination of 60 °C temperature, three fingers and a speed of 350 rpm. The highest mean machine output capacity (19.93 kg/h) was obtained at the combination of 60 °C temperature, three fingers and a speed of 350 rpm.

The highest mean oil yield (40.53 %) was obtained at a combination of 60 °C temperature, three fingers and a speed of 400 rpm. These results show a remarkable improvement on the performance indices over the existing kneader designs.

#### 4. Conclusion

An improved kneader was successfully designed, fabricated and tested. From the performance evaluation of the kneader, it was observed that all the evaluated factors are significant at  $p \leq 0.05$ . The result of optimization of the machine performance, output capacity revealed that the optimum conditions of 60°C, 400 rpm, and F3 for water temperature, speed, and fingers respectively.

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