Full Length Research Paper

Modification in the design of an already existing palm nut - fibre separator

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The modified palm nut-fibre separator machine comprises of a feed hopper, a separating chamber with an upper shaft carrying beaters which act as both conveyor and cake breaker and a lower shaft with sharp edged spiral worm and four fixed blades, a pair of adjustable blades, a prime mover (a 7.5 Hp electric motor of 1900 rpm, or its equivalent IC engine) and inlet and outlet funnels for nuts and fibers respectively. The performance test analysis indicates that the separation capacity is about 500 Kg/h with an efficiency of 92.5% and an optimum radial blade clearance of 2 mm. It is energy saving and affordable for small scale palm nut fruit processing mill operators.

Key words: Modification, palm nut - fibre, separator, palm oil.

INTRODUCTION

The shortages and importance of palm oil over the years in West Africa in particular, and other parts of the world where the production of the oil normally takes place has necessitated the need to improve upon the design of the palm oil machine, the most important of the components of which is the palm nut fibre separator . By doing so there will be enhancement in the productivity, efficiency, ergonomics and safety of handling the machine in order to achieve its cost effectiveness and its operation in a more hygienic, conducive and environmentally friendly conditions. These conditions will also attract the peasant farmers who produce the oil manually as well as investors to have a keen interest in investing in the palm oil producing industry to revitalize and expand the cultivated area under oil palm and this will go a long way in contributing to the economy of the countries where large cultivation of palm oil takes place. Palm oil production has been a target for small and large scale investors, and to follow the trend and encourage mass and qualitative production of the oil by local oil-palm farmers as well as supplement governments' efforts toward increment of local contents (in terms of machinery and equipment), there is the need to modify the design and manufacture of the existing palm-nut fibre separator machine that will

reduce the problems of crude, time and energy consuming, uneconomical and laborious methods of the palm oil production. This modified machine will also enhance the recovery of the fibre and palm kernels. The palm kernels can also be used to produce palm kernel oil in similar manner by the same small scale producers. The fibre and the shells can also be used to generate energy and/or for the production of other products.

Oil palm (*Eleasis guineesis*) is a perennial plant indigenous to tropical areas. It originated from Africa mostly in the southern parts of Ghana and Nigeria, but is grown in plantations in equatorial tropics in Southeast Asia and South America in different varieties (Hartman et al., 1993).

There are three main varieties of oil palm distinguished by their fruits characteristics. These are:

- Dura: This has a thick shell separating the pulp from the kernel. The kernel tends to be large, comprising 7 - 20% fruit weight.

- Tenera: This has a thin shell between pulp and kernel, together with a fibrous layer round the nut. The kernel is relatively small, comprising 3 - 15% fruit weight. The oil content is higher at 24 - 32%.

- Pisifera: This has no shell and is very frequently female sterile. As a result of their very marked tendency to female sterility, pisifera palms are not used for commercial

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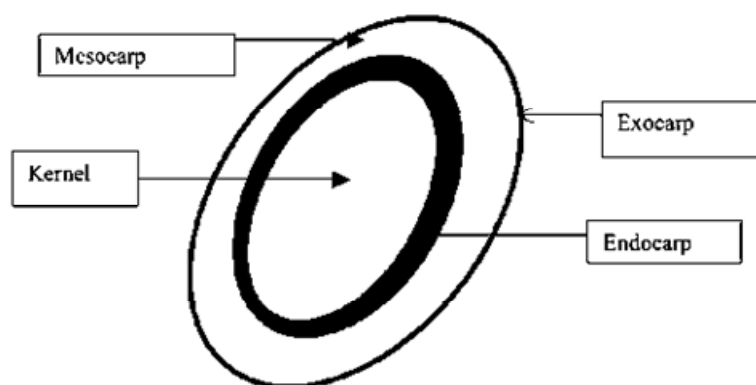*Corresponding author. E-mail: skadzimah@yahoo.com.

Figure 1. Layers of the palm fruit.

planting.

The pericarp is composed of large numbers of oil cells, which are full of oil when the fruit is freshly ripe. A cement-like material binds the cells to one another and to a skeleton of hard fibre running lengthwise through the pericarp, keeping it together.

Oil palm can be grown on a wide range of soils, the best being the coastal alluvial clay, riverine and coastal and soils of volcanic origin with slight acidity of pH value of about 4.6 - 6. They are grown in nursery for about a year before field planting with spacing of 7.8 × 9 m (Oluyemi, 1997).

It is generally known that the following conditions promote maximum palm growth; rainfall of 2000 mm, distributed evenly over the year (That is. with no very marked dry season). This accounts for yields in South East Asia (with no marked regular dry season) out-stripping those achieved in West Africa. It has been found that adequate soil moisture is more important than nutrient supply, which can be supplied artificially; a mean minimum temperature of 20° - 23°C and a mean maximum temperature of 28 - 32°C which is peculiar to tropical countries is best suited. If the temperature falls below this, particularly at night, say below 19°C, bunch development will be affected and yield will be reduced. Growth in young seedlings stops at temperature below 15°C. Constant sunshine amounting to at least 5 h per day over all the months of the year and as much as seven hours per day during some months, high atmospheric humidity and high CO_2 concentration are very good weather conditions for the growth of the crop (Bunker, 1995).

Germination can be accelerated by scarification, plus soaking in gibberellic acid at 100 ppm (part per million) for 72 h (Caulifield, 1997).

At the beginning of the twentieth century, Nigeria was the world's largest exporter of palm oil. At that period, oil palm accounted for 90% of the national total export. In fact, up till 1956, Nigeria was one of the foremost world's

producers and exporter of palm produce which accounted for over 40% of the total kernel exported and about 20% of palm oil in the world market. But between 1929 and 1974, there was a decline in the proportion of Nigeria's total exports from 47 - 13.2%. Though, latter in 1987, her exports increased to about 6.5 million tones, which earned her the third largest exporter of oil that year (Omuta and Onorkahrage, 1997).

