Design and Analysis of a Centrifugal Separator for the Separation of Pith from Bagasse

Prachi Sawant\(^1\), Sayali Thombre\(^2\), Priyanka Shingate\(^3\), Siddhi Shirode\(^4\), Prof A.K. Pathak\(^5\)

\(^1,2,3,4,5\) Department of Mechanical, D.Y. Patil College of Engineering, Akurdi, Pune-44, Maharashtra, India

Abstract—Among the by-products that we get from sugarcane, bagasse is the most relevant and important. As the natural resources are being depleted, use of bagasse as an alternative resource is being encouraged. The pith from the useful fibrous material of sugarcane is separated by various means viz. dry depithing, wet depithing and chemical depithing. The use of chemicals for pith separation is expensive so mechanical ways are used for pith separation. The purpose of the project is to reduce the pith content and separate it from the useful fibre at a faster rate. The design and calculations of the centrifugal separator for pith separation are explained in the paper.

I. INTRODUCTION

Small scale industries create an innovative idea to accompany the agricultural growth. The intention of proposed work is to develop product that separates the non fibrous material i.e. pith from fibrous material i.e. fibre in the bagasse. Bagasse is produced after the crushing of sugarcane with extraction of juice. Bagasse consists of fibre, pith and sand particles. The worldwide pulp and paper industry is gradually realizing that there is shortage of the traditional raw material of cellulose fibre. Bagasse is a fibrous residue remaining after the extraction of sweet juice from sugarcane. Till recently the bagasse generated in the sugar mill was mainly utilized as fuel for generation of steam and power by sugarcane mill itself and only a small portion was available for other uses mainly paper making.

Bagasse is produced after the crushing of sugarcane with extraction of juice. This bagasse contains the fibres, pith and sand particles. Each tons of sugarcane delivered to processing mills yields 740 kg of juice and 260 kg of moist bagasse.

Bagasse is an abundant resource with easy accessibility, cost effectively, high compressibility and moisture retention capability. Bagasse represents a potential source of fibre for the paper industry without further compromising the environmental concern. It is cheap, renewable each year, presently it does not have an alternative economically attractive value added usage, and however it has adequate chemical and mechanical properties for paper making. When leaving the last mill tandem, raw bagasse, contains 55-60% of fibre. The other fraction, rich in pith or parenchymatous tissue (30-35%), being non fibrous in nature and rich in juice, contributes to various problem.

Bagasse is also used for thermal power plant as a fuel and this is also majorly used in production of papers and pulp, agglomerated boards, polymers, construction bricks etc.

Effective depithing and cleaning is the key for the successful production of quality acceptable pulp and paper from bagasse. The main purpose of this project is to reduce the pith content in bagasse; mainly the purpose of pith reduction conventionally takes a long period to execute itself. The project is completely automated and effectively reduces pith and separates fibre.

The Project benefits the industry in many ways. It improves Calorific Value of the boiler fuel. Fast processing of the manufacturing of agglomerated board. Maximum amount of pith is removed from bagasse in minimum time.

II. CONSTRUCTION & WORKING

The system consists of a single phase motor running at a speed of 1440 rpm. The motor is connected to the central shaft by using belt and pulley arrangement. The speed reduction is in the ratio 1:2. The system is divided in three stages. Each stage consists of hammers which are linked together by a dovel pin, Each stage is separated by using filters of 5mm, 3mm and 2mm. The whole setup is surrounded by a circular perforated sheet. The system is supported by a rectangular frame.

Sugarcane is inserted in the system through a hopper. As the sugarcane travels in the downward direction, because of the high speed of shaft the hammers rotate at a high speed, the sugarcane is crushed between the perforated sheet and the hammer surface. Using centrifugal force exerted on crushing hammers, pith formation takes place. At the bottom there is an arrangement for a tray fitment for collection of pith produced.
III. MECHANICAL DESIGN

1. Hammer:
Length = 100 mm
Width: W1 = 45 mm  W2 = 30 mm
Thickness = 4 mm
Material: Mild Steel

Volume of hammer = (l×b×t) - 2×(B×h/2)×t + ((π×R²)×t)/2 - ((π×r²)×t)/2
= (90×45×4) - 2×(7.5×90/2)×4 + (π×22.5²)×4/2 - (π×15²)×4/2
V = 15266.5 mm³

Where,
l = length of the rectangular portion
b = breadth of rectangular portion
t = thickness of rectangular portion
B = base of triangular portion
h = height of triangular portion
R = radius of larger circle
r = radius of smaller cut circle

Density of Mild Steel = 7850 kg/m³
Mass of hammer = ρ×V
= 7850×15266.5×10⁻⁹
m = 0.1198 kg

Weight of hammer = mg
= 0.1198×9.81
W = 1.1756 N

2. Angle Plate:
Consider angle plate as cantilever beam.

Actual load at B = (Mass of 3 hammers) + (Mass of Cuff)
= (3×0.1198) + (0.3)
= 0.6594 kg

Consider, load as 1 kg approximately.

