Development and Testing of a Tappered Screw Mecahanism for Groundnut Oil Extraction

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ABSTRACT
A groundnut oil expeller having a capacity of 800kg per day was designed and fabricated as one of the equipment with which oil can be extracted from oil bearing seeds. The equipment was fabricated in Desfabeng Company Nigeria Limited, Bida-Niger State. It consists of the seed inlet unit (hopper), oil extraction unit, cake discharge outlet, oil collector, power transmission unit, covers and frames. A gear box having a turn ratio of 1:2 was fitted to the end of the worm shaft. This helps in reducing the speed of the 20Hp electric motor to the speed required to expel the oil from the oil bearing seeds. The machine was fabricated with about 90% local materials. Test results of the oil expeller using groundnut variety "Rmp 12" reveals extraction efficiency of 89.2%, extraction losses of 10.8% and cake recovery of 56% at a moisture content of 6% and seed temperature of 60^0C. It was also found suitable for extracting oil from neem seed, sesame and other oil bearing seeds. The machine was generally found to be easy to maintain by local artisans due to its simple design features.

Keywords: *Design, Fabricate, Groundnut, Oil expeller.*

1 INTRODUCTION

Groundnut (*Arachis hypogaea*) also known as peanut is a specie in the legume or "bean" family (fabaceae). It is an annual herbaceous plant growing 30-50cm tall. The mature fruit develops into a legume pod, the peanut a classical example of geocarpy pods are 3-7cm long, containing 1-4 seeds (Michael, 2004).

Groundnut grows favourably under warm climates and often provides food for humans and livestock and in the absence of meat forms a valuable dietary protein component (Hammos, 1994). The cake that remains after the oil has been removed finds uses in local dishes, in the manufacture of secondary products or for animal feeds.

Groundnut seeds are composed of the following; Protein 25.7%, oil 48.2%, starch 11.5%, soluble sugar 4.5%, crude fiber 2.1% and moisture 6% (Jambunathan, 1991).

Similar to other oil seeds, oil can be obtained from groundnut seeds through one of the following ways:

Mechanical Extraction: This involves obtaining the oil through crushing the groundnut seeds using a screw press otherwise called an expeller. This method ensures extraction of a non-contaminated, protein-rich low fat cake at a relatively low-cost (Bamgboye and Adejumo, 2007). Extracted oil is collected, filtered and refined.

Solvent Extraction: This involves using solvent mostly hexane to extract oil from oil bearing seeds. Fernandez, (2004), reported that for processed food and bio-fuels, it can be a cost-saving high yield operation.

Traditional Method: Oil is extracted traditionally by kneading and alternate wetting with hot water until the oil in the dough- materials begins to ooze out (Olaifa and Adenuga, 1998). Tribesmen in oman used this technique to extract oil from moringa peregrina seed with some success (Folkard and Sutherland, 2005).

Oil expelling or oil pressing is a mechanical method of extracting oil from raw materials. The raw materials are squeezed under high pressure in a single step (Wikipedia, 2015). This method ensures extraction of a non-contaminated protein-rich low fat cake at a relatively low-cost (Bamgboye and Adejumo, 2007).

An expeller press is a screw-type machine that presses oil seeds through a caged barrel-like cavity. Raw materials enter one side of the press and waste products exit the other side. The machine uses friction and continuous pressure from the screw drives to move and compress the seed material. The oil seeps through small openings that do not allow seed fiber solid to pass through. Afterwards, the pressed seeds are formed into a hardened cake which is removed from the machine. Pressure involved in expeller pressing creates heat in the range of 140-210°F (60-99°C) (Wikipedia, 2015).

The earliest design of expeller presses utilised a continuous screw design. After the continuous screw design, Valerius Anderson invented the interrupted screw design and patented it in the year 1900. After the 1900 patent, a major improvement was made with the addition of resistor teeth fitted into the gaps where there is no flighting. These teeth increase the agitation within the press, further diminishing co-rotation tendencies.

Most of the oil expellers are imported leading to high cost of maintenance and procurement of spare parts leading to limited expertise in fixing up faulty expellers. This necessitated the development of a suitable groundnut oil expeller using local materials which would be adaptable to our local conditions. As such, this paper explains the development and testing of a groundnut oil expeller which would be found very useful in the edible oil production industry. Thus, increasing indigenous oil production and reducing edible oil importation.