The oil palm fruit is a sessile drupe and consists essentially of an exocarp (skin), a fleshly mesocarp which contains palm oil, a hard stony Endocarp (shell) and kernel (seed), the source of the kernel oil and meal (Poku, 2002) (Figure 1).

Oil of two kinds is obtained from oil palm: From the pericarps come the palm oil, and the inside, palm kernel oil.

The primary products of commerce of the oil palm tree are palm oil and palm kernel oil and kernel cake. The oils are by far the most important vegetable oil trade on the Nigerian (and indeed the world) market. However, the current annual demand is in excess of one (1) million metric tons of palm oil. There is, thus, clearly a deficit. The supply gap, high returns on investment and bright external trade opportunity in the oil palm business makes investment in the oil palm sector a safe and profitable venture (Spychalla et al., 1997).

To adequately meet domestic requirement and to go into the export trade, there has recently been a Presidential initiative in Ghana on oil palm to increase annual plantation to ultimately put at least one million hectares under improved cultivation in about five years (F.A.O., 2002).

Current estimate of total existing and functional palm fruit processing capacity is 295.3 tones of fresh fruit bunches (FFB) per hour. However, a lot of processing is still done by inefficient traditional methods. For this reason, locally manufactured machines are in high demand because of their adaptability and simplicity of operation. Large - scale mills can use recovered fibre and nutshells to fire steam boilers. The super-heated steam generated is then used to drive turbines to generate elec-

tricity for the mill. For this reason it makes economic sense to recover the fibre and palm kernels.

The specific objective of this paper is, therefore to improve upon the design of an existing palm nut-fibre separator machine with labour saving technologies that will enhance efficiency and reduce the cost of palm oil and palm kernel oil production by determining, experimentally, the optimum performance parameters of the machine.

MATERIALS AND METHODS

This project has been carried out using the methods of analytical and experimental procedures. These include:

1. Paying visits to the mills where the existing palm nut-fibre separator machines have been used.
2. Conducting interviews with the owners, operators, users and those who patronize these machines, to acquaint one with the problems they encounter in the course of using and operating the machines.
3. Observing the use, operation and functioning of the machines, ascertain the problems associated with them in order to come out with what modifications could be carried out on the design with the view of addressing these problems.
4. A performance testing was also carried out with the help of a weighing scale which was used to weigh the palm nuts, cake, fibre and the kernels.

Trends in the development of small- scale palm oil processing

Non - mechanized traditional methods of palm oil production: In small-scale processing, digestion, the breaking up of the oil - bearing cells of the palm fruit's mesocarp, is the most labour intensive. In general all crude palm oil extracting methods include:

1. A sterilization process where the fruit is softened up usually by heat treatment (boiling).
2. A digesting stage where the pulp is broken up to release the oil.
3. An extraction process to release oil from mashed fruit, and
4. A purification and clarification process where the oil is separated from water and cell debris (sludge), fibre and shell.

Two methods of fruit maceration are common in traditional processing

1. Pounding cooked/soaked fruit in large wooden or concrete mortars with a wooden pestle;
2. Foot trampling on the cooked but cold fruit in canoes or specially constructed wooden troughs.

The extraction rates for these methods are in the neighbourhood of 6 - 11%
The traditional method of oil extraction consists of:

1. Steeping the pounded fruit mash in hot or cold water.
2. Removing fibre and nuts in small basket and hand squeezing.
3. Filtering out residual fibre from the oil/water emulsion inperforated metal collanders or basket.
4. Boiling and skimming palm oil from the oil/water mixture.
5. Drying the recovered oil.

Mechanization of palm oil production

With the advent of international trade in palm products markets, mechanized and more efficient methods have been developed and continued to be improved on for both palm oil and palm kernel oil extraction. Locally, the traditional methods, with some introduction of labour saving machinery, are still used in processing (Bergert, 2000).

Mechanization was introduced to Cameroon in the 1930's through the importation of coil palm oil expellers. The coil is a low - pressure, continuous-feed expeller made in France. It has two 6' (2 m) diameter coaxial counter-rotating screws that turn horizontally or vertically in a perforated cage. The discharge end is fitted with a backpressure cone. As the cooked palm fruit is fed into the expeller it is pushed forward by the spiral flights (worms) against the backpressure of the end cone. The oil is forced out through the perforated sides of the cage. The remaining fibre and nut are released at the end of the cage through the gap between the end cone and cage body. The ability to simultaneously de-pulp and press is a major advantage of this type of press (Badmus, 1991).

In Nigeria and other West African countries like Ghana, the earliest equipment introduced was the stork manual hydraulic press. The impression was created that, for economic reasons, the only operation that needed mechanization was oil pressing. In colonial days farm labour was cheap and easily available. Hence there was no attempt to mechanize the digestion operation. Thus, in the British colonies Nigeria and Ghana, for example, early attempts at mechanization had to focus on complementing the presses with mechanical digesters. Two types of digesters were developed: horizontal digesters based on the dry process technique and the vertical digester, which adopted the wet process technique.

The mechanical digesters currently in use consist of a cylindrical shell and a system of beater-arms driven by a 6 hp. Diesel engine through a speed reducer (where necessary).

It was long realized that pressing is a bottleneck in small-scale palm oil processing. The process is usually conducted slowly to avoid the huge loss of oil that might result from inadequate pressing. The economic importance of this process was therefore long recognized and has received the greatest attention for mechanization. Presses developed over the years have included models such as:

1. Manual vertical screw-press
2. Stork hydraulic hand press
3. Motor-jack press
4. Motor-jack/cantilever press
5. Nigerian Institute for Oil Palm Research (NIFOR) hydraulic hand press
6. Combined screw/hydraulic hand press
7. Mechanical screw-press
8. Combination mechanical digester and screw-press
9. Combination digester and hydraulic press systems (by Techno Serve Inc.)

