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DESIGN ENHANCEMENT OF A DUAL-MODE MOTORIZED PALM FRUIT STRIPPER FOR QUARTERED PALM BUNCHES.

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Abstract

Lack of adequate processing technology to meet the growing interest of local oil palm (elaesis guineansis) farmers in West Africa and Nigeria in particular had compelled the conceptualization of a dual-mode powered double discharge outlet palm fruit stripper machine designed to enhance efficiency while operated both electrically or manually with an output capacity of 0.729 tone/hr stripping efficiency of 44.2% and high-quality operational efficiency of 51.9% at 90 minutes of sterilization time. At the time the machine is physically fabricated and powered by an electric motor, it will likely run at I beater speed (1145rpm) with quartered bunches sterilized at 90 minutes. The optimal working performance of the machine will be rated at 1145 rpm, time of sterilization at 90 minutes and the output capacity of 2.12 tone/hr., stripping efficiency of 46:8% and excellent operational efficiency of 54.1%. The economic analysis of physically producing one unit of the designed palm fruit stripper machine is currently estimated at five hundred and eighty thousand, one hundred and fifty naira only (₦580, 150.00) excluding cost for electric motor requiring output power of 0.75Kw when operated.

Key words: design, palm fruit stripper, efficiency, machine, manually, electrically.

Nomenclature/Abbreviations

W_b	=	Weight per unit length of belt
T_c	=	Centrifugal tension
V_b	=	Belt Velocity
δ	=	Maximum safe of the belt
a	=	Cross Sectional area
L	=	Length of belt
ρ	=	Density
μ	=	Coefficient of friction
θ	=	Active angle on pulley
T_1	=	Tension on the tight side of the belt
T_2	=	Tension of the slack side of the belt
β	=	Angle of flat belt groove
P	=	Power
Q	=	Torque

R	=	Radius of the driven pulley
R_c	=	Reaction at A
R_d	=	Reaction at B
W_c	=	Load on the shaft in the chamber
W_g	=	Weight of the quartered bunches
V_s	=	Volume of separating chamber
D	=	Diameter of shaft
T	=	Maximum tension in the belt
n_1	=	Speed of driver pulley in rpm
n_2	=	Speed of driven pulley in rpm
d_1	=	Outside diameter of driver pulley
d_2	=	Outside diameter of driven pulley
d_A	=	Pitch diameter of driver pulley
d_B	=	Pitch diameter of driven pulley
K_s	=	Service factor
P_r	=	Power range
t	=	Thickness of a belt
X	=	Distance between the shaft
P_d	=	Design power
V	=	Speed of the belt
q	=	Distributed load
T_a	=	Average time of stripping
C_t	=	Output capacity
η_s	=	Stripping efficiency
η_q	=	Quality performance efficiency
W_g	=	Weight of quartered bunches
W_{fb}	=	Weight of stripped fruit at the bunch outlet
W_{bs}	=	Weight of fruits at the fruit outlet
W_{bf}	=	Weigh of stripped bunch at the fruit outlet.

1.0 Introduction

The processing palm fruit bunches in a modern way involves different method of application which may be likely categorized according to their throughput and degree of complexity. Ologunagba & Ojomo (2010) identifies these categories as traditional methods, small scale mechanical unit, medium scale mills and large industrial mills.

Ologunagba & Ojomo (2010) further argues that any processing units capable of handling at least two tons of fresh palm fruit bunches (FPFB) per hour is categorized under small-scale processing unit. Whereas those that process from three to about eight tones FPFB per hour falls under the medium-scale category, and those that can process from ten tones and above per hour are categorized as large-scale.

Several literatures abound on traditional processing methods, medium and large-scale processing methods of fresh palm fruits; yet little or no information on small-scale processing can be seen. Salinaih (2005) attributed the reason for the availability of long history of information on medium to large-scale palm fruit machinery processing in Europe to the fact that most innovation work on fresh palm fruit bunches processing machinery in Europe was inspired by the crude traditional methods practiced in West Africa.

