Design Analysis of a Reciprocating Cassava Sieving Machine

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Abstract: The separation of course particles, big lumps or unwanted materials or impurities from grains (millets, rice, Soya beans, maize, dehydrated cassava etc) has always been a serious problem as it goes with massive/tremendous stress when done manually. This study is intended to case the stress involved in sieving grated dehydrated cassava using an electric motor as a source of power. This work uses the principle of slider crank mechanism which converts rotary motion of the pulleys to the reciprocating (sliding) movement of the sieving tray. The machine was tested and confirmed to have an output capacity of 100.59kg/hr and an efficiency of 75.7%, which makes it very adequate and capable for mass production.

Keywords: Reciprocating, Cassava, Sieving Machine

I. Introduction

Energy is the driving force (power) that makes man, machines and systems work perfectly and efficiently. And food is the major source of energy that gives man the ability to work efficiently. In Africa, especially in Nigeria, Garri is the major staple food for man to be productive and as a result, the production processes need to be improved upon and to be taking seriously to enhance mass production in order to meet up the demand of the masses. The processed involved obtaining the final product called Garri includes, cultivation, tuber harvesting, peeling, grating, dewatering (squeezing), sieving and drying (frying). The sieving process which forms the basis of this study, involves the separation of particles that is, ungraded portion of the cassava lumps from time and smoother ones. this is done after the moisture content of the meshed or pulp have been reduced to about 35% or 40% in the process of dewatering, a small lump is put on the palm and squeezed. If it is sufficiently dewatered, it will disintegrate that is break into smaller particles easily. Then it will be put on the local filter where little force and motion will be applied by hands to sieve and the smaller particles goes beneath the filter.

1.2 Purpose of the Study

This study is geared towards producing an end-product of better and more uniform quality and to reduce the drudgery and labour intensiveness involve when sieving manually.

1.3 Benefit of Study

This work will enhance and promote the establishment of economically viable small and medium scale cassava based industries that will mass produce garri (end product) and create new employment opportunities in rural areas.

1.4 Materials and Method

The first phase of the work was the design consisting of layout drawings as well as detailed production and assemble drawings. The fabricated parts are: the sieving tray, sieving chamber, collector which are made of Garlaza steel, the frames and sieving table made of mild steel were welded. The sieving power comes from electric motor through v-belts on pulleys and transmitted to the connecting rod and the sieving tray.

II. Design Analysis

2.1 Design Considerations

The following factors were considered during the design of this work. They are: strength of materials, wear, corrosion, moisture content, size and shape, and shape, cost/maintenance, power requirement etc.

III. Result and Discussion

The machine was tested for ten (10) different input values of dehydrated (squeezed) cassava and the time for each was taken and recorded.

Table 1 below shows the result. The output capacity of the machine was then calculated from the test to be 100.59kg/hr and efficiency is 75.7%. Which shows that the performance of the machine is high as compared to the manual method. And from all indications, the ratio of the performance of the manual method of sieving to...
Design Analysis OF A Reciprocating Cassava Sieving Machine

DOI: 10.9790/1684-12420715 www.iosrjournals.org 8 | Page

this mechanized method is 1:7. This justifies the fact that the machine meets all design specifications, performs accurately with better efficiency, and so the results support the objective of the study.

2.2 Design Analysis/Calculations

1. The Maximum Displacement of the Siever (Slider)
   The maximum displacement occurs when the crank is at an angle of 180° with the horizontal. 
   So, \( r = 92mm, L = 435mm \).
   \[
   X_{\text{max}} = r (1 - \cos \theta) + \frac{r^2 \sin \theta^2}{2L}
   \]
   \[
   = 92 (1 - \cos 180) + \frac{90^2 \times (\sin 180)^2}{2 \times 435}
   \]
   \[
   = 92 (1 + 1) = 184mm = 184mm
   \]
   \[
   \therefore \text{The maximum displacement} \ X_{\text{max}} = 184mm \@ 180^0
   \]