2 METHODOLOGY

2.1 MACHINE DESCRIPTION

The oil expeller is made up of the following components as described below:

1 Oil Extraction Unit: This is made up of a worm shaft being caged inside a barrel as shown in figure 2. The length of the worm shaft is 75cm. The barrel is cylindrical in shape and has little perforations for oil to ooze out as such enhancing maximum oil extraction. The end of the worm shaft fits into the gearbox. An adjustable choke is attached to the front end of the worm shaft so as to regulate the pressing pressure. The internal pressure ruptures the oil cells in the seeds and oil flows through perforations in the barrel. The worm shaft has two pressing points. At these points, the seeds are properly pressed so as to ensure maximum oil extraction. The worm transports the compressed cake with little or no oil content to the discharge outlet while the extracted oil drains through the perforations in the barrel to the oil collection trough. A clearance is always provided between the flight worm and the barrel so as to avoid them from making contact with each other. The rear end of the worm shaft fits into the gearbox and the gearbox helps in reducing the speed of the electric motor to the recommended speed of the worm shaft.

2 Seed Inlet Unit: The seed inlet unit as shown in figure 1, is primarily the hopper which guides the seeds into the extraction chamber. The hopper is conical in shape having a protruded base. The hopper is made from thick gauge 16 mild steel plate.

3 Cake Discharge Outlet: The cake discharge outlet is located at the rear end of the barrel where cakes formed after oil extraction with very minimal oil content are discharged.

4 Oil Collector: The oil collector is a trapezoidal shaped trough placed directly below the barrel in order to collect the extracted oil passing through the screen which prevents seeds from passing through. It is inclined at an angle of 25^{0}C from the horizontal plane in order to enable the extracted oil flow freely into the collecting container as shown in figure 1.

5 Power Transmission Unit: This unit comprises of a 20HP electric motor, a gearbox, pulleys and belts. The electric motor and gearbox are connected together through belts and pulleys while the gearbox is linked to the extraction unit through the rear end of the worm shaft via flanges.

6 Frames and Covers: The frame of the oil expeller was fabricated with 3inches angle iron while the machine covers were made from mild steel sheets.

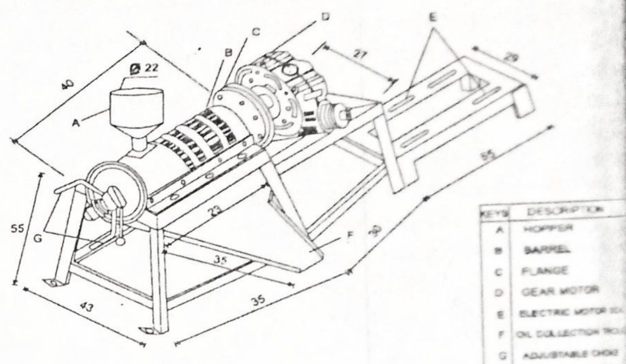

Fig.1. Isometric View of the Oil Extractor

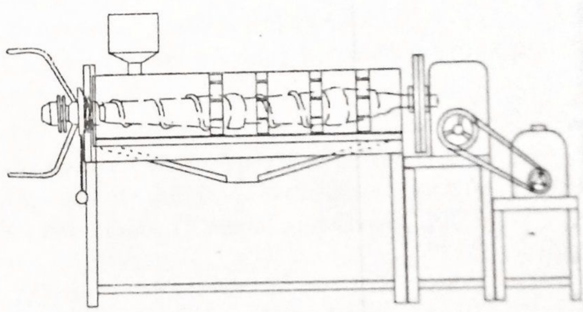

Fig.2. Orthographic Front View

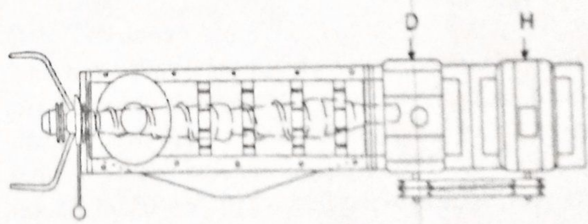

Fig.3. Orthographic Plan View

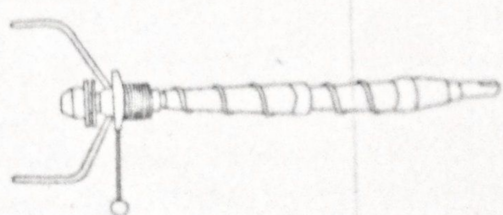

Fig.4. Expeller Shaft

3 DESIGN CALCULATIONS

Determination of the Power Requirement of the machine

The power requirement for the pelletizing machine is a combination of the following:

