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Design and Production of Palm Nut and Fibre Separating Machine

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Authors' contributions

This work was carried out in collaboration between all authors. Authors OPC, OBS, EON and AOA designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. All authors managed the analyses of the study. All authors managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Palm nut and fibre separating machine have been designed, constructed and tested. The essential components of the machine are the feeding chute, separating unit, pulverizing unit, discharge outlets for nut and fibre, and the prime mover. The power required for operation of the machine is 2.86 KW. The machine was tested with both dry and wet samples of the nut and fibre mixtures for three different runs and the average gotten and tabulated. The investigation results revealed that the machine gave its optimum work performed using the dry mixture at the throughput capacity, separating efficiency and quality performance efficiency of 0.155 kg/sec, 89.7 % and 82.3 % respectively. However, the throughput capacity, separating efficiency and quality performance efficiency with the wet mixture gave 0.144 kg/sec, 79.3 % and 80.1 % respectively.

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1. INTRODUCTION

The traditional palm kernels extraction process involves sun drying of nuts for days and cracking of the nuts using stones or any other hard objects. This is followed by separation of the kernels from their shells by hand picking and drying of the extracted kernels under the sun for about two to four days before storage or sale [1]. The production of palm oil in West Africa and most especially Nigeria, has proven difficult over the years due to the use of crude implements. This difficulty has made it paramount that existing palm oil production be modified.

The design of more efficient equipment will create favourable conditions for the processing of palm fronts. These conditions will attract the peasant farmers who produce the oil manually as well as investors to have a keen interest in investing in palm oil production.

In as much as Palm oil production has been a target for small and large scale investors, we are still running a deficit in its production due to poor equipment. This makes it imperative that existing palm-nut fibre separator machine must be improved. Hence, this research aimed at designing and constructing an efficient palm nut fibre separator using locally sourced materials that will be affordable for low and medium scale investors in rural areas.

2. DESIGN CONSIDERATIONS

For an efficient design the following factors were considered:

i. Physical factors of the machine, such as size, shape, surface texture and moisture content.
ii. Mechanical factors to consider for appropriate material selection are
iii. Corrosion, wear rigidity, deflection, stability and vibration.
iv. Setting up of different chutes to aid the discharge of nuts and fibres in other to have thorough separation.
v. The fibrous oil rich digested pulp can pass through narrow slits (dimension<3 mm) but palm nuts cannot, and also that the cake from the digestion process is fairly compacted which must be thoroughly slacked before the effective separation of the pulp and nuts will be possible.
vi. The hopper arrangement to prevent the splash off of nuts, oil and fibre during cake break down.

3. MACHINE DESCRIPTION

The machine is made up of the following components; the prime mover, which is an electric motor, the separating unit, the feeding unit, pulverizing unit, the discharge outlets and the frame for rigidity. The frame of the machine is constructed with two (2) angular bar of 3mm in thickness and have a dimension of 380mm x 980mm x1200mm having a v-shaped leg, elongating the width to 600mm for rigidity. The congested combination of palm nuts and fibre gotten from the palm fruit expeller are served via the hopper into the machine [2]. Construction of the hopper is from 16-guage mild steel sheet moulded into a square shape, with the topmost opening of 600mm x 360mm, and bottommost opening of 250mm x 360mm and a tallness (height) of 100mm, with a covering on the bottom opening to prevent flash off of nuts and fibre as it advances the beater inside the pulverizing unit. It is in this unit that the clogged mixture is broken down into smaller particles sizes to allow the entangle nuts inside the fibre. The unit comprises of a shaft 1700mm in length composed of 25mm mild steel rod a 75mm diameter pipe. Connected to the shaft are beaters composed of 12mm diameter mild steel rod that are positioned alternately at a spacing of 100mm from one another to yield the necessary outcome of breaking the clogged mixture thus separating the nuts from the fibrate separating unit (nibbling unit) is located below the pulverizing unit and the real separation of the palm nut and the fibre takes place in this unit. The separating unit is made up of a shaft of 1300mm in length which is composed of 25mm mild steel rod and 75mm diameter pipe and with a flat bar of 2mm thick having a length of 900mm connected parallel to the shaft at 40mm spacing. The shaft is so positioned in a way to produce a modifiable fibre discharge outlet. The fibre is discharged at the nut discharge outlet of the machine. The machine is powered by a 3.33 KW (4 hp) electric motor (details given in section 3.1.5), with the aid of belt and pulley arrangement which has 150 mm diameter driven pulley and 100 mm diameter driver pulley.

