Design of dehulling machine for rubber seed processing

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Abstract
The designed Dehulling Machine is a machine used to removes shells from rubber seeds and as well separates the foreign materials from the rubber seed kernels. The Dehulling Machine for rubber seed processing is powered by Electric Motor, the Electric Motor drives the Shaft for dehulling operation and the blower/Fan Shaft, the Total Power required is 70KW. The Transmission System consists of arrangement of driven and driving Pulleys, Belt, and Shafts with Bearings. The diameter of the driven and driving pulleys for the dehulling operation is 70 mm and 330 mm respectively and V-belt of 1.2 m long. The blower has driven and driving pulley diameter of 63 mm and 130 mm respectively and V-belt of 761 mm long. The Dehulling Mechanisms include: Dehulling Shaft that accommodates the Dehulling Stone of diameter 300 mm and thickness 80 mm. The Shaft is supported by bearing and the driven by driving pulley mounted on the eletric motor. The chaffs and the kernels collector is designed such that the kernels (heavier) fall freely while the chaffs and other foreign materials are blown off. The blower has fan duty of 1 m³/s and made of the blades Support (length = 20 mm, breath = 10 mm, thickness = 10 mm, no = 12), Blade (length =100 mm, breath = 60 mm, thickness = 0.5 mm, no of blade = 6) and Blower Cylinder. The main frame is made of mild-steel and it accommodates all other members of the machine.

1. Introduction

Natural rubber is an economic tree crop in Nigeria and has diversity of uses which include provision of raw materials for agro-based industries, foreign exchange earning and offers employment to a sizeable segment of the Nigerian farming rural population [1]. The usage of rubber is related to its property. The predominant property of solid rubber is its elastic behaviour or deformation by compression or tension. The tyre industry is the major consumer of natural rubber. It is well suited for the manufacture of tyre especially radial, heavy duty and high-speed tyres because of its dynamic qualities such as good tear strength and low heat build up. Beyond the use of rubber for manufacture of tyres, rubber is used for the manufacture of specific products such as flexible oil resistance pipelines for offshore oil fields, inner tubes of tyres, footwear, bridge pad and building foundation in Earthquake prone areas. The latex concentrate is used for the production of carpet underlay, adhesives, foam, balloons, condoms, and medical accessories such as gloves and catheters. Rubber
wood is used for furniture, particleboards and fuel [2;3].

The rubber seed weight is between 3.5-6.0 g, it is ovoid in shape with the ventral surface slightly flattened. The average sizes of rubber seed is 15.2 mm longitudinally and 2.0 mm transversely. The seed coat (husk) is hard and shiny, brown or grey to brown with numerous darker mottles or streaks on the dorsal surfaces, but few or none on the ventral side [4]. The average weight of the dried seed is about 4.5 g, the kernel of the rubber seed is roughly half the weight of the total seed [5]. Rubber plant grows for about 4 – 5 years before it starts to flower. In Nigeria flowering is once between February and March, while in Malaysia flowering is twice a year between March and April and between August and September [6]. Rubber fruit drops naturally when matured and dehisces to release seeds which are then picked by hand from the plantation floor for use as planting materials or for processing into rubber seed oil. Rubber seed oil and cake are extracted from the rubber seed after processing. The oil is a semi drying oil that contain 29% saturated, 23% oleic, 32.5% linoleic and 22.5% linolenic, the oil is used in production of putty, hair shampoo and also used as industrial oil (raw materials) to replace linseed oil. The rubber seed is also used in the manufacture of putty and alkyds resins, which find application in the paint and leather industry. Furthermore, rubber seed cake extracted from rubber seeds is valuable livestock feeds [2]. The cake contains tolerable quantities of cyanogeni glucoride and can be used as livestock concentrate after drying and toasting [7]. Nigeria has a total of about 247,100 hectares of land under rubber cultivation and it is estimated to yield a total of 43,000 tonnes of rubber seeds which if properly harnessed will add value to the downstream sector of the rubber industry in the areas employment generation for seed collection and processing. Research has shown that these seeds are useful in the manufacture of valuable consumers’ goods as mentioned. It is however regrettable the crude methods of seed processing is devised by users and the urgent need for the fabrication of dehulling machine to avoid colossal loss in the processing process.