Let, b = Length of the angle plate = 150 mm
I = Moment of Inertia
E = Modulus of Elasticity
W = Weight of the angle plate
ib = Angle of deflection for angle plate

I = bt³/12 = 150×t³/12 = 12.5×t³ mm⁴
E = 210 GPa = 210×10⁹ N/mm²
W = 9.81 N
ib = (w×b³) / (2×E×I)
= (9.81×150³) / (2×210×10³×12.5×t³)
= 6.306/t³

CC2 = BB1 = yb = (w×b³) / (3×E×I)
= (9.81×12.6³) / (3×210×10³×12.5×t³)
= 2.491/t³

C2C1 = bxib = 24×(6.306/t³)
= 151.34 / t³

CC1 = yc = (2.491/t³) + (151.34/t³)
= 153.83/t³ mm
When \( t = 5.3581 \), \( y_c = 1 \text{ mm} \)

But \( y_c \) should be as less as possible for safety purpose

Consider \( t = 6 \text{ mm} \) for \( y_c = 0.81 \text{ mm} \)

3. Dimensions of angle plate:

Length = 150 mm

Width = 45 mm

Thickness = 6 mm

Material = Mild Steel

Volume of angle plate = (volume of rectangular part) - (volume of hole)

\[
V = (lxbxh) - (\pi \times r^2) \times t
\]

\[
V = (137.5 \times 45 \times 6) - (\pi \times 7.5^2) \times 6
\]

\[
V = 36065.25 \text{ mm}^3
\]

Mass of angle plate = \( \rho \times V \)

\[
7850 \times 36065.25 \times 10^{-9} \]

m = 0.2831 kg

Weight of angle plate = \( mxg \)

\[
0.2831 \times 9.81
\]

W = 2.7773 N

4. Anvil Rod:

Rod diameter = 4 mm

Length = 238 mm

Volume of anvil rod = \( \pi \times r^2 \times l \)

\[
V = \pi \times 2^2 \times 238
\]

\[
V = 2990.79 \text{ mm}^3
\]

Mass of anvil rod = \( \rho \times V \)

\[
7850 \times 2990.79 \times 10^{-9}
\]

m = 0.0234 kg

Weight of anvil rod = \( mxg \)

\[
0.0234 \times 9.81
\]

W = 0.2203 N

5. Semi-circular anvil plate (solid):

d = 30 mm

r = 15 mm

l = 360 mm

Volume of anvil shaft = \( \pi/4 \times (r/2)^2 \times l \)

\[
V = \pi/16 \times (15)^2 \times 360
\]

\[
V = 15904.31 \text{ mm}^3
\]

\[
V = 1.590 \times 10^{-5} \text{ m}^3
\]

Mass of semi-circular anvil shaft = \( \rho \times V \)

\[
7850 \times 1.590 \times 10^{-5}
\]

m = 0.1248 kg

Weight of semi-circular anvil shaft = \( mxg \)

\[
0.1248 \times 9.81
\]

W = 1.2244 N

6. Perforated sheet:

\( r = 240 \text{ mm} \)

1 = 360 mm

Circumference of perforated sheet = \( 2 \times \pi \times r = 2 \times \pi \times 240 \)

\[
= 1507.96 \text{ mm} \]

Area of perforated sheet = 1.50796 \times 0.360

\[
A = 0.5428 \text{ m}^2
\]

Area of 2.88 \text{ m}^2 perforated sheet is 4 kg then calculate for 0.5428 \text{ m}^2 area.

\[
(2.88/0.5428) = (4/x)
\]

\[
x = 0.7538 \text{ kg}
\]

7. G.I circular plate

\( D = 240 \text{ mm} \)

\( d = 25 \text{ mm} \)

\( t = 0.5 \text{ mm} \)

Volume of plate = \( \pi/4 \times (D^2-d^2) \times t \)

\[
= \pi/4 \times (240^2-25^2) \times 0.5
\]

\[
V = 2.237 \times 10^{-5} \text{ m}^3
\]

Mass = \( \rho \times V \)

\[
7850 \times 2.237 \times 10^{-5}
\]

m = 0.1756 kg

Weight of circular plate = \( mxg \)

\[
0.1756 \times 9.81
\]

W = 1.756 N

8. Design of hammer cuff:

\( l = 70 \text{ mm} \)

\( D = \text{O.D.} = 28 \text{ mm} \)

\( d = \text{I.D.} = 24 \text{ mm} \)