4. DESIGN ANALYSIS

4.1 Volume Capacity

The effective volume, V_{eff} (m^3) that this separator can be occupied by the digested palm fruit mash rest on its trough that forms an upper chamber where the mash from the hopper is slacked prior feeding to the separating unit at the lower chamber (see equation (1). Therefore V_{eff} is gotten by the volume (V) of the separator that can be occupied by the digested palm fruit mash and 50% of V headspace [3]. Calculation of the volume of the digested palm fruit mash was gotten by using equation one (1) below.

$$W = V \rho g \tag{1}$$

Where: W is maximum weight the machine was designed to carry at every point in time which is designed to be 98.1 N, ρ is the bulk density of digested palm fruit cake, given by [4] as 1060 kg/m^3, g is acceleration due to gravity (m/s^2) and V is the volume (m^3) occupied by the digested palm fruit. Hence the effective volume of the machine was determined as 0.045m^3 using equation (2);

$$V_{eff} = V + 0.5V \tag{2}$$

4.2 Selection of Pulleys

The machine needs four pulleys for its operation, one fixed on the electric motor shaft, one each at both ends of the auger shaft and the remaining one mounted at the left end of the cake breaker shaft. Due to its availability, cost and performance; cast iron pulleys were carefully chosen. The intended ratio of the speed of the driven pulley to that of the driver is 2:3. Therefore, equation (3) was used to determine the diameter and speed of the pulleys.

$$\frac{n_2}{n_1} = \frac{D_1}{D_2} = \frac{2}{3} \tag{3}$$

Where n_2 and n_1 are the speed of the driven and driver pulleys respectively and D_1 and D_2 are the diameters of the driver and driven pulleys respectively. Henceforth the machine was designed to run at the speed of 1000rpm for effective pulverization and separation. If small driver pulley is used assume 100mm diameter, therefore, n_1= 1500rpm, n_2= 1000 rpm, D_1 = 100mm and $D_2 = D_3 = D_4$ = 150mm.

4.3 Design for Belt

Equation (4) below was used to ascertain the length of the belt as given by Adegoke [5] as;

$$L = 2C + 1.57(D_2 + D_1) + \frac{(D_2 - D_1)^2}{4C} \tag{4}$$

Where, L is the length of the belt in (mm), D_1 and D_2 are the diameters (mm) of the driver and driven pulleys, and C is the centre to centre distance (mm) of the two pulleys, and is given by equation (5) below, [5].

$$c = \frac{(D_1 + D_2)}{2} + D_1 \tag{5}$$

The centre distance, C between the adjacent pulleys were ascertained using equation (5) above to be 225 mm and 300 mm for the motor/auger and auger/cake breaker drives respectively. Putting D_1, D_2, and C into equation (4), gives the length of the V-belts required as 845mm and 450mm for the motor/auger and auger/cake breaker drives respectively. Since each of the drives transmits less than 3.5kW, V-belt of type "A" is required for both drives [5].

4.4 Shaft Design

Equation (6) gives the maximum stress relations for determining the diameters, d of the auger shaft and cake breaker shaft given as;

$$d = \left[\frac{16}{\pi\tau}\sqrt{(k_b M_b)^2 + (k_t M_t)^2}\right]^{1/2} \tag{6}$$

Where: τ is the stress (allowable stress) for steel shaft with provision for key ways, and is given as 42N/mm^2. M_t is the maximum twisting moment on the shafts (N-mm). M_b is the maximum bending moment on the shafts (N-mm). k_b is the combined shock and fatigue factor for bending. And k_t is the combined shock and fatigue factor for twisting. Note that Bending and twisting moments occur on shafts as a result of applied loads and belt tensions. The maximum twisting moment on each of the shafts was ascertained using the relationship as shown in equation 7 below as given by Adegoke [5].

$$M_t = (T_i - T_j)\frac{D_2}{2} \tag{7}$$

Where T_i for the motor/auger and auger/cake breaker drives was ascertained using equation (8), as given by Adegoke [5].

$$T_i = T_{max} - T_c \tag{8}$$

Where, T_c and T_{max} are the centrifugal and maximum tension of the belts, and is given as;

$$T_{max} = \sigma a \quad (9)$$

And

$$T_c = mv^2 \quad (10)$$

The coefficient of friction, μ between the pulleys and the belts, mass per unit length m, maximum safe stress σ, and cross-sectional area a, of the belts were obtained from standard tables as 0.3, 0.108kg/m, 2.1N/mm^2 and 81mm^2 respectively (IS: 2494-1974) [5] and [6].