In rubber seed processing, the seeds and the kernels are crushed and processed together for extraction of rubber seed oil and cake. The research has been shown that more oil is recovered when only the kernels are processed. In this study the prospect of the use of dehulling machine is to remove the seed coat/outer shell of seeds (nuts, grains etc). The designed machine aids the rubber seed oil recovery by processing only the kernels and also saves time and energy as it dehusks and as well separates the shell from the kernel which has been done by hand picking before.

2. Machine Conception

The dehulling machine in view is to dehusk and separates the rubber seeds at an appreciable efficiency, lower power consumption with relatively low cost. The machine components and system mechanism consist of the following:

**Feeding Hopper**

This serves as the inlet of the machine, it is trapezoid in shape, and accommodates the whole seeds from which the kernels is to be removed.

**Shaft**

Shaft is a transmission element for dehulling operation as well as the blowing operation, the first shaft is for dehulling operation that rotates the dehulling stone and the second shaft carries the fan blade of the dehuller blower.

**Blowing/Cleaning Unit (Fan)**

This cleans/separates the dehulled rubber seed kernels by removing the shells and other foreign materials by blowing stream of air across the mass of dehulled seeds and other plant materials. The considerations for effective design of the blowing unit are to determine the appropriate volume of air and the discharge rate.

**Main Frame**

The main frame is the main body of the machine on which the other members are rested.

**Pulley and Transmission Belt**

The pulley and belt are transmission system through which shafts is coupled to the electric motor.

**Foreign Materials/Chaffs Outlets**

Foreign materials and chaffs are blown through the foreign materials/chaffs outlets. The outlet is inclined to allow the seed to slide back directly below the dehulling unit housing, while the foreign materials and chaffs are blown off. The blown off chaffs are collected at the outlets of inclined tray and the kernels are collected at the bottom outlets.

**Dehulling Chamber/Dehulling Stone Housing**

This is where the dehulling operation takes place and it accommodates the dehulling stone.

**Operation of the Machine**

The rubber seeds to be dehulled are feed into the hopper; the dehulling point is located between the dehulling stone and the housing. Due to the pressure exerted by the rotating dehulling stone, the rubber seed kernels are separated from the seed and collected at the bottom along with the shells. The shells or husks are separated from the kernels by means of blower. The cleaned kernels are therefore collected at the bottom outlets.

The efficiency of the operation of the dehulling machine depends on: physical properties of the rubber seed e.g. size, shape, hardness, e.t.c., the feed rate of the charge, the dehulling speed and effectiveness of the dehulling surface in the dehulling chamber and the volume of effective air to blow the chaffs and other consideration, which include the moisture content.

3. Material Selection

**Belt a and pulley**
The selection of v-belt is based upon obtaining a long and free life. The selection is also hinged on its efficiency. In general, efficiency of v-belt ranges from 70% - 90%. Therefore, this type of belt is chosen with the following dimensions.

\[ w = 20mm = 0.02m, \ h = 11mm = 0.011m, \]
\[ \text{the pitch width}(p) = 17mm = 0.017. \]

The required speed for v-belt is 4000rpm. If the belt runs faster than 5000rpm or much slower than 1000rpm trouble may be encountered [Joseph et al, 1983]. Also the minimum recommended pitch diameter \( D_p \) = 125mm

**First Set of Pulley**

The first set of pulley is the electric motor and fan (blower) pulleys

\[ N_1 = 1000rpm \rightarrow \text{selected}, \ N_2 = 2050rpm \]  
[1]

**Second Set of Pulley**

This set of pulley is for electric motor and shelling/dehulling stone pulley.

\[ d_2 = \frac{(N_1d_1)}{N_2}, \ d_2 = 63mm \]

The pulley of steel material is selected due to its strength. The density of mild steel \( \rho = 7840 \text{ kg/m}^3 \) [10]

**Shafts**

Due to the strength, toughness, reliability on resistance to shock and repeated loading, steel material is selected for the shaft to accommodate the loads that would be impacted on it. The parameters to be considered on shaft design calculation include: maximum allowable stress for shaft \( (\sigma) \), maximum shear stress \( (\tau) \), density of steel \( (\rho) \), combine shock and fatigue factor as applied to torsion \( (k_t) \), combine shock and fatigue factor as applied to bending \( (k_b) \) [10].