According to Ademola & Oluatosin 2017, a survey conducted shows that 80% of Nigerians oil palm resource exists locally with the uses of either manual or traditional processing techniques, hence the reason why palm oil industry in the country remain subsistent with very few large estate plantations that make large mills and imported mills relatively expensive and unaffordable by most local farmers, thereby making the traditional method to predominate (Ohimain et al. 2013).

Kamaldeen et.al. (2024) argues that in view of the predominant manual processing method by small and medium processors, the quality of palm oil produced is poor and production costs are high. Again the significant and intensive nature of the labor demand, the processing methods which is time consuming, and threshing of fresh palm fruit from bunches which is done manually can lead to injuries, damage to the fruits, and subpar oil quality due to the accumulation of Free Fatty Acids (FFAs) during the fermentation process (Tan et. al. 2023).

To improve on the prevailing situation, the use of better technology which aims at improving efficiency for extracting palm oil is now a necessity Busari et at 2022 & Sanusi et al 2022.

While Nigeria is still technologically lacking backward, development of sophisticated machinery to improve upon the traditional methods requires a holistic and intentional approach at all levels if any progress is to be made in modern high quality palm oil processing (Stephen 2014).

This research therefore conceptualized a design for a quarter bunch dual-mode palm fruits stripper machine for small scale stripping process in Nigeria.

2.0 Structure of the palm fruit

The structure of the individual fruit shown in (Fig 1) ranging from 6 to 20gm, are made up of an outer skin (Exocarp), a pulp (Mesocarp) containing the palm oil in a fibrous matrix, a central nut consisting of a shell (Endocarp) and the kernel, which itself contains an oil, quite different to palm oil, resembling coconut oil while the full palm fruits bunches is shown (Fig2) varying from 10 to 40kg in weight.

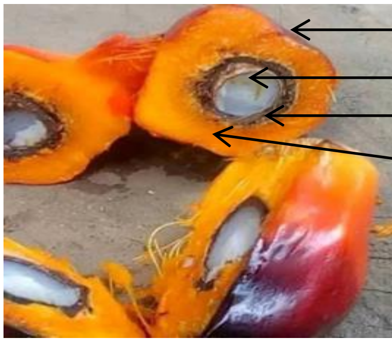


Diagram 2.1: Structure of the Palm Fruit.

Fig. 2.1: Fresh Fruit Bunch

2.1 : Design and Equipment Selection Criteria

A key criterion to consider when designing equipment for small-scale oil extraction is the quality required. Quality is entirely subjective and demands of the ultimate consumer.

The important quality criteria for crude palm fruit stripper considered by the threshing industries are;

- Output Capacity.
- Stripping Efficiency
- Quality performance efficiency

The most critical stages in the processing sequence for threshing fruit, seeking to safety the criteria is the bunch sterilization time, the sterilization time determines the result output. This is boosted by the sterilization time that take place within the fruits where the bunches are heated. Therefore, quality performance processing during threshing of palm fruit need not be prescribed or incorporated in the design.

Traditionally manual methods are normally referred to as low technology production. The village traditional method of threshing of palm fruit involves sterilization of fruits and then hitting the sterilized bunches with machete or hard wood to separate the fruit from the bunches. The mechanized units are likewise referred to as intermediate technology production.

The mechanize method involves electric motor, V belt, pulley and the main body fitted with 1115mm shaft long and attached with beaters.

2.2 : Material Selection

The proper selection of a material or component for engineering purpose is one of the most difficult problems in engineering design, as stated by Khurmi, and Gupta (2005). However a decision of material selection must be taken into positive consideration to enhance the functionality and the durability of the machine (Takim et.al 2023). The best materials or component is one which gives the desired objective at the separator; these are the belt, pulley, Electric motor, bearing, shaft, fruits and bunch outlet attached to the separating chamber.

a) The belt material selected was V-belt because it is readily available and also cheap. V-belt are also high efficiently, soft, flexible and strong. This material is suitable in dam atmosphere and they can be exposed to moisture.
b) The pulley material selected was cast iron steel because of its cheap and affordability, resistance to heat, wear and easily machine able.
c) The frame comprises of the main frame of the separator and brazed, both of them are designed with an angle bar bin to avoid vibration during operation.
d) The shaft is filled with beaters for stripping function. The material used is mild steel materials due to non-toxicity local availability and its strength.
e) The bearing selected is a radial ball bearing (6306) 40mm outside diameter.
f) The stripper machine has bunch outlet and two discharge fruit outlets at the front of the separator, which is made from mild steel sheet 16-guage metal. A thin sheet were used to discharge fruit. The outlet was projected at the front edges of the stripper machine for faster discharge fruit.