The NIFOR mechanical screw-press is the latest used by the small scale palm oil processing industry in Nigeria. This consists of a perforated tube inside which a transport screw rotates. The press outlet is more or less closed by a cone that regulates the pressing pressure. The worm transports and gradually compresses the macerated fruits. Released oil drains through the perforations in the tube. The press is mounted directly below a feed conveyor, which is fed by gravity by the horizontal digester. The body of the feed conveyor is perforated to allow oil released in the digester to drain away. Preliminary trials have shown that the press can handle over 1 ton FFB per hour with an average oil loss to fibre of 10.7%. The unit is sold together with the NIFOR sterilizer and continuous clari-

fier as a standard set of machines for palm oil processing (Ajibola, 1998)

Large scale automated palm oil production mills

Whilst the machinery used in extracting oil and kernel from fresh fruit bunches varies widely in the design of certain components, the general principles and required end products are similar at each stage of production. The essential features of automated oil palm mills are standard in that they consist of sections or stations for sterilization of bunches, stripping of bunches, digestion or mashing of fruit, extraction of mesocarp oil, clarifying the oil, separation of fibre from the nuts, nut drying, nut grading and cracking, kernel separation and discarding of the shell, and kernel drying and bagging (Cornish, 1991).

There is now a growing demand for locally produced machines in Nigeria and Ghana. In 1996, about 140 local fabricators were involved in producing machines to process oil seeds. About 95% of these fabricators produced machines for oil palm processing. (FAO, 2002).

Palm kernel recovery process

The residue from the press consists of a mixture of fibre and palm nuts (cake). Palm kernel recovery therefore is the process of separating the nut from the fibre. This process forms the onus of the design.

In the course of research for this project, the authors discovered limited sources and records on existing designs for small scale palm oil processing industry.

Hand sorting of palm nuts from the fibre

Traditionally, the nuts are separated from the fibre by hand in small scale operations. This early method is associated with enormous manpower and low efficiency. The sorted fibre is covered and allowed to dry, using its own internal exothermic reactions, for about two or three days. The fibre is then pressed in spindle presses to recover second grade (technical) oil that is used normally in soap-making. The nuts are usually dried and processed into palm kernel oil. The sorting operation is usually reserved for the youth, women and elders (Poku, 2002).

Hand sickle sorting of palm nuts from the fibre

The injurious nature of hand sorting is facilitated by the use of sickles. This is a hand tool usually made up of a wooden handle and a metallic part having serrated cutting edges. The tool is held with the handle while the serrated cutting edges are moved against the fibre kernel cake, breaking them and pulling out the fibre in-between the serrated cutting edges. Lots of time and energy is wasted in this method. The method increased safely with less improvement in manpower requirement and efficiency.

Depericarper sorting of palm nuts from the fibre

In large-scale kernel recovery process, the nuts contained in the pressed cake are separated from the fibre in a depericarper. This method involves the use of cyclone to drive the fibre off from the nut-fibre mixture after the cake has been broken down by the cake-breaker. This method is fully mechanized and has a high efficiency but is costly (Muthurajah 2000).

Components of the existing palm nut-fibre separator machine

The existing machine comprises of a hopper, a restriction bar to aid falling of the nuts, a gearing mechanism, a shaft on which twenty (20) pieces of beater arms in spiral form or of worm-like nature, and of specific diameter rod are welded along its length. The shaft is connected to a spindle through a simple spur gearing system. The spindle is attached to a handle and a crank with which the operator can start the machine (Figure 2).

Mode of operation of the existing palm nut-fibre separator machine

The machine is operated manually. The fruit is fed through the hopper/shroud manually with specific quantity, after which the operator rotates the shaft through the handle. The machine is then started on. The beaters break the fruits/cake and also separate the fibre from the nuts. Since the fruits are boiled the fibre slips round in the direction of rotation of the shaft until it passes through the fibre outlet funnel whilst the nuts also drop down through another outlet by gravity.

Problems associated with the existing palm nut-fibre separator machine

1. It has very low efficiency.
2. It operates with very low productivity.
3. It lacks ergonomics.
4. It is not safe to use.
5. It consumes a lot of energy.
6. It is not environmentally friendly.

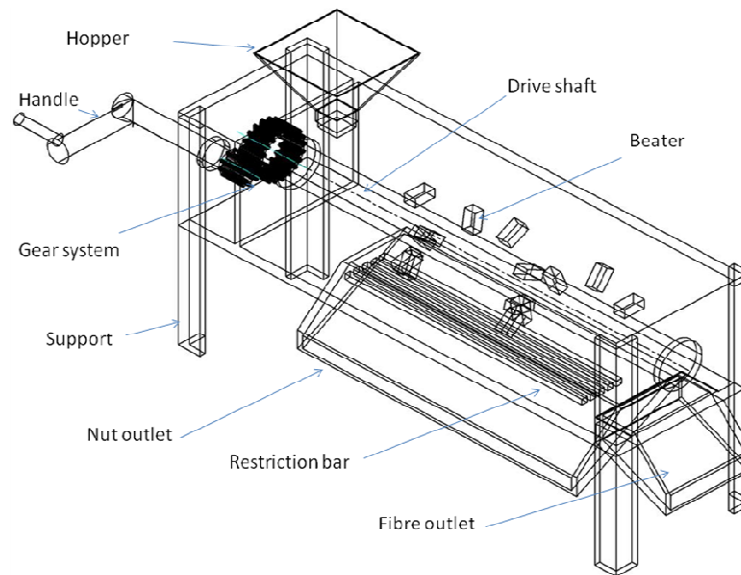## The modified design of the palm nut-fibre separator machine

This consists of two horizontal shafts: one above the other. The lower shaft carries four 2 mm axially fixed blades and worm blade of equal pitch that grabs the fibre and sends them to a funnel discharge: the second and upper one carries spikes of equal pitch in organ wheel arrangement which digests the cake and transports the nut in the main housing to the nut discharge funnel. Separating the lower shaft from the fibre discharge funnel are two adjustable plates, each on either sides. The lower shaft is driven by the upper shaft through a flat belt connected to the left end pulley which itself is driven by a 7.5 Hp electric motor engine. It is designed for efficiency above 90% with process capacity of about 500 kg/h.