2. The Maximum Velocity of the Siever
   The maximum velocity will occur when the acceleration \( a_s = 0 \).
   Where
   \[
   \Rightarrow a_s = w^2r \left( \cos \theta + \frac{\cos 2\theta}{n} \right)
   \]
   So, since \( a_s = 0 \) (acceleration of siever).
   \[
   0 = w^2r \left( \cos \theta + \frac{\cos 2\theta}{n} \right)
   \]
   \[
   \Rightarrow 0 = n\cos \theta + \cos 2\theta
   \]
   But \( \cos 2\theta = 2\cos^2 \theta - 1 \)
   \[
   \Rightarrow 0 = n\cos \theta + 2\cos^2 \theta - 1
   \]
   So, Using Almighty Formula, and \( n = \frac{L}{r} = \frac{435}{92} \)
   \[
   \Rightarrow n = 4.728
   \]
   \[
   \Rightarrow 2\cos^2 \theta + 4.728\cos \theta - 1 = \theta.
   \]
   \[
   \cos \theta = \frac{-4.728 \pm \sqrt{4.728^2 + 4 \times 2}}{2 \times 2}
   \]
   \[
   = \frac{-4.728 \pm \sqrt{30.3536}}{4}
   \]
   \[
   \cos \theta = \frac{-4.728 \pm 5.5094}{4}
   \]
   So, taking positive (+ve).
   \[
   \cos \theta = \frac{-4.728 + 5.5094}{4} = 0.1954
   \]
   \[
   \theta_{\text{max}} = \cos^{-1} 0.1954 = 78.7^0
   \]
   \[
   \therefore \text{The} \ V_{\text{max}} = wr \left( \sin \theta_{\text{max}} + \frac{\sin 2\theta_{\text{max}}}{2n} \right)
   \]
   So, using \( N = 450 \) rpm (khurmi 2005)
   \[
   \Rightarrow w = \frac{2nN}{60} = \frac{2 \times 3.142 \times 450}{60} = 47.13 \text{rad/s}
   \]
   \[
   \Rightarrow V_{\text{max}} = 47.13 \times 0.092 \left( \sin 78.7 + \frac{\sin 157.4}{2 \times 4.728} \right)
   \]
   \[
   = 4.34 \left( 0.9806 + \frac{0.3842}{0.456} \right)
   \]
   \[
   = 4.34 \text{m/s}
   \]
   \[
   \therefore \text{The maximum velocity of the siever (slider)} \ is V_{\text{max}} = 4.34 \text{m/s}
   \]
3. The Output Capacity (Kg/hr)

The output capacity, \( Q_c = \frac{w_c}{t} \)

Where: \( w_c \) = Total weight of the sifted mass (kg) and \( t \) = total time taken to sift (hr)

<table>
<thead>
<tr>
<th>Table 1</th>
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<tbody>
<tr>
<td>Number of loading</td>
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\[ Q_c = \frac{\text{Total mass of sifted dehydrated grated cassava}}{\text{Total time taken to sift}} \]

\[ Q_c = \frac{29.20 \times 3600}{1045} \]

\[ Q_c = 100.59 \text{ kg/hr} \]

That is, the machine will be able to sift 100.59kg of dehydrated grated cassava in one hour.

4. The Sifting Efficiency (%)

Efficiency (%) = \( \frac{w_2}{w_1} \times 100 \)

Where, \( w_2 \) = weight of the sifted mass (kg)
\( w_1 \) = Initial weight of the grated cassava mesh (kg)

But \( w_2 = 29.20 \text{ kg} \)
\( w_1 = 38.6 \text{ kg} \)

\[ \text{Efficiency} = \frac{29.20}{38.6} \times 100 = 75.7\% \]
5. The Total Load of the Siever Mechanism
The total load of the sieving mechanism consists of:
(a) Mass of sieve tray
(b) Mass of sieving chamber
(c) Mass of garri in container
(d) Mass of the screening material

(a) **Mass of Sieving Tray**
\[ M_{st} = T_{st} \times V_{st} \]  \hspace{1cm} (1)
But \[ V_{st} = A_{st} \times T_{st} \]  \hspace{1cm} (2)
Where; \[ A_{st} = 2(L_{st} \times H_{st}) + 2(B_{st} \times H_{st}) \]  \hspace{1cm} (3)
Density of metal material, \[ T_{st} = 7800 \text{ kg/m}^3 \]
So, substituting values,
\[ A_{st} = 2(0.42 \times 0.125) + 2(0.310 \times 0.125) \]
\[ = 0.105 + 0.0775 = 0.1825 \text{ m}^2 \]
and \[ V_{sb} = 0.1825 \times 0.002 \]
\[ = 3.65 \times 10^{-4} \text{ m}^3 \]
\[ \therefore M_{sb} = 7800 \times 3.65 \times 10^{-4} \]
\[ = 2.85 \text{ kg} \]