Then the belt speeds, v for the motor/auger and auger/cake breaker drives were computed as 7.84m/s and 5.82m/s respectively from the relation;

$$v = \frac{n_2 \pi D_2}{60} \quad (11)$$

Therefore, substituting the values of equations (9, 10 and 11) into equation (8) gives the tension on the tight side for the motor/auger and auger/cake breaker drives as 163.79N and 168.52N respectively.

Consequently, the tension on slack side of each belt, T_j was determined using equation (12) as stated below;

$$2.3 log \frac{T_i}{T_j} = \mu \theta cosec\beta \quad (12)$$

The groove angle (2β) of each of the pulleys is 38^0 (thus, β = 19^0), while the angles of lap θ were determined as 2.74rad and 3.14rad for the motor/auger and the auger/cake breaker drives using equation (13) shown below as given by Adegoke [5].

$$\theta = 180 - 2\left[sin^{-1}(\frac{D_2+D_1}{2C})\right] \quad (13)$$

Therefore substituting the values of equation (13) into equation (12) gives 13.08N and 9.29N as the tension on the slack side for the motor/auger and auger/cake breaker drives respectively. Hence substituting the values of T_i, T_j, and D_2 from equations (8, 12 and 3) respectively into equation (7) gives the maximum twisting moments on the shafts as 7462.50N-mm and 145031N-mm for the cake breaker and auger respectively.

For the bending moment on the cake breaker shaft, consider the line diagram of the shaft as shown in Fig. 1;

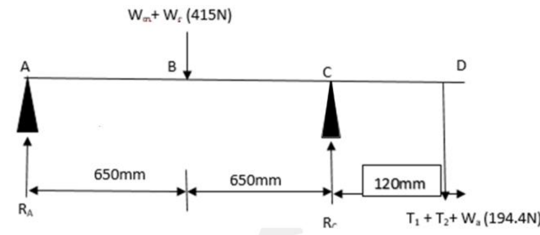

Fig. 1. The cake breaker shaft showing forces acting on it

Where:

W_c is the weight of the cake breaker = 29.43N
W_{cp} is the weight of the auger/cake breaker shafts driven pulley = 16.73N.
T_1 is the auger/cake breaker drive belts tight side tension = 168.52N.
T_2 is the auger/cake breaker drive belts slack side tension = 9.29N.

Therefore, the reactions, R_A and R_c were calculated by taking moment about A [7].

$$\sum M_A = 0$$
$$\therefore R_C(1300) = 194.4(1420) + 415(650)$$
$$\therefore R_C = 414.47N$$

Also $\sum F_y = 0$
$$\therefore 414.47 + 194.4 = 415 + R_A$$
$$\therefore R_A = 174.6N$$

Thus, the bending moments on this shaft were computed as follows; B.M. at A and D = 0N-mm
B.M. at B = 120755.25N-mm; B.M. at C = 25535.60N-mm

Thus, the maximum bending moment on the cake breaker shaft is 120755.25N-mm and since the feeding of the fairly compacted digested palm fruit cake from hopper into the uppermost part (chamber) of the machine is partially sudden, then K_b and K_t = 1.5. The maximum twisting moments on this shaft was also computed from equation (7) as 7462.50N-mm. Thus, the shaft diameter was calculated as 43.31mm using equation (6). Hence, a standard 45mm diameter solid shaft was selected for the operation of the cake breaking unit. Consequently, for the bending moment on the auger shaft, consider the line diagram of the shaft as shown in Fig. 2.

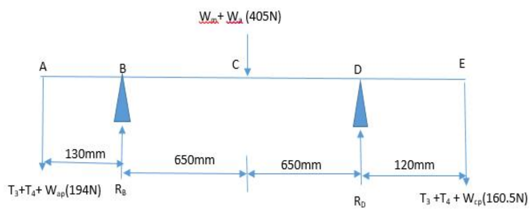

Fig. 2. The auger shaft showing forces acting on it

Where;

W_a is the auger weight = 40N
W_{ap} is the weight of the motor/auger shafts driven pulley = 17.13N
$W_{cp}$is the weight of the auger/cake breaker shafts driving pulley = 16.73N.
T_3 is the auger/cake breaker belts tight side tension = 163.79N
T_4 is the auger/cake breaker belts slack side tension = 13.08N.