The system is a continuous flow without idle time the moment operation commences, except for maintenance (Figure 3).

Procedures and analyses on the design of the modified palm nut-fibre separator machine

Modifications made in the design and operation of the palm nut-fibre separator:

1. A second shaft has been introduced to carry four spiral blades, equidistantly fixed on the shaft, to aid the first shaft (carrying the beaters) to facilitate the separation of the fibre from the nuts.
2. The restriction bar has been replaced with metallic mesh to facilitate falling of the nuts by gravity.
3. A motor has been introduced to drive the shaft mechanisms through a pulley assembly in place of manual operation through a gearing mechanism.

Figure 2. Diagram of the existing palm nut-fibre separator machine.
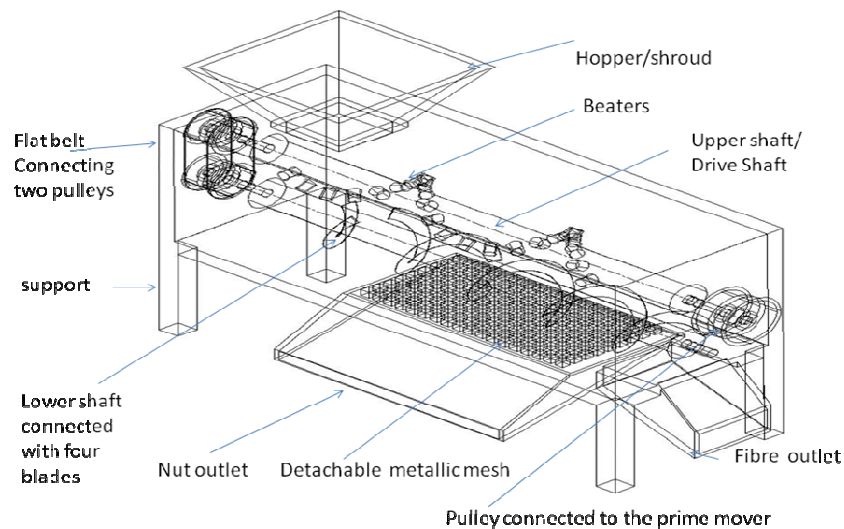
Figure 3. Diagram of the modified palm nut-fibre separator machine.

With these modifications the machine will have the following advantages over the existing one.

1.) It will be more productive.
2.) It will be more efficient.
3.) It will save time and energy.
4.) It will remove the fibre that will mix with the nuts.
5.) It will be automatic.
6.) It will be environmentally friendly.

The intended modification in the design of the machine is based on the impact force of the spikes on the upper shaft on cake, the gripping effect of the lower shaft on the fibre to the discharge funnel. To accomplish these, the following were taken into conside-

ration:

1. Sizing of the shafts
2. Selection of the pulley and determination of transmitted speed
3. Rating of the prime mover
4. Selection bearings
5. Choice of belt
6. Capacity of the hopper
7. Volume of the chamber
8. Process capacity
9. Force needed for digestion
10. Shear force and bending moment on the shafts
11. Determination of torque acting on the shafts
12. Determination of shaft life

13. Design for screw conveyor
14. Selection of the materials for the various components of the machine.

Selection of the pulleys and determination of their speeds

The system requires four pulleys for the drive: one pair on each end of the upper and the lower shafts. They are connected by open flat belts (Figures 4 and 5).

The relationship below is used to determine the transmitted speed.

$$\frac{Speed\ of\ driven}{Speed\ of\ driver} = \frac{Diameter\ of\ driver}{Diameter\ of\ driven}$$

The intended ratio of the speed of the driven pulley to that of the driver is 2:3
Therefore;

$$n_1 \times D_1 = n_2 \times D_2 \quad \text{or}$$

$$\frac{n_2}{n_1} = \frac{D_1}{D_2}$$

and

$$n_2 = \frac{n_1 \times D_1}{D_2}$$

$$n_2 = \frac{2850 \times 100}{150} = 1900 \text{ rpm}$$

$$n_3 = n_4 = n_2 \text{ For } D_3 = D_4 = 100 \text{ mm}$$

Where n_1 is the speed of primary driver pulley = 2850 rpm
D_1 is the diameter of primary driver pulley = 100 mm
D_2 is the diameter of primary driven pulley = 150 mm
n_2 is the speed of the primary driven pulley

Determination of centre distance

The centre distance, C, between two adjacent pulleys was determined using the relation:

$$C = \frac{D_1 \times D_2}{2} + D_1$$

(Khurmi and Gupta, 2005)

$$C = \frac{100 \times 150}{2} + 100$$

$$C = 225 \text{ mm}$$

(Note that the value of centre distance calculated must be approximated to match up with the available standard belt)
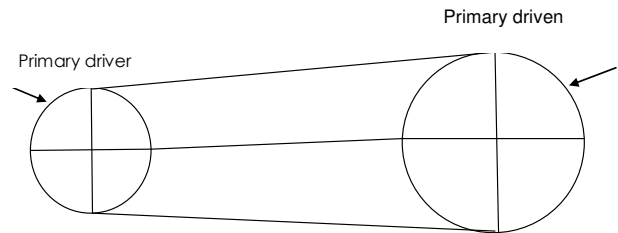

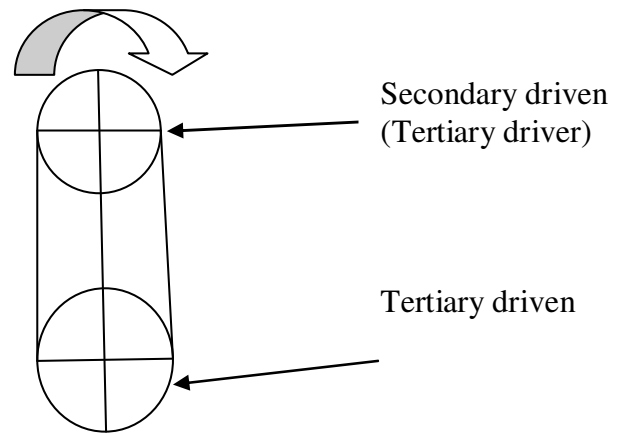**Figure 4.** Arrangement of the first pair of pulleys.