1. Power required forming and extruding the formed pellets.
2. Power required to drive the worm shaft
3. Power required to drive the pulley

Each of the design calculations are presented below:

Power Required to Extrude the formed Pellets

This was determined by the expression below:

$$P_e = T_s W_s \quad (1)$$

Where, P_e = Power required to extrude the pellets (kW)

T_s= Torque of the worm shaft (Nm)

W_s = Angular velocity of the worm shaft (rad/sec)

$$\text{But } W = \frac{2\pi N}{60} \quad (2)$$

Where N = Speed of the worm shaft

$$\text{Also, } T_s = Fr \quad (3)$$

Where, F= The impact force required to extrude the pellets (N), r = The distance of point of application from the axis of rotation (force radius) (m)

Power Required to Drive the Worm shaft

This was determined as follows:

$$P_w = W_w \times r_w \quad (4)$$

Where, P_w = Power required to drive the worm shaft (kW), W_w = The weight of the worm shaft (N), r_w =The radius of the worm shaft (m)

$$\text{But } W_w = M_w \times g \quad (5)$$

Where M_w =Mass of the worm shaft (kg), g = Acceleration due to gravity (m/s^2)

Power Required to Drive the Pulley

$$P_p = W_p \times r_p \quad (6)$$

Where, P_p = Power required to drive the pulley (kW)

W_p = Weight of the pulley (N),

r_p = Radius of the pulley (m)

$$W_p = mg \quad (7)$$

Where, m= mass of the pulley (kg), g = Acceleration due to gravity (m/s^2)

∴ The total power required by the machine is given by;

$$P_T = P_e + P_w + P_p \quad (8)$$

Determination of the Speed Reduction ratio of the Gearbox

The speed reduction ratio of the gearbox is a function of the electric motor, recommended speed of the worm shaft connected to the gearbox and the diameter of the pulley of the electric motor and the gear box. Thus, it is computed from established relationship (Gbabo, 1991).

$$N_m D_m = N_g D_g \quad (9)$$

$$N_g = \frac{N_m D_m}{D_g} \quad (10)$$

$$\text{Also } N_g = G_r \times N_r \quad (11)$$

Substituting equation 11 into 10 gives

$$G_r = \frac{N_m D_m}{D_g N_r} \quad (12)$$

Where, G_r= The expected gear ratio of the gearbox

N_m = Speed of the pulley of the electric motor (rpm)

D_m = Diameter of the pulley of the motor (m)

N_r= Recommended speed of the worm shaft (rpm)

Determination of the Length of the Belts

Two "B" V-belts of equal lengths were used to transmit power from the electric motor to the speed reduction unit. Their lengths were compared using the following equation (Gbabo, 1991; Khurmi and Gupta, 2005).

$$L = 2C + \frac{\pi}{2}(d_1 + d_2) - \left(\frac{d_2 - d_1}{4C}\right) \quad (13)$$

$$C = \left(\frac{d_2 + d_1}{2}\right) + d_1 \quad (14)$$

Where, d_1= Diameter of motor pulley (m)

d_2= Diameter of gearbox pulley (m)

C= Center to center distance between gearbox pulley and motor pulley

Determination of the Speed of the Belt

The speed of the belt was determined by using the expression below, (Khurmi and Gupta, 2005)

$$V = \frac{\pi \times N_1 \times D_1}{60} \quad (15)$$

Where, V= Speed of belt (rpm)

N_1= Speed of the electric motor pulley (rpm)

D_1= Diameter of the electric motor pulley (m)