The reactions of the bearings, R_B and R_D were determined by taking moment about B;

$$\sum M_B = 0$$
$$\therefore 170.8(1420) + R_D(1300) + 160(120) = 405(650)$$
$$\therefore R_D = 5.05N$$

Also $\sum F_y = 0$
$$\therefore 405 + 194 = 170.8 + 5.05 + R_B$$
$$\therefore R_B = 450.40\text{N}$$

Thus, the resultant bending moments on this shaft are as follows;

B.M. at A and E = 0N-mm
B.M. at B = 29000N-mm
B.M. at C = 135189.05 N-mm
B.M. at D = 22500.20 N-mm

Therefore, the maximum bending moment on the auger shaft is 135189.05 N-mm. The maximum twisting moment on this shaft was also determined from equation (7) as 145031 N-mm. Since the feeding of the slacked digested palm fruit cake fro into the auger separator is gradual and steady, K_b = 1.5, and K_t = 1.0 [5] and also the shaft diameter determined using equation (6) is 44.15 mm. Consequently, a standard 45mm diameter solid shaft was selected as auger shaft.

4.5 Design for Prime Mover

The power required for the operation of this machine is the total sum of the power required to drive its units and the power required to overcome the drives friction. The power, P required in the cake breaking and separating units were determined as 1.05kW and 1.55kW respectively using equation (14);

$$P = (T_i - T_j)v \tag{14}$$

Taking care of 10% possible power loss due to friction, the total power required to drive the developed palm nut-pulp separating machine was computed as 2.86kW (3.80HP). Therefore a 4HP electric motor was selected for the operation of this machine.

Fig. 3(a). Picture of the constructed machine

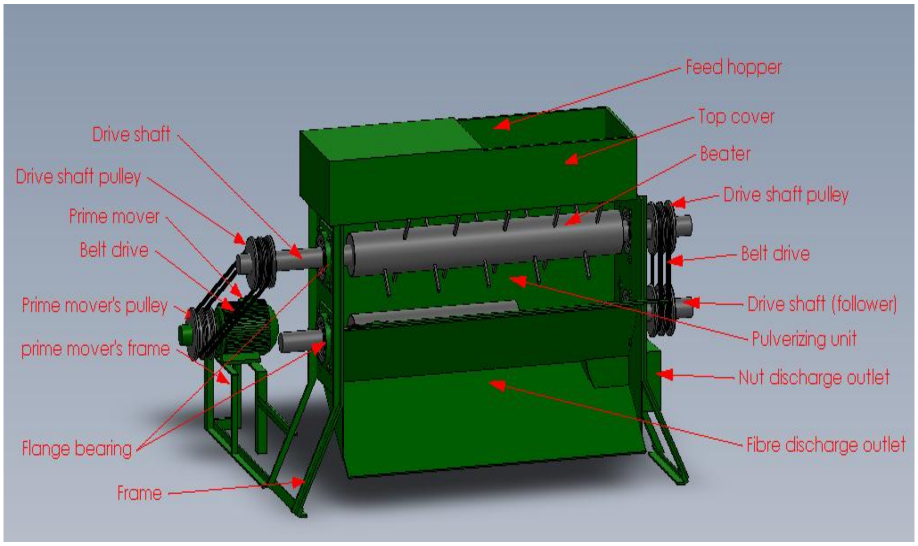

Fig. 3b. 3-D drawing of the constructed machine

5. RESULTS AND ANALYSIS

5.1 Test Procedure

The machine was assembled and run with no load for a period of five (5) minutes in other to certify that the different parts that make up the machine were working correctly. The separator was evaluated at different two levels of moisture content (dry and wet) and the quality performance efficiency, throughput capacity and separating efficiency were calculated at each of the various levels. In each of the test, 10kg weight of the sample was unsystematically fed through the hopper into the machine and the specific time t for the nut fibre mixture to be detached was recorded using a stopwatch. At the completion of each successive operation, the separated and unseparated nuts and fibre from the two outlets were carefully sorted out and weighed, and the machine performances such as throughput capacity, separation efficiency, and quality performance efficiency were computed using equations (15, 16, and 17) respectively.

Throughput capacity (C_t) was expressed as

$$C_t = \frac{(W_n + W_f)}{t} \qquad (15)$$

Where,

W_n (kg), is the weight of nuts collected after separation,
W_f (kg) is the weight of fibre collected after separation,
The average separation time (sec)

Separation Efficiency (E_s) as;

$$E_s = \frac{(W_n + W_f)}{W_m} \, x \, 100 \qquad (16)$$

Where, W_m (kg) is the weight of nut/fibre mixture sample fed into the machine

Quality Performance Efficiency (E_Q) as;

$$E_Q = \left[\frac{W_{nn}}{(W_{nn} + W_{nf})}\right] x \left[\frac{W_{ff}}{(W_{ff} + W_{fn})}\right] \qquad (17)$$

Where W_{nn} (kg) is the weight of separated nuts at the nut discharge outlet, W_{nf} (kg) is the weight of nuts at the fibre discharge outlet, W_{ff} (kg) is the weight of separated fibre at fibre discharge outlet and W_{fn} (kg) is the weight of fibre at nut discharge outlet. This process was repeated three times for each level and the average taken and result is presented in Tables 1 and 2.