Figure 5. Arrangement of the second pair of pulleys.

Determination of the length (L) for cross belt

$$L = \frac{\pi}{2}(D_1 + D_2) + 2C + \frac{(D_1 - D_2)^2}{4c}$$ (Khurmi et al., 2005)

$$L = \frac{\pi}{2}(100 + 150) + 2(225) + \frac{(100 - 150)^2}{4(225)}$$

$$L = 845.48 \text{ mm}$$

Selection of the belt

The method, applied for the selection of the belt is to rate each standard thickness of belt in power capacity per unit length of the width at several different velocities. Several thicknesses of the belt and corresponding values of power capacity per unit length of the belt are selected from a standard table. The latter are divided into the required power and multiplied by service factors to give the required belt width (b).

The belt is selected based on the nature of the load it carries, type of driving unit, horsepower rating, the speed of the driver and driven units and the plant layout.

One (1) horsepower (Hp) converted into kilowatts = (Hp x 0.746) kW
Horsepower rating = 7.5 Hp = 5.59 kW
From standard tables, Service Factor = 1.4
Design Horsepower = Rated Horsepower × Service Factor
= 7.5 × 1.4= 10.5 Hp
Actual design power rating = Rated Horsepower × Service Factor × 0.746 = 7.5 × 1.4 × 0.746 = 7.833 kW
For 10.5 Hp and driver speed of 2850 rpm and above, type "A" or "AX" belt is selected.

Forces exerted on the shaft of the machine

Both sides of the belt are in tension as shown by Figures 6 and 7. The net force, F_N,   exerted by the belt on the shaft can be determined as follows:

$$F_N = F_1 - F_2 \tag{1}$$

Torque acting on the pulley "A", T_A, is calculated as:

T_A = Force × Radius of Pulley

$T_A = (F_1 + F_2) (D_A/2)$

Torque acting on the pulley "B", T_B, is calculated as:

$T_B = (F_1 + F_2) (D_B/2)$

The magnitude of the net driving force is computed from the torque transmitted (Cornish, 1991).

$$F_N = \frac{Mt}{D/2} \tag{2}$$

Combining equations (1) and (2)

$$F_1 - F_2 = Mt/R_2 \tag{3}$$

$$Mt = R_2 (F_1 - F_2) \tag{4}$$

Where;
Mt =Torsional moment on the shaft.
F_1 =Tight side tension.
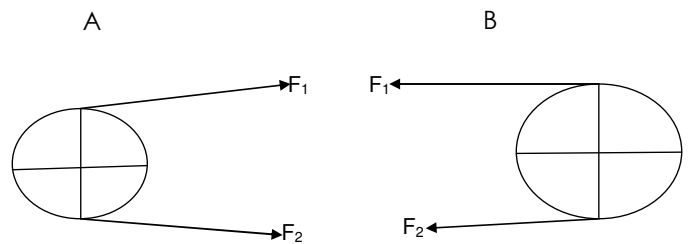F_2 = Slack side tension.
R_2 = Radius of driven pulley.

$$\frac{F1}{F2} = 1.5 \tag{5}$$

Calculation of torque acting on the shaft

Pulley motor rated horse power = 7.5 Hp
Power required = Design horse power × 0 .746 kW
= 10.5 × 0 .746
= 7.833 kW
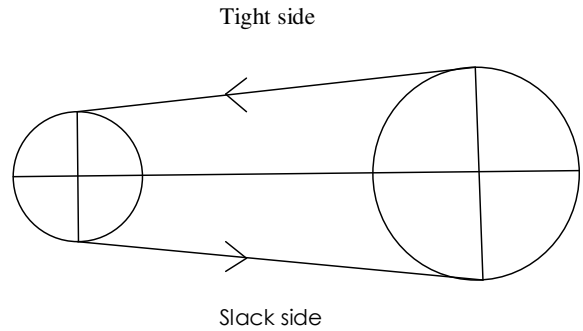
Figure 6. Tight and the slack sides of belt tension

Figure 7. Forces exerted by the belt.

$$Torque, Mt = \frac{power\ transmitted}{2\pi N}$$

Where; N = Shaft speed rpm

$$Torque, Mt = \frac{7.833 \times 1000 \times 60}{2 \times \pi \times 1000} = 39.37 \text{ N-m}$$

From equations (3) and (4), $Mt = R_2 (F_1 - F_2) = 39.37$ N-m and since $R_2 = 0.075$ m we solve for F_1 and F_2 as $F_1 = 656.2$ N and $F_2 = 131.2$ N
Therefore, belt tension $F_b = F_1 + F_2 = 656.2 + 131.2 = 787.4$ N

Shaft design consideration

The shafts are cylindrical with circular cross sections and pulleys and bearings mounted on them. One has beaters mounted on it, while the other has a short sharp spiral attachment. Since the shaft with beaters is more loaded, the design of the shafts is based on it. The shaft will be subjected to fluctuating torque and bending moments, and therefore combined shock and fatigue factors are taken into account.
To determine the shaft diameter, the equivalent bending moment, M_c, is used.

$$M_c = 1/2 [K_m \times M + \sqrt{[(K_m \times M)^2 + (K_t \times T)^2]}] \tag{6}$$