Belt Tensions

The belts that transmit power from the electric motor to the auger of the gearbox are subjected to tension due to the frictional resistance between the belt and pulley. The tension of the belt on the tight and slack side is expected not to be lower or exceed a particular limit in order for power transmission from the electric motor to the gearbox to be effective. These tensions were determined using the mathematically established equations (Gbabo, 1992).

$$T_1 = U \quad (16)$$

$$\frac{T_2}{W} = \frac{(T_1 - T_2)}{60} V \quad (17)$$

Where, T_1 is tension on the tight side

T_2 is tension on the slack side

U is coefficient of friction between belt and pulley

V is velocity of belt (m/sec)

Design of Pulley and Belt

This was done in order to know the equivalent ratio between the size of the electric motor pulley and that of the gearbox pulley. It was determined as follows, (Khurmi and Gupta, 2005)

$$N_1D_1 = N_2D_2 \quad (18)$$

Where, N_1= Speed of the electric motor pulley (rpm)
D_1= Diameter of the electric motor pulley (m)
N_2= Speed of the gearbox pulley (rpm)
D_2= Diameter of the gearbox pulley (m)

Determination of the Angle of Contact or Lap of the Gearbox pulley

The angle of lap of the belt in between the two pulleys was calculated from the expression below;

$$\theta = (180 - 2\alpha) \times \frac{\pi}{180} \quad (19)$$

Such that $\alpha = \sin^{-1}\left(\frac{r_2 - r_1}{C}\right)$ (20)

Where, θ = Angle of contact of belt between the two pulleys (Degree). r_2 =Radius of the gearbox pulley (m)
r_1 =Radius of the motor pulley (m)
C= Center distance between the two pulleys (m)

Determination of the Maximum Shear Stress of the Shaft

The shaft is under a combined load of bending moment and torque and is given as:

$$\tau_{max} = \frac{16}{\pi d^3}\sqrt{(M^2 + T^2)} \quad (21)$$

Where, τ_{max} = Maximum shear stress (N/m)
T= Torque (Nm)
M= Bending moment of shaft (Nm)
d= shaft diameter (m)

Time Required to Expel Oil from a Batch

The time required to expel oil from a batch of groundnut was computed using the equation shown below:

$$T = \frac{N_B}{T_T} \quad (22)$$

Where, T is the time required per Batch
T_T is Total time required
N_B is number of batches

3.1 WORKING MODE OF THE MACHINE

The various parts of the machine were assembled, after which the 20HP electric motor was mounted and connected through belts and pulleys to the gearbox while the gearbox is connected to the rear of the worm shaft by means of flanges. The gearbox with a turn ratio of 1:2 was used to reduce the speed of the electric motor to the speed required by the worm shaft to expel oil from the groundnut seeds. The expeller was then test run without groundnut or any seed poured into the hopper. This was done to study the behaviour of the machine. Heated groundnut seeds from a fabricated nut heater were fed into the extraction unit via the hopper. The extraction process was made possible by the rotary action of the worm shaft. The worm shaft is caged in a cylindrical shaped barrel which has little perforations for oil to ooze out as such enhancing maximum oil extraction. The end of the worm shaft fits into the gearbox. An adjustable choke is attached to the front end of the worm shaft so as to regulate the pressing pressure. The internal pressure ruptures the oil cells in the seeds and oil flows through perforations in the barrel. The worm shaft has two pressing points. At these points, the seeds are properly pressed so as to ensure maximum oil extraction. The worm transports the compressed cake with little or no oil content to the discharge outlet while the extracted oil drains through the perforations in the barrel to the oil collection trough. A clearance is always provided between the flight worm and the barrel so as to avoid them from making contact with each other.

3.2 TESTING OF THE MACHINE

200kg of groundnut (Rmp 12) variety with a percentage oil content of 48.2% was purchased from Bida old market in Bida Local Government Area, Niger state. The groundnut variety was divided into four samples of 50kg each which was then subjected to oven drying in order to obtain a moisture content of 6% wb (wet basis) which is the optimum moisture content for groundnut oil expelling as reported by Bongiwar *et al.* (1977). An instant moisture meter was used to determine the moisture content. With the aid of a nut heater, the four samples of the divided groundnut variety were subjected to steam heating so as to lower the viscosity of the oil to be extracted, coagulate the protein in the meal, and also adjust the moisture level of the meal to the optimum level of extraction. As such four different seed temperatures were obtained (30, 60, 75 and 90^{0}C). These temperatures were recorded by incorporating a thermometer into the seed chamber of the steam heater.