Volume of hammer cuff = \( \pi/4 \times (D^2-d^2) \times l \)
\[
\begin{align*}
\pi &= 4(28^2-24^2) \times 70 \\
&= 11435.39 \text{ mm}^3 \\
&= 1.143 \times 10^5 \text{ m}^3 \\
\text{Mass of hammer cuff} &= p \times v \\
&= 0.08796 \text{ kg} \\
\text{Weight of hammer cuff} &= mg \\
&= 0.8796 \times 9.81 \\
W &= 0.8806 \text{ N}
\end{align*}
\]

9. Design of hammer shaft:
Consider it as a simply supported beam
- Mass of 3 hammers = (0.12717 \times 3) kg = 0.38151 kg
- Mass of 2 bearings = (0.125 \times 2) kg = 0.25 kg
- Mass of hammer cuff = 0.303 kg

Total Weight = 9.175 N
At C & E = 4.5837 N
At D,

\[
\begin{align*}
\text{Centrifugal force} &= \frac{m \times v^2}{r} \\
\therefore \quad r &= 18.86 \text{ mm} \\
\omega &= (2 \pi n)/60 \\
&= (2 \times \pi \times 80)/60 \\
\therefore \quad \omega &= 8.37 \text{ rad/s} \\
\therefore \quad m &= 1.335 \text{ kg} \\
\therefore \quad \text{Centrifugal force} &= \frac{m \times v^2}{r} \\
&= (1.335 \times (0.157)^2)/0.01886 \\
\therefore \quad F &= 1.74 \text{ N} \\
\therefore \quad \text{Torque} &= (60 \times 10^6 \times P)/(2 \times \pi \times n) \\
&= 0.1256 \text{ KW} \\
\therefore \quad T &= (60 \times 10^6 \times 0.1256)/(2 \times \pi \times 80) \\
&= 14 \times 10^3 \text{ Nmm}
\end{align*}
\]

For design considerations,

\[
T = T \times 1.6 = 23.90 \times 10^3 \text{ Nmm}
\]

\[
\begin{align*}
\Sigma M_A &= 0 \\
&= (4.5837 \times 5.5) - (1.74 \times 50.19) + (4.5837 \times 66.5) - R_B \times 72 \\
\therefore \quad R_B &= 3.37 \text{ N} \\
\Sigma M_B &= 0 \\
&= -R_A \times 72 + 4.5837 \times 66.5 - 1.74 \times 21.81 + 4.5837 \times 5.5 \\
\therefore \quad R_A &= 4.056 \text{ N}
\end{align*}
\]

B.M at A and B = 0
At C = 4.056 \times 5.5 = 22.31 \text{ Nmm}
At D = 4.056 \times 50.19 - 4.5837 \times 44.69 = -1.27 \text{ Nmm}
At E = 4.056 \times 66.5 - 4.5837 \times 61 + 1.74 \times 10.81 = 8.92 \text{ Nmm}

\[
M = 22.31 \text{ Nmm}
\]

Equivalent bending moment:

\[
M_e = \frac{1}{2} (M + \sqrt{T^2 + M^2})
\]

\[
\therefore \quad M_e &= 11961.16 \text{ Nmm}
\]

Equivalent twisting moment:

\[
T_e = \sqrt{T^2 + M^2}
\]

\[
\therefore \quad T_e &= 23900 \text{ Nmm}
\]

\[
T_e = \frac{\pi}{16} (d^3 \times \varsigma)
\]

\[
23900 = \frac{\pi}{16} (d^3 \times 63.33)
\]

\[
\therefore \quad d &= 12.43 = 15 \text{ mm}
\]

\[
\varsigma = (0.5 S_a)/F.S
\]

Material 40C8,
\[F.S = 3\]

\[
\varsigma = (0.5 S_a)/F.S
\]

\[
= (0.5 \times 380)/3
\]

\[
\therefore \quad \varsigma = 63.33 \text{ Nmm}
\]

Volume = \frac{\pi}{4} (d^3) \times 1

Volume = 1.272 \times 10^{-5} \text{ m}^3

m = p \times v

\[
\therefore \quad m &= 0.09998 \text{ kg}
\]

\[
W = mx \times g
\]

\[
= 0.0998 \times 9.81 = 0.979 \text{ N}
\]

10. Hammer shaft bearing:

Radial load: \[F_r = 1.74 \text{ N}\]

Axial load: \[F_a = ((3 \times 0.12717) + 0.303) \times 9.81 = 6.71 \text{ N}\]

\[
P = X F_a + Y F_r
\]

\[
\therefore \quad P &= 8.45 \text{ N}
\]

\[
(\text{L}_{10}) = (60 \times n \times (\text{L}_{10})_h)/10^6
\]

\[
C = P \times (\text{L}_{10})^{1/3}
\]

\[
= 8.45 \times (192)^{1/3}
\]
\[ C = 48.45 \text{ N} \]