Where; K_m = Combined shock and fatigue factor for bending, and K_t = Combined shock and fatigue factor for torsion (Khurmi et al., 2005).
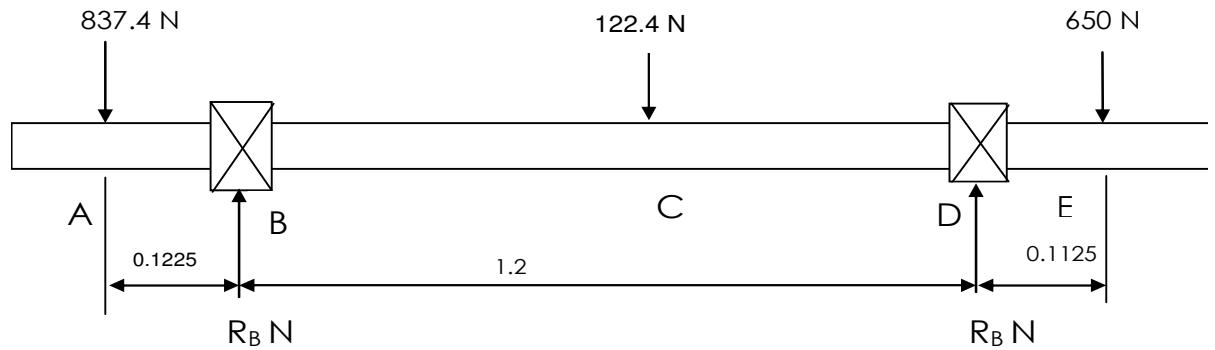Bending Moment and Shear Force Bending can occur as a result

Figure 8. Shaft Showing forces acting on It. (dimensions are in metres).
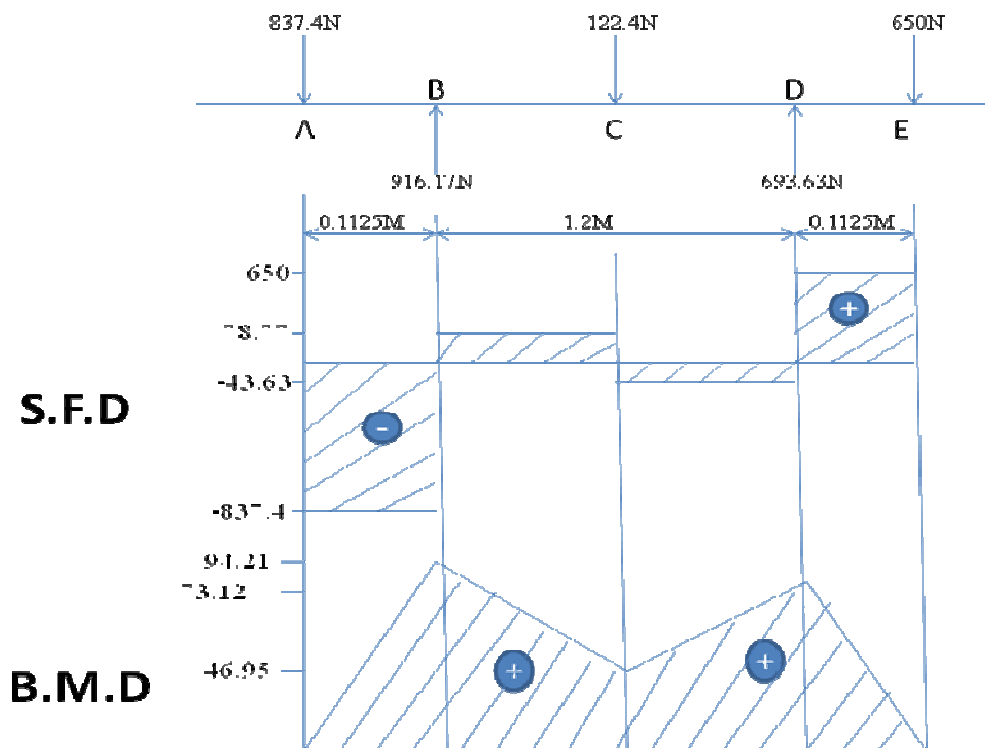

Figure 9. Shear force and bending moment diagram of the drive shaft in static position.

of the applied loads on the shaft and belt tension.

Belt tension, F_b = 787.4 N
Weight of pulley = 50 N
Estimated distributed load = 102 N/m
Force at point A = 787.4 + 50 = 837.4 N
Force at point E = 650 N (Figure 8).
$R_B + R_D$ = 837.4 + 122.4 + 650 = 1609.8

Taking moment about point B

$R_D \times 1.2 + 837.4 \times 0.1125 = 122.4 \times 0.6 + 650 \times 1.3125$

R_B = 832.36 / 1.2 = 693.63 N
R_B = 1609.8 - 693.63 = 916.17 N (Figure 9).

Shear forces acting on the shaft

Taking downward force to be negative (-) and the upward force to positive   (+).

For point A = -837.4 N.
For point B = -837.4 + 916.17 = 78.77 N.
For point C = 78.77 - 122.4 = -43.63 N.
For point D = - 43.63 + 693.63 = 650 N.

For point E = 650 + 650 = 0 N.

Bending moments on the shaft

M_A = 0.1125 × 0 = 0.
M_B = 837.4 × 0.1125 - 916.17 (0.1125 - 0.1125) = 94.21 N.
M_c = 837.4 × 0.7125 - 916.17 × (0.7125 - 0.1125) + 122.4 (0.7125 – 0.7125) = 46.95 N

M_D = 837.4 × 1.3125 - 916.17 × (1.3125 - 0.1125) + 122.4 (1.3125 - 0.7125) = 73.12 N
M_E = 834.4 × 1.425 - 916.17 × (1.425 - 0.1125) + 122.4 × (1.425 - 0.7125) - 693.63 (1.425 - 1.3125) = 0

Diameter of the shaft

Choosing shaft material of 0.26 carbon steel (BS 070m26) cold drawn with maximum permissible working stress, σ_b = 84MPa (ASME CODE - Khurmi et. al., 2005).
The maximum bending moment $M_{max} = M_B$ = 94.21 N
Using the equivalent bending moment M_c we have:

Torque = 39.35 × 10³ N-mm
$M_c = \frac{1}{2} [(K_m \times M_B) + \sqrt{(K_m \times M_B)^2 + (K_t \times M_t)^2}]$ 　　(7)
K_m = 1.5
K_t = 1.0
$M_c = \frac{1}{2} [(1.5 \times 94.21 \times 10^3) + \sqrt{(1.5 \times 94.21 \times 10^3)^2 + (1.0 \times 39.35 \times 10^3)^2}]$
= 143 × 10³ N/mm²

Also,

$$M_c = (\pi \sigma_b d^3)/32$$ 　　(8)

Thus d = $[(32 \times M_c)/ \pi \sigma_b]^{1/3} = [(32 \times 143 \times 10^3)/ \pi \times 84]^{1/3}$ = 26 mm

As standard, 30 mm diameter shaft is chosen.

