Design and Construction of a Conical Screen Centrifugal Filter for Groundnut Oil Slurry

Abdulkadir Baba HASSAN, Matthew Sunday ABOLARIN,
Ikechukwu Celestine UGWUOKE

Department of Mechanical Engineering, Federal University of Technology, Minna, Niger State, Nigeria, abdulkadir_hassan2003@yahoo.com, abolarinmatthew@yahoo.com, ugwuokeikechukwu@yahoo.com

Abstract

This work focuses on the design and construction of a conical screen centrifugal filter for the separation of groundnut oil slurry. The major component of the machine is the rotary conical screen which separates the pure groundnut oil from the slurry via centrifugal filtration. Sludge particles were removed from the slurry through the open end of the rotary wide-angle conical screen when the half angle of the cone is greater than the angle of repose of the sludge. From the design analysis and calculation the required half angle and the thickness of the conical screen were found to be 30º and 1mm respectively.

Keywords

Groundnut oil slurry, Separation, Centrifugal filter

Introduction

There are various methods of removing oil from oil seeds which includes traditional method of extraction and mechanical expression. The traditional method as in the case of oil palm fruit involves boiling the fruit in water which makes it easier, possibly by breakdown of oil cells and coagulating the protein to squeeze off the succulent fleshy part. By washing the mass in water the oil floats and is skimmed off. This is further cooked to get the right quality and colour. Other traditional methods as in the case of groundnut, melon and similar seeds in question involves pre-grinding with mortar or other local grinding equipment and hand pressed to extract the oil. Groundnut is an annual crop, which can be cultivated at any time of the year with proper irrigation. It is also known to thrive best in rich sandy loam soil (Woolrich and Carpenter, 1933). In Nigeria, yields as high as 200lbs (90kg) has been obtained (Irvin, 963). Nigeria is among the three largest producers in the world with about 6.5% of the total world production (Pulsegroove, 1968). Groundnut contains 25% protein and 45-50% oil (Muller, 1988). The harvested nut can be useful in so many ways. The husk could be used in making fertilizers or be fermented into alcohol or acetones while the whole kernel yields the oil and the cake. Groundnut oil shows good resistance to oxidation. Its fatty acid consists of about 20% saturated and 50% unsaturated lipids. It also contain up to 30% linoleic (essentially fatty acid), which plays a major part in human diet. Having seen the high economic importance of groundnut to the economy, the diet of the average Nigerian and the rising demand for vegetable oil in the market, it becomes inevitable to quickly replace the traditional method of separation of groundnut oil slurry which is rather wasteful, unhygienic and labour intensive with a mechanized method. In view of these, mechanical filtration by wide-angle conical screen centrifugal filter is necessary. It is therefore believed that this work will produce a conical screen centrifugal filter which is affordable by an average local processor of vegetable oil and which will greatly improve vegetable oil filtration.

Design analysis

Half Angle of the Conical Screen

The following forces acts on the particle lying on the rotating conical screen:

1. Force “mg” due to the weight of the particle directed downwards.
2. The reaction “R” of the wall on the particle.
3. The frictional force “F”.
4. The centrifugal force “$m\omega^2T$”.

In commercial centrifuges, the centrifugal component is much greater than the gravitational force that the latter may be practically neglected (Perry, 1997).

For the sludge to move upwards along the wall of the cone $F_L > \mu F_P$, where F_L = the resolution of centrifugal force along the cone wall, F_P = the resolution of centrifugal force perpendicular to the cone wall, and μ = the coefficient of viscosity of the slurry medium.

$F_L = m\omega^2 r \cos\alpha$

$F_P = m\omega^2 r \sin\alpha$

where α = the angle of repose of the sludge medium.