(b) **Mass of the Sieving Chamber**
\[ M_{sc} = T_{sc} \times V_{sc} \]  \hspace{1cm} (4)
\[ V_{sc} = A_{sc} \times t_{sc} \]  \hspace{1cm} (5)
and \[ A_{sc} = 2(L_{sc} \times H_{sc}) \times 2(B_{sc} \times H_{sc}) \]  \hspace{1cm} (6)
But the density of the metal material used is given as 7800 kg/m³ and \[ L_{sc} = 484 \text{ mm}, B_{sc} = 475 \text{ mm}, t_{sc} = 2 \text{ mm} \] and \[ H_{sc} = 75 \text{ mm} \]
\[ A_{sc} = 2(0.484 \times 0.075) + 2(0.475 \times 0.075) \]
\[ = 0.0726 + 0.07125 \]
\[ = 0.1439 \text{ m}^2 \]
and \[ V_{sc} = 0.1439 \times 0.002 \]
\[ = 2.878 \times 10^{-4} \text{ m}^3 \]
\[ \therefore M_{sc} = 7800 \times 2.878 \times 10^{-4} \]
\[ = 2.24 \text{ kg} \]

(c) **Mass of Garri in the Container**
The mass of garri, \[ M_g = T_g V_g \]  \hspace{1cm} (7)
and \[ V_g = L_g \times B_g \times H_g \]  \hspace{1cm} (8)
For a dehydrated, grated cassava, the density is \[ T_g = 563 \text{ kg/m}^3 \]
Where: 
\[ L_g = L_{sc} = 484\,mm, B_g = B_{sc} = 475\,mm, H_g = H_{sc} = 75\,mm \]

\[ V_g = 0.484 \times 0.475 \times 0.075 = 0.0172\,m^3 \]

\[ M_g = T_g \times V_g = 563 \times 0.0172 = 9.71\,kg \]

(d) **The Mass of the Screening Material**

The screening materials consist of the net and the net frame.

\[ M_{sm} = M_n + M_f \tag{9} \]

Where;

- \( M_{sm} = \) Mass of screening material
- \( M_n = \) Mass of net
- \( M_f = \) Mass of net frame

Where;

- \( M_n = 0.003\,kg \) and \( M_f = 0.45\,kg \) (Olawale J. Okegbile, Abdulkadir B, 2014).

\[ M_{sm} = 0.003 + 0.45 = 0.45\,kg \]

The total mass of the reciprocal sieve bed is:

\[ M_{rsb} = m_{st} + m_{sc} + m_g + m_{sm} = 2.85 + 2.24 + 9.71 + 0.45 = 15.25\,kg \]

6. **Shaft Design**

(i) **Minimum Shaft diameter**

\[ d_s^2 = \frac{16}{\pi t_s^2} \sqrt{(k_b m_b)^2 + (k_t m_t)^2} \tag{k} \]

Where;

- \( m_t \) = torsional moment and \( m_b \) = bending moment
- \( k_b \) = Combined shock and fatigue applied to bending moment
- \( k_t \) = Combined shock and fatigue applied to torsional moment
- \( t_s \) = Allowable shear stress

\[ k_b = 1.0 \text{ and } k_t = 1.5 \text{ and } t_s = 40 \times 10^6\,N/m^2 \text{ (khurmi Design 2005).} \]

But first, let us calculate the bending moment.

\[ mg = (1.5 \times 9.81) = 14.72\,N \]

**Calculating the Reactions**

\[ R_A + R_B = 14.72 \tag{1} \]

\[ \sum M_B = 0 \]

\[ R_A \times 0.37 = 14.72 \times 0.185 \]

\[ R_A = \frac{2.7232}{0.37} = 7.36\,N \]

\[ \therefore R_A = R_B = 7.36\,N \]

**S.F Calculation**

@ Pt. A: \( S.F_A = R_A = 7.36\,N \)

@ Pt. C: \( S.F_C = R_A - 14.72 = 7.36 - 14.72 = -7.36\,N \)

@ Pt. B: \( S.F_B = R_A - 14.72 + R_A = 0 \)

**B.M Calculation**

@ Pt. A: \( B.M_A = 0 \)

@ Pt. C: \( B.M_C = R_A \times 0.185 = 7.36 \times 0.185 = 1.36\,Nm \)

@ Pt. B: \( B.M_B = 7.36 \times 0.37 - 14.72 \times 0.185 = 0 \)

\[ \therefore \text{The Maximum Bending moment is } 1.36\,Nm \]
S.F and B.M diagrams

So,\( M_b = 1.36 \text{Nm} \)
and \( M_t = \frac{\text{power}}{\text{speed}} = \frac{P}{r} \) (m)

But \( P = (T_1 - T_2)V = \text{power to drive motor.} \)
But Belt tensions \( T_1 \) and \( T_2 = ? \)
Recall that, \( T_{AV} = \text{Average torque on pulley} = (T_1 - T_2) \frac{D_1}{2} \)
Design Analysis OF A Reciprocating Cassava Sieving Machine

\[ T_{AV} = \frac{(T_1 - T_2) D_1}{2} \]  
\[ \text{(a)} \]