Determination of shaft life

The following mathematical relations are used in the determination of the life of the shaft:

$$N_L = 10^{b/m}/ S_f^{1/m}$$ 　　(9)

Where;
N_L = Shaft life.
S_f = Fatigue strength
M and b are constants to be determined; thus

$$m = 1/3 \log (0.9 S_{ut})/ S_c$$ 　　(10)

b = $\log (0.9 S_{ut})^2/ S_c$
S_{ut} = 430 MPa
S_c = 98.98 MPa
M = 0.1975
b = 3.1802
N_L = 443 × 10⁸ Cycles

Selection of the materials for the various components of the machine

The criteria for material selection of the materials for the various components of the machine is based on the type of force that will be acting on them, the work they are expected to perform, the environmental condition in which they will function, their useful physical and mechanical properties, the cost, toxicity of materials and their availability in the local market or the environment (Cornish, 1991).

Material for the hollow shaft for the machine

Material selected: A mild steel of 0.26% carbon.
Selection criteria: Easy machinability, local availability, non-toxicity and its strength.
Specification: Overall length = 2400 mm and the Diameter = 115 mm
Useful property values: it is cold drawn with a yield strength of 230 MPa, a maximum permissible working stress, σ_b = 84 MPa and permissible tensile stress of 56 MPa.

Material for the solid shaft of the machine

Material selection properties and criteria are as stated above.
Specification: Overall length = 3300 mm and the Diameter = 30 mm

Material for the pulleys of the machine

Material selected is cheap and affordable, resistant to heat and wear, and easily machinable.
Specifications: For the primary pulley the diameter = 150 mm and for the secondary pulley the diameter =100 mm.

Belt for the pulleys of the machine

Material selected: Tanned leather (flat) belt.
Selection Criteria: It is of high efficiency, soft, flexible and strong.

Specification: Thickness = 5 mm and width = 45 mm.

Beaters on the shafts of machine

Material Selected: Mild steel rod.
Selected Criteria: Non – poisonous, not easily worn out, easily machinable and strong.
Specification: Overall length = 560 mm; diameter = 20 mm.

Base of the machine

Material Selected: Mild Steel (Equal angle section).
Selection Criteria: Locally available and is of high carrying capacity.
Specification: Overall dimension (7300 × 5 mm).

Feed hopper, cover (top, side, and bottom) and discharge funnels

Material Selected: Mild steel plate.
Selection Criteria: Easy fabrication and non-toxicity.
Specification: Overall dimension (450 × 900 × 6 mm).

Main housing of the machine

Material Selected: Mild steel plate.
Selection Criteria: Non- toxicity and easy fabrication.
Specification: Overall dimension (1150 × 200 × 8 mm).

Bolts and nuts

Material Selected: Mild steel of 0.35% carbon and 0.60% manganese.
Selection Criteria: High strength and hardness.
Specification: 12 and 10 mm bolts and nuts.

Bearings on the shafts of the machine

Material selected: Ball Bearing (6306).

Fabrication details and methods

The important components of the machine are listed below:

1. The feed hopper and cover plate.
2. The main housing.
3. The drive shaft (conveying shaft/cake breaker).
4. The lower shaft.
5. Flat belt pulleys.
6. Adjustable blades
7. Machine base supports

Fabrication procedures of the components of the machine

Feed hopper and cover plate of the machine

The hopper is a square frustum-shaped component placed on the top left hand side of the cover plate of the machine.
The flat plate is cut into four (4) with the size of 400 mm top length, 155 mm base length of 300 mm each. They are welded together to form a square (shaped) frustum. The base forms the throat.
The hopper is attached to a cover plate by fillet weld. It is easily detachable for inspection and maintenance purposes. The cover plate is attached to the main body with 10 - M10 bolts and nuts.

Main housing of the machine

The main housing of the machine consists of the bottom plate, side plates and the discharge funnels, all made from 6 mm thick mild steel plate. The bottom plate is welded together with the discharge funnels to the machine base while the side plates are rigidly bolted to the machine base with 12 - M12 bolts and nuts.

Drive shaft of the machine

This is a solid shaft of diameter 30 mm and length of 1650 mm. It is attached to a hollow shaft of diameter 102 mm and length 1200 mm. Beaters of short mild steel rod in organ - wheel arrangement are attached on the shaft. This shaft is enclosed inside the main housing, fixed at both ends with 6306 bearings.

Lower shaft of the machine

This is of the same dimension as the drive shaft except that the right - end is stepped down for the passage of the nuts and on it are 4 blades at right angles to each other with sharp-edged spiral running from left to right with a pitch of 220 mm. It is driven by the upper shaft through a pulley and belt.

Adjustable blades of the machine

The blades are attached in between the drive and the lower shafts on both sides. They can be adjusted by 2 adjusting studs welded to them. The dimension is 1075 × 100 × 8mm.

Beaters on the solid shaft of the machine

These consist of twenty-four (24) pieces of 40 × 20 mm diameter rod. It is uniformly arranged and welded in spiral form (organ wheel) of 220 mm pitch to drive shaft. This arrangement enables the shaft to function as both cake breaker and conveyor.

Base and support of the machine

The base is fabricated from angle section bar cut into four (4) pieces welded together with round bars of mild steel.