**Dehulling Stone**

Dehulling stone is made from metal sheet, parameter considered in selecting dehulling stone include; density \( (\rho) \), ultimate tensile strength [11].

The thickness of the metal sheet=2m, the diameter of dehulling stone= 300mm , allowances between the dehulling stone and narking surface= 21mm wrt average size of rubber seed.

**3.1. Fan**

[Cylinder diameter= 30mm = 0.03m, Cylinder length= 120mm = 0.12m]

**Blade Support**

Length= 20mm = 0.02m, Breath = 10mm = 0.01m,  
Thickness = 10mm = 0.01m Number of Support = 12

**3.2. Design Calculation**

**Belt Design**

**Length of the Belt**

\[ L_1 = \frac{\pi}{2}(d_2 + d_1) + 2x + \frac{(d_2-d_1)^2}{4x} \]
[10]

Where \( x = \text{centre of the sheaves} \)

**First Set of Pulley : (Blower and Motor Pulley)**

\[ d_1 = 130mm = 0.14m, \ d_2 = 63mm = 0.06m, \ x = 0.2265m; \]
\[ L_1 = 0.7611m \]

**Second Set of Pulleys: (dehulling pulley and the motor pulley)**

\[ d_3 = 0.333m, \ d_3 = 0.07m, \ x = 0.27m \]
\[ L_2 = 1.2m \]

**Tension in the Belt**

\[ \frac{T_1}{T_2} = e^{a\mu}, \ [T_1 = \text{tension in the tight side}(N)] \]
[3].

\[ T_2 = \text{tension in the slack side}(N) \]
\[ \alpha = \text{wrap angle on the smaller pulley}, \]
\[ \mu = \text{coefficient of friction.} \]

\[ \frac{\sigma_1}{\beta_1} \]

\[ \frac{\alpha_2}{\beta_2} \]

Diagram. 1

\[ \alpha_1 = (180 - 2\beta); \ 180 - 2 \sin^{-1} \left( \frac{R-r}{c} \right) \]
\[ \alpha_2 = (180 - 2\beta); \ 180 - 2 \sin^{-1} \left( \frac{R-r}{c} \right) \]

a. First Set of Pulleys

\[ R = 65mm, \ r = 31.5mm, \ c = 226.5mm \]

\[ \beta = \sin^{-1} \left( \frac{R-r}{c} \right), \ \beta = 8.51^0, \ \alpha = 162.98^0 \]

**Power in the Belt is given by:**

\[ p = \frac{(T_2-T_1)}{1000} \]
\[ v = 0.5kw \]
[12]

**Belt Speed**
Therefore; \( T_1 - T_2 = \frac{(1000 \rho)}{v} = 73.42N \)

Torque Developed is given by:

\[
T_r = (T_1 - T_2) \frac{d^2}{2} = 2.31Nm
\]

b. Second Set Pulleys

\[
\sin \beta = \frac{(R-r)}{x}, [R = 166.5 mm, r = 35mm, x = 271.5 mm.]
\]

\[
\beta = 28.97^0, \alpha = 122.06^0
\]

### Tension in both Sets of Pulley

**First Set of Pulleys**

\[
\frac{T_1}{T_2} = e^{0.52x2.83}, \quad T_1 = T_2 \times 4.4, \quad P = \frac{(T_1 - T_2)V}{1000}
\]

\[
T_2 = \frac{P \times 1000}{3.4 \times V} = 21.63N \text{ and } T_1 = 95.172N.
\]

Torque is given by:

\[
T_r = M_r = (T_1 - T_2) \frac{d^2}{2} \quad [10]
\]

\[
= 12.24Nm
\]

**Second Set of pulleys**

\[
\frac{T_1}{T_2} = e^{0.52x2.13}, \quad P = \frac{(T_1 - T_2)V}{1000}
\]

\[
T_2 = \frac{P \times 1000}{2.03 \times V} = 14.13N
\]

\[
T_1 = 42.82N
\]

For Transmission Shafts, maximum permissible working stress in tension and compression (\( \sigma \)) is 112MPa and maximum permissible shear stress (\( \tau \)) is 56MPa [11].