$m\omega^2 r\cos\alpha > \mu m\omega^2 r\sin\alpha$, $\mu > \cos\alpha/\sin\alpha$, $\alpha > \cot^{-1}\mu$

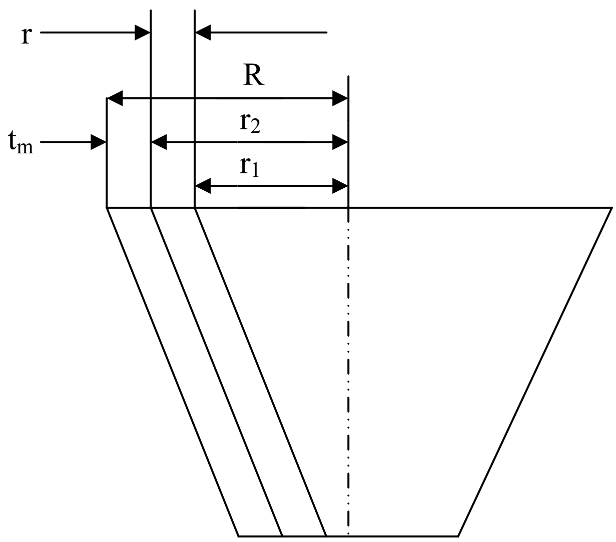
If the half angle of the conical screen is greater than the angle of repose of the solid, the solid will slide across it with a velocity which depends on the frictional properties of the sludge and not on feed rate. If the half angle exceeds the angle of repose, the velocity will be high and the retention time under centrifugal force will be too short for effective filtration (Perry, 1997).

Relative Centrifugal Force

$F_R = 5.59 \cdot 10^{-4} n^2 D$, where n = number of revolution per minute, and D = top diameter of the conical screen (mm).

Allowable Thickness of Material for the Construction of the Truncated Conical Screen

The total stress experienced by the wall of the conical screen as stated by (Perry, 1997) is given as:



$$S_t = \omega^2 r_2 \left[r_2 \rho_m + \left(r_2^2 - r_1^2 \right) \frac{\rho_c}{4 t_m} \right]$$

where S_t = Total stress experienced by the bowl wall (N/m2); ω^2 = Selected machine speed (rad/s); r_2 = Outer radius of bowl (mm); r_1 = Inner radius of bowl (mm); ρ_m = Density of material for construction of the screen (Kg/m^3); ρ_c = Average density of bowl (Kg/m^3); t_m = Thickness of material for the construction of bowl (mm)

$$t_m = \frac{\rho_c \omega^2 r_2 \left(r_2^2 - r_1^2 \right)}{2.236 \times 10^{-3} n^2 D \frac{S_t}{F_R} - 4\omega^2 r_2^2 \rho_m}$$

Pulley and Belt for Power Transmission

A V-belt and pulley is preferred for use to transmit power from the electric motor to the machine due to the following advantageous factors:

1. Ability to absorb vibration
2. Quietness while in operation.
3. Low cost of maintenance and repair.
4. Easy detection of fault.

Minimum Pulley Diameter corresponding to Maximum Torque

The *Diameter of Larger Pulley* is:

$d_2 = (d_1\omega_1)/\omega_2$

where:

- d_2 = Larger pulley diameter (mm);
- d_1 = Smaller pulley diameter (mm);
- ω_1 = Input shaft angular speed (rad/s);
- ω_2 = Desired output shaft angular speed (rad/s).

The *Speed Ratio* is given by the formula:

$U = \omega_1/\omega_2$

where U = The speed ratio.

The *Belt Speed* is given by the formula:

$\nu = (\omega_1 d_1)/(2 \cdot 1000)$

where ν = Belt speed (m/s).

The *Tentative Centre Distance*

$a_{min} = 0.55(d_1 + d_2) + h$

$a_{max} = 2(d_1 + d_2)$

where:

- a_{min} = The minimum tentative centre distance (mm);
- a_{max} = The maximum tentative centre distance (mm);
- h = Belt height (mm).

The *Belt Length*:

$L = 2a + (\pi/2)(d_1 + d_2) + [(d_2 - d_1)/4a]^2$

where L = Length of belt (mm)

The *Final Centre Distance*:

$a = 0.25[(Ld - A_1) + sqrt[(Ld - A_1)^2 - 8A_2]]$

where $A_1 = 0.5\pi(d_2 - d_1)$, and $A_2 = 0.25(d_2-d_1)^2$.