The machine was switched on and was allowed to run without groundnut or any seed poured into the hopper using an electric motor of 20HP attached to a gearbox having a turn ratio of 1:2. This was done to study the behaviour of the machine. Afterwards heated seeds from the nut heater were fed into the oil expeller via the hopper. The adjustable choke was used in adjusting the internal pressure of the barrel. With this, oil was extracted from the oilseeds. The testing of the machine was targeted to evaluate its capacity, percentage extraction efficiency, extraction losses and cake recovery based on 6% wb moisture content of the seeds. The performance test was conducted using 50 kg of groundnut seeds of each of the seed temperature at 30, 60, 75 and 90^{0}C. Each of the experiment was replicated three times.

The weight of the extracted oil, cake and time taken to extract the oil were recorded. As such, the capacity of the machine, percentage extraction efficiency, extraction losses and cake recovery efficiency were computed and recorded.

3.3 COMPUTATION OF THE PERFORMANCE PARAMETERS

The formulae used in computing the machine capacity, percentage oil yield, extraction efficiency, extraction losses and cake recovery are stated as follows:

Capacity of machine (C_m): It is the ratio of the weight of groundnut crushed to the total time taken to crush the groundnut and obtain the oil expressed in kg/day and is given as:

$$C_m = \frac{W_g}{t} \qquad (23)$$

Where, C_m= Capacity of Machine with respect to time (Kg/day), W_g= Weight of groundnut crushed (Kg)

t = Total time taken to crush the groundnut and obtain oil (s)

Percentage oil yield: It is the ratio of the weight of groundnut oil extracted to the weight of groundnut fed into the hopper expressed in percentage and is given as reported by Gana *et al.* (2017), as

$$Percentage\ Oil\ yield\ (\%) = \frac{W_o}{W_g} \qquad (24)$$

Where, W_o = Weight of oil extracted (Kg)

W_g = Weight of groundnut fed into the hopper (kg)

Percentage extraction efficiency: It is the ratio of the weight of groundnut oil extracted to the total oil content in the seeds expressed in percentage and is given as reported by Gana *et al.* (2017), as

$$E_e = \frac{W_o}{W_c} \qquad (25)$$

Where, E_e = Percentage extraction efficiency

W_0= Weight of oil extracted (Kg)

W_c= Total oil content in the seed (Kg)

Percentage extraction Losses: It is obtained by subtracting the percentage extraction efficiency from 100. Expressed as given given as reported by Gana *et al.* (2017), as

$$E_L = 100 - E_e \qquad (26)$$

Where, $E_L = Extraction\ losses$

$E_e = Percentage\ extraction\ efficiency$

Cake recovery efficiency: It is the ratio of the weight of groundnut cake obtained to the weight of groundnut fed into the hopper expressed in percentage and is given as:

$$C_r = \frac{W_d}{W_g} \qquad (27)$$

Where, $C_r = Cake\ recovery\ efficiency$

W_d = weight of groundnut cake obtained

W_g = weight of groundnut fed into the hopper

3.4 RESULTS AND DISCUSSION

Percentage extraction efficiency

The results of the percentage extraction efficiency which is the ratio of the weight of groundnut oil extracted to the total oil content in the seeds expressed in percentage are presented in Table 1. Extracting oil at a seed temperature of 60°C and moisture content of 6% produced the highest extraction efficiency of 89.20%. This is because increasing the seed temperature of oil-seeds for extraction purposes helps to lower the viscosity of the oil to be extracted, coagulate the protein in the meal, and also adjust the moisture level of the meal to the optimum level of extraction. Sivakuraran *et al.* (1985) reported that heating temperature, heating time and moisture content were interactive factors that influenced the yield of oil extracted. Thus heating oil seeds break the oil bearing cells; allowing for easy flow of the oil. Oil extraction carried out at a seed temperature of 30°C yielded no oil at all thereby giving an extraction efficiency of 0%. This is because at a temperature of 30°C, the oil bearing cells are yet to be broken for the release and flow of oil. This agreed with the result of an earlier study by Olaomi (2008) who reported that when groundnut seeds were not heated prior to expelling, only groundnut paste was observed coming out of the cake outlet of the expeller, with no oil. As such a seed temperature of 30°C is too low to break up the oil bearing cells. At a seed temperature of 90°C, the extraction efficiency reduced to 51.0%. This is because at this high temperature, the oil seeds have been over heated thereby making it difficult to separate the oil from the cake. As such a gummy rubber-like cake begins to come out from the cake discharge outlet with oil accompanying it. As such most of the oil that ought to come out from the oil trough begins to come out with the cake from the cake discharge outlet. This agrees with Adeeko and Ajibola (1990) who reported that prolonged heating t ime beyond 25 minutes for groundnut samples heated at temperature above 90°C did not improve oil yield.