2.3 : Design Consideration

The intended modification of machine will be based on the impact of force on the shaft, the gripping effect of the shaft on the bunch to the discharge outlets while taking into consideration the following:

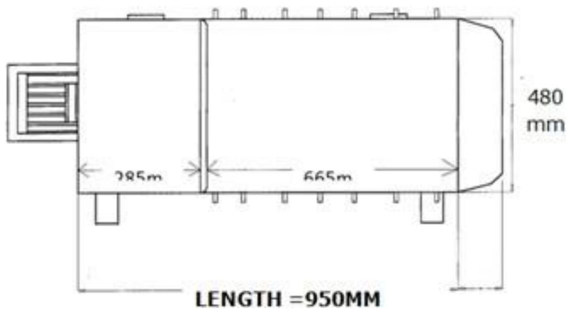
i. Selection of bearing
ii. Size of the shaft
iii. The volume of the chamber
iv. The size of the belt
v. Selection of pulley & determination of transmitted speed

2.4 : Simplicity

The simplicity of fabrication of the machine for efficient productivity, the ease of dismantling for routine checks, cleaning and maintenance of the machine as the need may arise was of topmost consideration during the design.

PLAN VIEW

SIDE VIEW



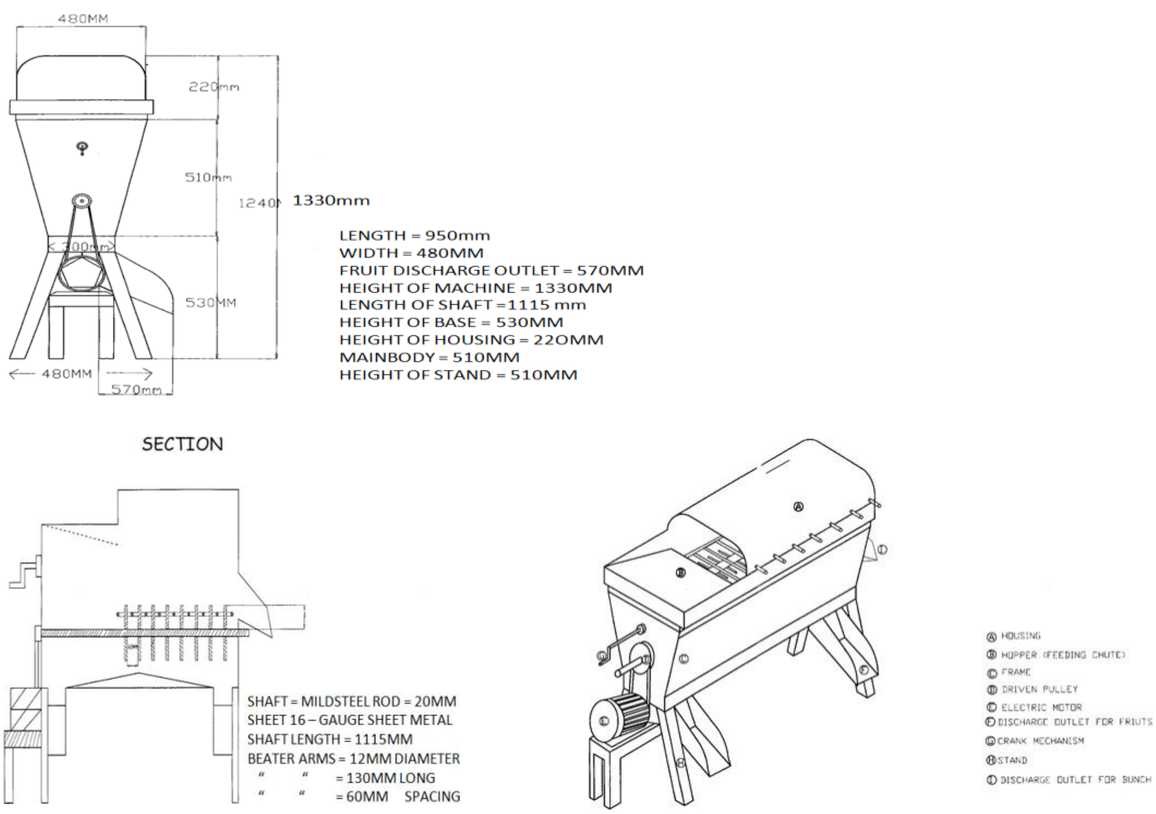


FIG 6 : This figure shows the Isometric view of the dual motorized palm fruit stripper for quarter bunch.

3.0: Design Analysis/Calculation

Determination of power required by the machine

$n_1 = 1400$ r.p.m

$n_2 = \frac{n_1 d_1}{d_2}$, $n_2 = \frac{1400 x 90}{110} = 1145$

$n_2 = 1145$ r.p.m
$d_1 = 90mm$
$d_2 = 110mm$
$d_A = 20mm$
$d_B = 20mm$
$K_S = 1.2$
$Pr = 0.75kw$
$t = 12.5mm$
$d = 20mm$
n_1 is the speed of driver pulley in r.p.m
n_2 is the speed of driven pulley in r.p.m
d_1 is the outside diameter of driver pulley
d_2 is the outside diameter of driven pulley
d_A is the pitch diameter of driver pulley
d_B is the pitch diameter of driven pulley
d is the diameter of the shaft
K_S is the service factor
P_r is the power range
t is the thickness of a belt
(From the table: section A type V-belt)
Distance between the shaft

$X = 3 \frac{(d_A + d_B)}{2} = 3 \frac{(20 + 20)}{2} = 120$

$X = 60mm$
(Where x is the distance between the shaft)
Length of the belt =1225mm

Design power = Rated Power x Service Factor
$P_d = P_r x K_s$
$= 0.75 x 1.2 = 0.9$
:. $P_d = 0.9kw$
(Where pd is the design power)