But comparing it with design data book,

\[ C = 1560 \text{ N} \]

\[ d = 1.0 \text{ ID} = 15 \text{ mm} \]

\[ D = 0.0 \text{ OD} = 24 \text{ mm} \]

Designation = 61802

\[ B = 5 \text{ mm} \]

\[ C_0 = 815 \text{ N} \]

11. Design of central shaft:

Weight of 4 hammer shaft = 3.9192 N

Weight of 12 hammers = 14.964 N

Weight of 2 G.I plate = 3.458 N

Weight of 8 bearing for hammer shaft = 9.81 N

weight of angle plate = 29.8224 N

Total weight = 61.97 N

Assume,

Weight of main shaft bearing = \( m \times g \)

\[ = 0.4 \times 9.81 \]

\[ W = 3.924 \text{ N} \]

Length of anvil plate = 238 mm

Diameter = 5 mm

Volume = \( \frac{\pi}{4} (d^2) \times l \)

\[ = 4673.11 \text{ mm}^3 \]

\[ \therefore V = 4.673 \times 10^{-6} \text{ m}^3 \]

Mass = density \times volume

\[ = 0.0366 \text{ kg} \]

\[ \therefore \text{Weight} = 0.3598 \text{ N} \]

\[ \therefore \text{Weight of main shaft bearing} = 3.924 \text{ N} \]

\[ \therefore \text{Weight of 4 anvil angles} = 4 \times 0.3598 \text{ N} \]

Total weight = 5.3692 N

\( W_1, W_2, W_3 = \text{Weight of each stage} \)

\( W_2, W_4 = \text{Weight of bearing + anvil angle} \)

\[ W_3 = \text{Total weight + Bagasse weight} \]

\[ = 61.97 + 49.05 \]

\[ \therefore W_3 = 111.02 \text{ N} \]

\[ \therefore W_1 = W_5 = 61.97 \text{ N} \]

\[ \therefore W_3 = 111.02 \text{ N} \]

\[ \therefore W_2 = W_4 = 5.36 \text{ N} \]

\[ \Sigma M_A = 0 \]

\[ = 61.97 \times 200 + 5.36 \times 260 + 111.02 \times 320 + 5.36 \times 380 + 61.97 \times 440 - R_B \times 505 \]

\[ \therefore R_B = 155.67 \text{ N} \]

\[ \Sigma M_B = 0 \]

\[ = 61.97 \times 65 + 5.36 \times 125 + 111.02 \times 185 + 5.36 \times 245 + 61.97 \times 305 - R_A \times 505 \]

\[ \therefore R_A = 90 \text{ N} \]

\[ B.M \text{ at } A \& B = 0 \]

At C = 90 \times 200 = 1800 \text{ Nmm}

At D = 90 \times 260 - 61.97 \times 760 = 19681.8 \text{ Nmm}

At E = 90 \times 320 - 5.36 \times 60 - 61.97 \times 120 - 111.02 \times 60 = 15741 \text{ Nmm}

At G = 90 \times 440 - 61.97 \times 240 - 5.36 \times 120 - 111.02 \times 120 - 5.36 \times 60

\[ = 10118.4 \text{ Nmm} \]

\[ \therefore M = 21042 \text{ Nmm} \]

\[ B.M \text{ at } C \]

\[ = 90 \times 200 = 1800 \text{ Nmm} \]

\[ \therefore T_e = \sqrt{T^2 + M^2} \]

\[ = 63582.74 \text{ Nmm} \]

Equivalent bending moment:

\[ M_e = \frac{1}{2} (M + \sqrt{T^2 + M^2}) \]

\[ = \frac{1}{2}(21042 + 63582.74) \]

\[ \therefore M_e = 42312.37 \text{ Nmm} \]

\[ T_e = \frac{\pi}{16} (d^3 \times \xi) \]

\[ 63582.74 = \frac{\pi}{16} (d^3) \times 63.33 \]

\[ \therefore d = 17.22 \text{ mm} \]

Take diameter as 25 mm.

\[ \text{Volume} = \frac{\pi}{4} (d^2) \times l \]

\[ \therefore \text{Volume} = 2.47 \times 10^{-4} \text{ m}^3 \]

\[ m = \rho \times v \]

\[ \therefore m = 1.945 \text{ kg} \]

\[ W = mxg \]

\[ W = 19.08 \text{ N} \]
IV. MATERIALS USED

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V. CONCLUSION

Due to high efficiency and good results obtained in the overall performance assessment of the process, we use pith as a replacement of paper and pulp industry. The remaining material form the paper and pulp industry which is thrown out, is utilised in those machine and used for various purposes. as it is cheaper, it is economically beneficial and profitable. as has ability of low absorption of water it is widely being used in todays industry.

REFERENCES