Table 1: Machine Performance parameters at different seed temperatures

Temp of oil seed (°C)	Weight of g.nut seeds (kg)	Expected weight of oil (kg)	Expected weight of cake (kg)	Avg. weight of oil extracted (kg)	Avg. weight of cake (kg)	Avg. weight of retained material (kg)	Extraction eff. (%)	Extraction losses (%)	Cake recovery Eff. (%)
30	50.0	24.1	25.9	NIL	48.8	1.2	NIL	100	97.6
60	50.0	24.1	25.9	21.5	28.0	0.5	89.2	10.8	56.0
75	50.0	24.1	25.9	19.3	30.2	0.5	80.1	19.9	60.4
90	50.0	24.1	25.9	12.3	36.7	1.0	51.0	49.0	73.4

Percentage extraction losses

The percentage extraction losses were obtained by subtracting the percentage extraction efficiency from 100. The results obtained are presented in table 1. Extraction of oil at a seed temperature of 60°C gave the least value for percentage extraction losses. This is because at this temperature virtually all the oil was extracted from the groundnut leaving very little trace of oil in the retained material and cake produced. But at a seed temperature of 30^{0}C, no oil was extracted (collected at the oil collector) only pastes (cakes) were collected thereby giving rise to a high percentage of extraction losses. This was in agreement with Onwuka, (2013) who reported that for oil to be extracted from groundnut, heating is necessary. Otherwise there would be no oil yield and only paste would be observed passing through the cake outlets. It can therefore be inferred that the value of percentage extraction losses gives an index of oil not extracted (not collected at the oil collector) with respect to the oil content of the seeds.

Cake recovery efficiency

The cake recovery efficiency which is the ratio of the weight of groundnut cake obtained to the weight of groundnut fed into the hopper expressed in percentage was obtained for different seed temperatures and presented in table 1. The highest cake recovery efficiency was obtained at a seed temperature of 30^{0}C. This is because no oil was collected so the bulk of the collected product was entirely cake while at a seed temperature of 60^{0}C, the least value of cake recovery was recovery because virtually all the oil in the was extracted. It therefore shows that the cake recovery efficiency is inversely proportional to the percentage extraction efficiency.

4 CONCLUSIONS

The machine capacity was found to be 800kg/day. The highest machine extraction efficiency of 89.2% was achieved when the ground nut seeds were heated to a seed temperature of 60^{0}C at a moisture content of 6% wb while the lowest extraction efficiency of 0% was achieved at a seed temperature of 30^{0}C.

The highest extraction losses of 100% was obtained when the groundnut seeds were heated to a seed temperature of 30^{0}C while the lowest extraction losses of 10.8% was achieved at a seed temperature of 60^{0}C.

The highest cake recovery efficiency of 97.6% was obtained when the groundnut seeds were heated to a seed temperature of 30^{0}C while the lowest cake recovery efficiency of 56.0% was achieved at a seed temperature of 60^{0}C.

Generally, it can be presented that the oil expeller works more efficiently at a seed temperature of 60^{0}C and moisture content of 6% wb. Increasing the seed temperature above 60^{0}C does not increase the oil yield. The machine was found suitable for extracting oil from neem seed, sesame and other oil bearing seeds. It was also be easy to operate and maintain by local artisans. Within the period it was used in expelling oil, it worked continually without interruptions from mechanical failures. These results indicates that the design of the machine suits its purpose as one of the equipment for expelling oil in developing countries like Nigeria.

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