**The Dynamic Loads on the Shaft Pulley**

Cross volume (\( v_c \)) of pulley = \( \frac{\pi wd^4}{4} = 1.74 \times 10^{-3}m^3 \) [9]

Volume of the groove on the pulley (\( v_g \))

\[
= \text{belt cross sectional area } \times \text{diameter} = d_4 \times w \times h \times \pi = 2.30 \times 10^{-4}m^3
\]

Net volume of pulley:

\[
v_{net} = v_c - v_g = 15.1 \times 10^{-4}m^3
\]

Force exerted by the Pulley (\( F_p \))

\[
= \text{weight of the pulley acting on the shaft} = \text{density}(\rho) \times \text{volume}(v_{net}) \times g = 116.13N
\]

### Dehulling Stone

Volume of Dehulling Stone = \( \pi r^2 l \) [9]

\[
[r = \text{dehulling stone radius} = 0.15m, l = \text{dehulling stone thickness} = 0.08m \text{ volume} = 0.0057m^3]
\]

Weight of the Stone = \( \rho \times \text{vol} \times g = 434.97N \)

**Weight of the Rubber Seeds**

The average weight of rubber seed (dried) is about 4.5g [13].

The Capacity of the Designed Hopper

\[
\frac{(ab+b^2 \text{tan} \theta)c}{2} = \frac{(150 \times 250+250^2 \text{tan} 29)150}{2} = 8.2 \times 10^{-3}m^3
\]

\[
\frac{b}{e} = \cos \theta, \quad e = \frac{250}{\cos \theta} = 0.286m.
\]

**Gravimetric Capacity of the Hopper**

The gravimetric capacity of the hopper is an estimate from the weight of the seeds that will be resting in the hopper.

\[
\text{Density (\( \rho \))} = \frac{\text{mass}}{\text{volume}}
\]

mass= volume \times density (Density of Rubber Seed= 548.8g/m³)

Gravitational Capacity = mass \times volumetric capacity \times density of rubber seed.

Volume of Rubber Seed

\[
= \text{volume that will occupy the hopper} = \text{volume of the hopper} = 8.2 \times 10^{-3}m^3 \text{. [m = 4.5g (dried seed)]} [10]
\]

Mass = volume \times density = 8.2 \times 10^{-3} \times \rho_r

Total Weight of Rubber Seed in the Hopper

\[
= m \alpha = (4.5 \times 9.81)N = 44.15N \quad [10]
\]

**Rupture Force**

Rupture force refers to the hardness of the rubber seed shell, tested and found to be 0.61N [http://polymerweb.com].

Total Weight on the Dehulling Shaft:

\[
= 44.15 + 434.97 + 116.13 + 0.61 = 595.86N
\]
3.3. General Force Representations

\[ F_1 = 116.13 \text{N}, \quad F_2 = 434.97 \text{N}, \quad F_3 = 44.76 \text{N} \]

Taking moment about \( B \)
\[ R_A = 417.23 \text{N} \]

Total upward forces = total downward force
\[ R_B = 178.63 \text{N} \]

Table 1. Shear Force and the Bending Moment for Vertical Loading Consideration.