Painting of the machine

To prevent surface corrosion and for aesthetic purposes, the machine is painted with blue paint after priming with red oxide pain

Assembly of the machine

Assembly procedure

The lower shaft is fixed and positioned in the base with the bearings and the bearing cups. The adjustable blades are fastened on the top of the supports on both sides with 3 - M10 bolts and nuts.
The drive shaft is then mounted on the blade and lower shaft with free clearance. The pulleys are then fastened and keyed to the shaft using 10 × 10 mm square keyed M12 lock screws. The side plates are then fastened with 12 M bolts and nuts (Burr and Cheatham, 2002). The hopper, which is attached to the cover plate, is then fastened to the top of the main housing with 10 - M10 bolts and nuts. The electric motor is mounted on its base and firmly bolted while the pulleys are connected together from the motor to the primary (large) pulley between the two secondary pulleys that are attached at the driving shaft to the lower shaft by flat leather belts.

Installation, operation and maintenance of the machine

Installation procedure of the machine

The machine should be installed on a 4" concrete slab to avoid vibration. It should be firmly bolted on the foundation using foundation bolts and shock pads to avoid excessive vibration.
The shaft and pulley alignment is essential to prevent wobbling and noise.
The space for installation should be about 4 × 2 m since the to-

Table 1. Mass of cakes separated over a specific time.

Test	Mass of cakes (kg)	Time taken (s)	Blade/shaft clearance (mm)
1	8.00	58	2
2	8.00	56	2
3	8.00	60	2
4	8.00	58	2

tal length is about 2.0 m. The height of the machine, which is about 1.2 m, should be considered while building a shelter for it.

The equipment requires a 7.5 Hp electric motor and the service of two operators.

The condition of belts, mounting, tightness of bolts, alignment of shafts and pulley should be properly checked before every operation.

The machine should not be overloaded or its design capacity exceeded; and it must be ensured that the equipment attains sufficient speed before loading.

In maintenance procedure, the reverse of the installation should be followed. Sufficient and proper lubrication of the bearings should be carried out since insufficient and excess lubricant will cause high operation temperature.

The equipment should not be exposed to rainfall to minimize corrosion of components (Burr et al., 2002).

Performance test for the machine

In actualizing the aims of this project, the performance test should be carried out after the equipment has been assembled. The machine should be started and four different samples of equal weighted mass of palm fruits pressed cakes fed through the hopper, each time. A stop watch should be used to monitor the time taken for separation per batch. A 7-Hp-3-phase motor should be used as prime mover. A clearance of 2 mm should be maintained between the adjustable blades and lower shaft. The possible result is given in Table 1.

The average performance of the machine is estimated to be 8 kg/ 58 s. Hence, the capacity of the machine is approximately 500 kg/h.

Efficiency of the machine

From the four tests carried out, 8.00 kg of cake will be taken and fed through the hopper when the machine is running. The outputs of a separated nut and fibre will be taken and weighed. The expected result is as follows:

The input (weight of cake) = 8.00 kg
Weight of nuts = 6.00 kg
Weight of fibre = 1.40 kg
The output (weight of nuts + weight of fibre) = 6.00 + 1.40 = 7.40 kg
Efficiency = (Output/Input) × 100% = (7.40/8.00) × 100% = 92.5%

Cost analysis of the materials and production of the machine.

The major components of the machine have been quantified. The estimated cost of the materials used (as selected above), the cost of their production (labour) and other (miscellaneous) expenditures

have been summarized and presented as shown in Table 2

DISCUSSION OF RESULTS

The results of the performance test show that the machine performed above 90% efficiency as expected at optimal blade clearance of 2 mm (Table 1).

Conclusion

The modifications introduced in the design and operation of palm nut - fibre separator machine, if implemented, will be beneficial and advantageous in the following:

1. The processing of palm fruit bunches will be enhanced to achieve the production of high quality palm oil on relatively large scale for domestic and industrial uses.
2. It will guide the manufacturers to modify the components of the existing machine which entails promotion of technology transfer and adoption for the production of palm nut- fibre separator from small to medium scale level.
3. It is anticipated that the patronage by peasant farmers and other users of the new machine so modified will reduce drastically the labour, fatigue and cost involved in the production of palm oil in a more hygienic way and under very conducive environmentally friendly conditions.
4. Agricultural sector in the West African sub-region and other parts of the world where palm trees are cultivated will be boosted once again through the use of such modified machines aimed at adding values to very important agricultural product such as palm oil.
5. The national economy will be boosted since adoption of such machines will help in high productivity of quality palm oil as one of the agricultural products which has been the bed rock of national economy through earning of more foreign exchange.

Recommendations

I recommend that subsequent work on nut recovery should be focused on for further improvement and incurporation of this equipment. The following suggestions can be adopted:

Table 2. Cost analysis of materials and production.

Item no	Description	Unit	Quantity	Unit price(US$)	Total price(US$)
1	Mild steel plate 2438 × 1219 × 2	mm	1 pc	80	80
2	3'' V-section mild steel bar of 18 ft length	ft	2 pcs	48	96
3	105 × 2400 × 6 hollow steel pipe	mm	1 length	95	95
4	30 × 2000 × 6 steel rod	mm	2 length	80	160
5	Bearing with housing	6306SKF	4 pcs	12	48
6	20 × 560	mm	1 pc	70	70
7	Pulley (50 × 150)	mm	1 pc	20	20
8	Pulley(25 × 100)	mm	2 pcs	15	30
9	M-12 bolts and nuts	mm	10 pcs	0.30	3
10	M-10 bolts and nuts	mm	24 pcs	0.20	4.80
11	7.5 Hp electric motor (rented)	Hp	1 pc	50	50
12	Labour				200
13	Miscellaneous				100
	Total				956.80

1. A feedback system that automatically re-feeds cakes which have not been separated.

2. The use of diesel or petrol powered engine to eliminate dependency on the epileptic electric power supply.

3. The previous process preceding the separation of fibre and nuts like the digestion and pressing should be efficient so that the cake will be dried and the pericap loosened from the nuts before separation to aid easy cake breakage and separation.

4. The conveying screws system should be improved upon to reduce the separation.

5. The use of belt and pulleys to increase power transmission efficiency instead of gearing systems should be encouraged.

I strongly recommend that manufacturers take up the modifications outlined in this paper and implement them in the existing palm nut -fibre separator machine.

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