Adding 10% 0f power due to friction
0.9 + 0.10 = 1hp
Therefore 1hp electric motor was selected
Speed of the belt (V)
$V = \pi d_A n_1$

$V = 3.142 x 0.020 x 1400 = 88$
:. V = 88m/s
Weight per unit of V-belt
$W_B = 1.06N$
$W_B = \frac{1.06}{10} = 0.106$

:. 0.106kg/m is the Centrifugal tension acting on the belt. According to Khurmi and Gupta (2006)

Tc = MV2..(1)

Hint: the velocity of a V belt is selected at the range of 10 – 16m/s since centrifugal force is taken into account. According to Khurmi and Gupta (2006)

$Tc = 0.106 x 10^2 = 10.6N$

The maximum tension in the belt

$Tmax = \delta x a$ ----------(2)

Hint: the maximum safe stress in the materials selected as 2.5 Mpa because an allowable stress of 2.8mpa will give a reasonable belt life (khurmi and Gupta 2006)

$W_B = a x L x e$ --------------- (3)

Tc is the centrifugal tension of the belt

W_B is the weight per unit of the belt

δ is the maximum safe of the belt

a is the cross section area of the belt

L is the length of the belt

ρ is the density of the belt

:. $a = \frac{W_B}{L x e}$ -------------------- (4)

Where L = 1225mm
$\rho = 1.140kg/m^2$
$W_B = 1.06$

$a = \frac{1.06}{1225 x 1.140}$

$= 7.590$

$a = 7.590 \times 10^3 m$

The maximum tension in the belt

$T = \delta \times a$-------------(5)

$T = 2.5 \times 7.590$

$= 18.97 \times 10^3 = 189.7N$

Tension in the tight side of the belt (T1)

Maximum tension centrifugal tension (Tc)

$T_1 = T - Tc$------------------(6)

$T_1 = 189.7 - 10.6$

$= 179.1N$

Tension on the slack side of the belt (T_2)

Hint ($\text{Cosec}\,\beta = \frac{1}{\sin\beta}$

$= 0.81 \times 2.9238 = 2.368$

$:. = \text{Log}\left(\frac{T_1}{T_2}\right) = \frac{2.368}{2.3} = 1.0296$ or $\frac{T_1}{T2} = 10.7$

$T_2 = \frac{T_1}{10.7}$

3.3.1 : Design of the Shaft

The torque exerted on the driven pulley shaft is determined from the equation below.