<table>
<thead>
<tr>
<th>S/N</th>
<th>Forces (N)</th>
<th>Point (m)</th>
<th>Shear Force (N)</th>
<th>Bending Moment (Nmm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>116.13</td>
<td>0</td>
<td>-116.13</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>434.17</td>
<td>400 from A</td>
<td>301.1</td>
<td>-17.42</td>
</tr>
<tr>
<td>3</td>
<td>44.76</td>
<td>180 from B</td>
<td>-133.8</td>
<td>57.86</td>
</tr>
<tr>
<td>4</td>
<td>417.2</td>
<td>150 from A</td>
<td>-178.63</td>
<td>32.16</td>
</tr>
<tr>
<td>5</td>
<td>178.65</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Source: Data Analysis

**Horizontal Loading Consideration**

Horizontal loading is produced due to the pull (tension) of the belt on the pulley against the shaft and force against the rupture force of the seeds [13]

Tension = \( T_1 + T_2 = F_4 = 116.802 \text{N} \) (calculated)

\[ F_5 = \text{force against the rupture force} = 44.76 \text{N} \]

Taking Moment About \( D \):
\[ R_C = 148.69 \text{N} \]

Downward Forces = Upward Forces:
\[ R_D = 12.87 \text{N} \]

Table 2. Shear force and the bending moment for Horizontal Loading Consideration.

<table>
<thead>
<tr>
<th>S/N</th>
<th>Forces (N)</th>
<th>Point (m)</th>
<th>Shear Force (N)</th>
<th>Bending Moment (Nmm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>116.802</td>
<td>150 from C</td>
<td>-116.80</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>44.67</td>
<td>180 from D</td>
<td>31.89</td>
<td>-17.52</td>
</tr>
<tr>
<td>3</td>
<td>148.61</td>
<td>150 from C</td>
<td>-12.87</td>
<td>2.32</td>
</tr>
<tr>
<td>4</td>
<td>12.87</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Source: Data Analysis

Max. Vertical Bending Moment \( M_v = 57.86 \text{Nm} \)
Max. Horizontal Bending Moment \( M_h = -17.52 \text{Nm} \)
Max. Bending Moment \( M_b = \left[ M^2_v + M^2_h \right]^{\frac{1}{2}} = 60.45 \text{Nm} \)

Shaft Diameter
\[
\frac{d^3}{16 \pi s_g} = \sqrt{\frac{(K_b M_b)^2 + (K_t M_t)^2}{}}
\]

\[ K_t = 1.75 \text{ selected }, K_b = 1.45 \text{ selected }, S_g = \text{Shear Stress (constant)} \times 45 \text{MPa} [10] \]

Diameter (\( d \)) of dehulling Shaft: \( d = 21.5 \text{mm} \)

\( d \) of 30mm is selected for safety, factor of safety \( = \frac{30}{21.5} = 1.4 \)

3.4. Fan Design

Centrifugal fan type is selected for this design work because it is relatively inexpensive and self cleaning [10].

3.4.1. Fan Shaft Design

Weights acting on the fan shaft are: weight of cylinder holding the blade support, weight of the blade support, weight of the pulley and weight of the blade

**Weight of the Pulley**

Gross Volume of Pulley \( (v_g) = \frac{\pi d^2 w}{4} = 7.6979 \times 10^{-5} \text{m}^3 \)

Volume of Groove on the Pulley \( (v_b) \)

\[ \text{belt cross sectional area} \times \pi h \frac{d_3}{2} = (w + p)h \frac{d_3}{2} = 4.47 \times 10^{-3} \text{m}^3, p = 0.07 \text{m}, w = 0.02 \text{m}, h = 0.011 \text{m} \]

Net vol. of pulley = \( (7.698 - 4.47) \times 10^{-3} = 3.23 \times 10^{-3} \text{m}^3 \)

Weight of pulley = density \times volume \times \text{g} = 2.48 \text{N}

**Weight of Cylinder (w_c)**

Volume of cylinder = \( \pi r^2 l = 8.48 \times 10^{-3} \text{m}^3 \) \( (r = 0.015 \text{m}, l = 0.12 \text{m}) \)

\[ w_c = \text{vol} \times \text{density} \times 9.81 = 6.52 \text{N} \]

**Weight of Blade Support (w_s)**

\[ w_s = \text{length} \times \text{breath} \times \text{thickness} \times \text{density} \times 9.81 \times \text{no of blade supports} = 0.02 \times 0.01 \times 0.01 \times 7840 \times 9.81 \times 12 = 1.85 \text{N} \]