5.2 Throughput Capacity

The throughput capacity is the rate at which the developed machine completely discharge the sample fed into it. This was calculated using equation (15), for each of the runs and the average values were obtained as 0.155kg/sec and 0.144 kg/sec for dry and wet sample respectively. The difference in the values of throughput capacity for the dry and wet sample was because the wet sample is sticky and some quantity of the fed sample sticks to the shafts and inner walls of both breaking and separating chambers. It was also seen that the time for complete separation reduced for the wet sample.

Table 1. The test result of the developed machine using dry digested palm fruit

S/N	W_n (kg)	W_f (kg)	W_{nn} (kg)	W_{fn} (kg)	W_{ff} (kg)	W_{nf} (kg)	t (sec)	C_t (kg/sec)	E_s (%)	E_Q (%)
1	3.6	5.4	3.1	0.5	5.1	0.3	58	0.155	90	83.1
2	3.7	5.2	3.3	0.4	4.7	0.5	60	0.148	89	80
3	3.5	5.5	3.2	0.3	5.1	0.4	55	0.163	90	83.9
Average	3.6	5.3	3.2	0.4	5.0	0.4	58	0.155	89.7	82.3

Table 2. The test result of the developed machine using wet digested palm fruit

S/N	W_n (kg)	W_f (kg)	W_{nn} (kg)	W_{fn} (kg)	W_{ff} (kg)	W_{nf} (kg)	t (sec)	C_t (kg/sec)	E_s (%)	E_Q (%)
1	3.5	4.5	3.0	0.5	4.2	0.3	55	0.145	80	81.3
2	3.4	4.6	3.0	0.4	4.1	0.5	52	0.153	80	78.1
3	3.4	4.4	2.9	0.5	4.1	0.3	53	0.134	78	80.7
Average	3.4	4.5	3.0	0.5	4.1	0.4	53	0.144	79.3	80.1

5.3 Separation Efficiency

The separation efficiency of the machine is the ratio of the total weight of the separated sample to the weight of the sample fed into the machine. This was calculated using equation (16) for the three runs and the average values obtained as 89.7% and 79.3% for the dry and wet sample respectively. This shows that the machine is quit efficient for both small and medium palm oil production. Also, the difference in the values for both dry and wet sample is still attributed to the sticky nature of the wet sample.

5.4 Quality Performance Efficiency

The quality performance efficiency can be seen as the product of the ratio of the weight of the nut discharged at the nut discharge unit after sorting to the total weight of the nut discharged at both nut and fibre discharge unit after sorting, and the ratio of the weight of the fibre at the fibre discharge unit after sorting to the total weight of fibre discharged at both unit after sorting. Simply put, it is the multiplication of the separating efficiency for nut and separating efficiency for fibre. This was computed using equation (17) above for the three runs and the average obtained as 82.3% and 80.1% for dry and wet sample respectively. The reduction in the values was because, the wet sample test, the greater portion of the fibre went with the nuts to be expelled at the nut discharge outlet, while some of the fibres were stuck in the fibre discharge opening thus causing a partial blockage of the opening. This was caused by the sticky nature of the wet sample.

6. CONCLUSION

In this work, a palm nut and fibre separating machine were designed and developed through detailed design considerations and proper material selection to ensure smooth operation. The functionality of the separator was fairly appreciable in many of the test cases. Still, there is a direct variation between the performance of the machine and the dryness of the mix. Optimally, the machine gave a throughput capacity of 0.155kg/sec, separating efficiency of 89.73% and quality performance efficiency of 82.3%. However, the throughput capacity, separating efficiency and quality performance efficiency for wet mixture gave 0.144kg/sec, 79.3% and 80.1% respectively. With this performance, the machine will reduce the associated problems and difficulties in the traditional method of separation. The total cost of production is one hundred and fifty two thousand naira (420 USD). Hence the Separation of digested palm fruit mash into palm nut and pulp before pressing of the pulp is mechanized, thereby improving the quantity of palm oil produced, by eliminating drudgery, nut breakage, and excessive loss of palm oil to pressed fibre, nut-fibre separation and second pressing operations.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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