$q = (T_1 - T_2) R$ (Khurmi and Gupta 2006)

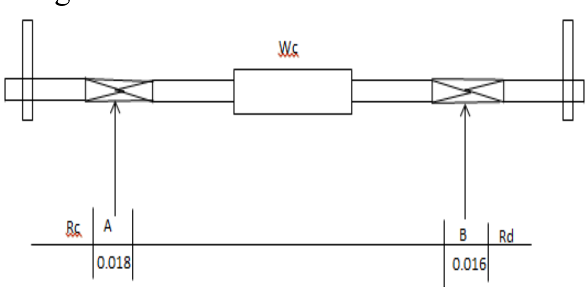
Where,

T_1 = Tension on the tight side of the belt

T_2 = Tension on the slack side of the belt

R = Radius of the driven pulley which measurement is 55mm

The shaft with pulley and bearing is shown in fig. 7 below



$2.3 \log \frac{T_1}{T_2} = \mu\, \theta \sec \beta$---------(7)

Where μ = Coefficient of friction between the Tanned length belt and the cast iron steel pulley = 0.3

Θ = is the active angle on the pulley

$\Theta = 155$

$= \frac{\Theta}{180} \times \pi$-------------------------- (8)

$= \frac{155}{180} \times 3.142$

$= 2.7$ rads

β is the angle of V–belt groove $= 20^0$

$2.3 \log \left(\frac{T_1}{T_2}\right) = 0.3 \times 2.7 \times \text{cosec}\, 20^0$

$\mathbf{T_2 = \frac{179.1}{10.7}}$

$T_2 = \mathbf{16.7N}$

Power transmitted (p)

$P = (T_1 - T_2)\, V$

$P = (179.7 - 16.7) \times 16$

$= 2598.4 = 2.5984W$

q = distributed load

$q = (179.1 - 16.7) \times 0.055$

$= 8.93N/m$

$= 8.93 \times 10^{-3} N/m$

Where W_C = Weight of the stripper fruit Rc and Rd are the reactions at the bearing support weight of pulley at A = 1kg

= 1.8kg = 1.8 x 10 = 18N

Total vertical load acting on the shaft at A

$Wa + T_1 + T_2$

$18 + 179.1 + 16.7$

= 214N
Also, weight of pulley at B = 1.6kg
W_b = 1.6kg
= 1.6 x 10 = 16N
But torque at B = torque on the shaft
$8.93 = (T_3 - T_2) \times 0.055$

$$T_3 - T_4 = \frac{8.93}{0.055}$$

$T_3 - T_4 = 162N$ --------------(9)

But

$$\frac{T_3}{T_4} = \frac{T_1}{T_2}$$

$$\frac{T_1}{T_2} = \frac{179.1}{16.7.} = 10.7$$

$$\therefore \frac{T_3}{T_4} = 10.7$$

$$\frac{T_3}{T_4} = \frac{10.7}{1}$$

$T_3 = 10.7\ T_4$ - -------------(10)

From equation (9)
$T_3 - T_4 = 162N$
$T_3 = 162 + T_4$
Putting $T_3 = 162 + T_4$ into equation (10)
$162 + T_4 = 10.7\ T_4$
$162 = (10.7\ T_4 - T_4)$
$162 = T_4\ (10.7\ T_4 - 1)$
$162 = 9.7\ T_4$

$$T_4 = \frac{162}{9.7}$$

$T_4 = 16.7N$
From equation (10)