But \( T_{AV} = 31.05 \text{Nm} \) (According to India standard)
and \( D_1 = 100\text{mm} \) and \( D_2 = 250\text{mm} \) (Khurmi and Gupta, 2005)
Where \( D_1 \) = Driver diameter
\( D_2 \) = Driven diameter
So, equation \( @ \) now becomes;
\[ 31.05 = \frac{(T_1 - T_2)}{2} \]  
\[ \Rightarrow T_1 - T_2 = 621 \]  
\[ \text{(b)} \]

Also, \( \frac{T_1}{T_2} = \rho^{\mu \theta} \)
\[ \Rightarrow T_1 = T_2 \rho^{\mu \theta} \]  
\[ \text{(c)} \]
Where \( \theta = 180 - 2\theta \) and groove angle varies between \( 32^0 \) to \( 40^0 \) (Khurmi and Gupta, 2005)
So using \( \theta = 32^0 \)
\[ \Rightarrow \theta = 180 - (2 \times 32) = 180 - 64 = 116^0 \]  
\[ \therefore \text{and } \mu = \tan \theta \]  
\[ \Rightarrow \mu = \tan 32^0 = 0.66 \]
So, substituting values into \( \text{(c)} \)
\[ T_1 = T_2 \times 2.718^{\frac{0.66 \times 116}{180}} \]  
\[ T_1 = T_2 \times 2.718^{0.4253} \]  
\[ \Rightarrow T_1 = 1.5299 \times 10 \times 1171.92 \]  
\[ \text{(d)} \]
So, putting \( \text{(d)} \) into \( \text{(b)} \)
\[ \Rightarrow 1.5299T_2 - T_2 = 621 \]  
\[ \Rightarrow 0.5299T_2 = 621 \]  
\[ \Rightarrow T_2 = \frac{621}{0.5299} = 1171.92\text{N} \]
So, putting the value of \( T_2 \) into \( \text{(d)} \)
\[ \Rightarrow T_1 = 1.5299 \times 1171.92 \]  
\[ = 1792.92\text{N} \]  
\[ \therefore T_1 = 1792.92\text{ and } T_2 = 1171.92\text{N} \]
So, power \( P = (T_1 - T_2) \times \nu \)
But \( \nu = w \times r \) and \( w = 47.13\text{rad/s} \) as calculated above.
\[ \therefore \nu = 47.13 \times 0.05 \]  
\[ = 2.36\text{m/s} \]
\[ \therefore \text{Power, } P = (1792.92 - 1171.92) \times 2.36 \]  
\[ = 1465.56\text{W} \]  
\[ \therefore P = 1.47\text{KW} \]
Also, from equation \( \text{(m)} \)
\[ M_1 = \frac{P}{\nu} = \frac{1465.56}{2.36} = 621\text{Nm} \]
So, substituting values into equation \( \text{(k)} \) to get the minimum diameter.

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\[
d_s^3 = \frac{16}{3.142 \times 40 \times 10^6} \sqrt{(1.5 \times 1.36)^2 + (1.0 \times 621)^2}
\]
\[
d_s^3 = \frac{16}{125680000} \sqrt{4.1616 + 385641}
\Rightarrow d_s = \frac{3}{3} \sqrt{1.27 \times 10^{-7} \times 621}
\]
\[
d_s = 0.0266m
\Rightarrow d_s = 26.6\text{mm}
\]

∴ We choose 25mm (standard diameter) as the shaft diameter.
IV. Recommendation

For further review, the following recommendations are hereby given:

1. This machine is highly recommended for domestic application especially for rular dweller to boost the production of garri.
2. It is highly recommended that, the machine be modified so that it can also perform the functions of disintegrating the cassava particles as well as sieving it than using the hand manually.
3. This machines is recommended not only for grated and dehydrated cassava but also to sieve grains (maize, beans, soya beans, rice, millets etc).
4. It is recommended that, the grated cassava should be properly dehydrated to reduce the moisture content to about 60% in or er to avoid slight resistance to push through the filter.
5. After sieving the fine particles from the larger (coarse) particles, it is highly recommended that further design should incorporate a method of discharging the undesired (coarse) particles automatically, instead of switching off the machines to remove these large particles before turning it on again for sieving.

V. Conclusion

Testing of the machine was done to evaluate the performance, and the results obtained showed that the study was successful as it was found to have an output capacity of 100.59kg/hr with an efficiency of 75.7%.

Therefore, the machine will absolutely facili ate the mass production of garri especially in rural areas and also overcome the massive/tremendous stress associated with the manual process.

Reference