**Weight of Blades (w_b)**

\[ w_b = \text{length} \times \text{breath} \times \text{thickness} \times \text{density} \times 9.81 \times \text{no of blades} = 0.1 \times 0.06 \times 0.0005 \times 6 \times 7840 \times 9.81 = 1.38 \text{N} \]
Total Weight on the Fan Shaft (\(W_T\))

\[ W_T = w_p + w_c + w_s + w_b = 12.23\text{N}. \]

Diameter of Fan Shaft selected is 30mm [14]

3.5. Power Required

Total power required = power to drive the stone + power
to drive the fan (Blower) [11]

\[ F_D = F_F + F_R, (P_D = F_D V = F_D \omega) \]

\[ F_R = \frac{w}{a} \omega^2 = F_R = 30.4\text{KN}. \]

\[ F_C = m \omega^2 = 30.4\text{KN} \quad (m = 4.944\text{kg}) \]

\[ F_F = \mu \cdot (F_C + 0.61) = 14.5\text{KN} \]

\[ \mu = 0.477 \quad \text{(selected)} \]

\[ F_D = F_F - F_R = 15.9\text{KN} \]

\[ P_D = F_D V = F_D \omega \text{r}. \quad (\omega = 26.18 \frac{\text{rad}}{\text{sec}}, \]

\[ r = \text{radius of pulley} = 166.5\text{mm} \]

\[ P_D = 69.30\text{KW} \]

For the Blower:

\[ \text{power} = \frac{(P_S \times Q)}{0.75} \text{[6]} \]

\[ Q = \text{Fan duty} \quad \left( \frac{m^3}{\text{sec}} = 1\text{m}^3/\text{sec} \right), \quad P_S = \text{static pressure} = 500\text{pa} \]

\[ P = \frac{(1 \times 500)}{0.75} = 666.6\text{W} \]

Total power required

\[ P_D + P \]

\[ = 69.30 + 0.6666 = 70\text{KW (94hp)} \]

Blower (rpm) =

\[ \text{motor rpm} \times \frac{\text{sheaves diameter of the motor}}{\text{sheaves diameter of the fan}} = 3,095\text{rpm} \]

4. Conclusion

From the outcome of the design, the dehulling machine
for rubber seed processing is used to remove shells from
the rubber seed and as well separates chaffs/shells and other
foreign materials from the kernels.

The machine is designed such that, it can be easily
fabricated and maintained with simplicity of operation.

The machine can be conveniently used by natural rubber
farmers to aid/enhances value of natural rubber products in
economic development. The rubber seeds kernels are
removed manually by beating before, the introduction of
this dehulling machine saves time, energy and cost of
production.

Therefore, the components are strong, the materials are
readily available and well selected, and the designed works
is best for fabrication method of production of the model.

DEHULLING MACHINE FOR RUBBER SEED PROCESSING.

M = Chaffs and Foreign Material Outlet
L = Kernels Outlet
K = Fan Blade
J = The Blower/Fan
I = Machine Frame/Stand
H = Dehulling Chamber
G = Dehulling Stone
F = Dehulling Surface
E = Motor Stand
D = Transmission Belt (Blowing Operation)
C = Transmission Belt (Dehulling Operation)
B = Dehulling Shaft
A = The Hopper

Nomenclature

\[ h \] Belt height (m). 
\[ w \] belt width (m). 
\[ P \] groove pitch width 
\[ d_1 \] pitch diammeter of driving pulley for fan. 
\[ d_2 \] pitch diammeter of driven pulley for fan. 
\[ N_1 \] speed in revolution per minute. 
\[ d_3 \] pitch diammeter of the driving pulley dehulling stone. 
\[ d_4 \] pitch diammenneter of the driven pulley for dehulling stone. 
\[ \times \] Centre of the sheaves 
\[ L_1 \] length of the blower belt (m) 
\[ L_2 \] length of the dehulling stone belt (m) 
\[ T_1 \] tension in the tight side (N). 
\[ T_2 \] tension in the slack side (N) 
\[ \alpha \] wrap angle on the smaller pulley 
\[ \mu \] coefficient of friction. 
\[ p \] power in the belt (W) 
\[ \psi \] belt speed (\( \text{m/s} \))

References