$T_3 = 10.7\ T_4$

$T_3\ 16.7 \times 10.7$

$T_3 = 178N$

Total vertical load acting on the shaft at B

B = Weight of pulley at B

$B = (W_b + T_3 + T_4)$

$= W_b + T_3 + T_4$

= 16 + 178 + 16.7

= 210.7N

The load on the shaft in the chamber
W_c = Vs x wg x g
Where vs = volume of the separating chamber
V_s = L x b x h
V_s = 950 x 480 x 510 = 232560
= $232m^3$
W_g = weight of quartered bunches
W_g = 5.0
g = 9.81 i.e. gravitational force
W_c = 232 x 5.0 x 9.81 = 11379.6
= 114×10^2
Total load acting down wards load at B + load at A
+ load on the shaft in the chamber
$210.7 + 214 + 114 \times 10^2$
424.7 + 11400 = 118247
= 118×10^3N

Performance Test Procedure

Performance analysis of the machine was done such that the stripper was experimented under the intended alternate source of power which is the motorized and manual power. The rotation of the crank assembly was used to determine the operating speed of the heater shaft by manual operation, while the speed of 1145 r.p.m was used in the motorized test

Table1 Performance Test of the Stripper when Manually Operated

Sterilization time (min)	90 min
Weight of quartered bunches for stripping (kg)	5.0kg
Weight of stripped bunches at fruit outlet (kg)	0.56kg
Weight of stripped bunches at bunch outlet (kg)	1.21kg
Weight of stripped fruit at bunch outlet (kg)	0.67kg
Weight of stripped fruit at the outlet (kg)	1.29kg

Average stripping time (min)	Output capacity (tunnel/hr)	Stripping efficiency (%)	Quality performance efficiency (%)
0.38	0.30	51.9	44.2

Table 2: Performance Test of the Stripper when Powered with Electric Motor

Sterilization time (min)	90
Weight of quartered bunches for stripping (kg)	5.0
Weight of stripped bunches at fruit outlet (kg)	0.54
Weight of stripped bunches at bunch outlet (kg)	1.37
Weight of stripped fruit at bunch outlet (kg)	0.79
Weight of stripped fruit at the outlet (kg)	1.46

Average stripping time (min)	Output capacity (tunnel/hr)	Stripping efficiency (%)	Quality performance efficiency (%)
0.14	0.82	54.1	46.8

4.0: Result and Discussion

The performance test results presented in tables 1 and 2 shows the stripping and quality of performance efficiencies and the output capacity was calculated using equation 1, 2 and 3 respectively.

From the test conducted, when the machine is motorized, the output capacity, stripping efficiency and quality performance efficiency were considerably high compared to the one conducted with manual operation. At sterilization time of 90 minutes and heater shaft speed of 1145r.p.m , the output capacity, stripping and quality performance efficiencies are 2.12 tone / hr 46.8% and 54.1% respectively, meanwhile, at sterilization time of 90 minutes when manually operated, the output capacity, stripping and quality performance efficiencies of 0.79 tone / hr, 44.2% and 51.9% respectively was recorded . Having a significant output with the motorized operation is remarkable; however, it is important to note that the increased stripping and quality performance efficiencies are evidences that a speed of 1145 r.p.m is optimum for the stripper at sterilization time of 90 minutes.

5.0 Conclusion and Recommendation

Designing and constructing of a dual powered motorized palm fruit stripper machine with double discharge outlet for separation of palm fruit from the bunches by easy mechanical process, when quartered bunches are thrown on the revolving beater shaft with the aid of V belt and pulley arrangement, due to the action of beater, entire bunch is thrown up and is allowed to fall again and again on the revolving beaters. Thus palm fruits are separated and fall out through the double fruit discharge outlets, while the quarter bunches are automatically pushed to the bunch outlet of the palm fruit stripper machine.

This provide the fastest solution in palm fruit separation process and also, processing mechanism prevents the associated problems of poor or low production and difficulties facing the farmers in the palm oil fruit threshing process.

Further research should be directed towards advanced selection of materials that have corrosion resistance, in fabrication of palm fruit stripper machine. Accordingly, there should be more research for developing of a sophisticated palm fruit stripper machine required, to improve on traditional method which will also shift from double discharge outlet unit operational stripper machine to an all-encompassing system which will not only be easy to operate but also easy to maintain.

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