The *Angle of Contact*:

$\alpha = 180° - 57°[(d_2 - d_1)/a]$

where α = the angle of contact.

The *Allowable Power*:

$[P] = P_0C_\alpha C_S$

where:

- [P] = Allowable power in KW;
- C_α = Service factor;
- C_S = Constant that accounts for effect of angle of contact.

The *Number of Belts*:

$Z = P/[P]$

where P = Power transmitted by drive in KW.

The *Pretension for One V-Belt*:

$F_{01} = 780P/[(vC_\alpha C_S)+(qv^2)]$

where:

- q = Mass per meter run of belt in kg;
- F_{01} = Pretension for one v-belt

The *Force Acting on the Shaft*:

$F_b = F_{01}ZSin(\alpha/2)$

The *Torsional Moment*:

$M_t = (P \cdot 1000 \cdot 60)/2\pi n$

where:

- P = Power transmitted to shaft in KW;
- n = Speed of rotation of shaft in rev/min;
- Mt = Torsional moment in Nm.

The *Bending Moment*:

$$B_{MAX} = \sqrt{BM_V^2 + BM_h^2}$$

where:

- BM_V = Maximum bending moment for vertical loading;
- BM_h = Maximum bending moment for horizontal loading.

The *Shaft Diameter*. For a solid shaft as given by (Hall et al, 1980) is:

$$d^3 = \frac{16}{S_S \pi}\sqrt{(K_b M_b)^2 + (K_t M_t)^2}$$

where:

- S_S = Allowable shear stress for shaft with key way (40 MN/m^2);
- M_b = Maximum bending moment in Nm;
- M_t = Torsional moment in Nm;
- K_b = Combined shock and fatigue factor applied to bending moment;
- K_t = Combined shock and fatigue factor applied to torsional moment.

Bearings

Two rolling contact bearings were employed to support the central shaft and withstand the expected restraint to externally applied load with a minimum amount of friction. Rolling contact bearings were chosen because unlike sliding bearing which does not use balls or rollers as load carrying elements. The presence of rollers makes them suitable to bear either radial or axial load at high speed. In addition, rolling contact bearing has less friction resistance and is suitable for use without the frequent application of lubricant.

Design calculations

The following results were obtained from calculation:

Name	Abb.	Value
Angle of slurry medium	α	> 27.23°
Relative centrifugal force	F_R	377.88 N
Allowable thickness of material for the construction of the truncated conical screen	t_m	0.85 mm
Torque	T	16.2159 Nm
Diameter of pulley	d_1	100 mm
Diameter of pulley for driven shaft	d_2	100 mm
Speed ratio	U	1
Belt speed	v	6.8 m/s
Tentative centre distance	a_{min} a_{max}	118 mm 400 mm
Belt length	L	1120 mm
Final centre distance	a	400 mm
Initial power transmitted by one belt	P_0	1.6 KW
Angle of contact	α	180°
Allowable power	[P]	1.28 KW
Number of belts	Z	2 belts
Pretension for one v-belt	F_{01}	109.25 N
Force acting on the shaft	F_b	218.50 N
Torsional moment	M_t	16.19 Nm
Weight of truncated cone		20.9540 N
Weight of pulley		41.03 N
Maximum bending moment	B_{max}	60.5546 Nm
Shaft diameter	d	22.7mm

Conclusion

The objective of this work was to design a conical screen centrifugal filter for the separation of groundnut oil slurry. Preliminary design analysis was made, using the data obtained from the physical and chemical properties of the groundnut oil slurry and working upon the principle of continuous filtering centrifuges, a wide-angle conical screen centrifuge was designed. The design consists of a rotary conical screen as the main component of the machine driven by a variable speed motor via a v-belt and pulley power transmission system.

References

[1] Irvin F. R. , *West Africa Crops*, Oxford University Press, Cambridge, London, Vol. 2, 1963, p. 24-30.

[2] Muller H. G., *Introduction to food technology*, McGraw-Hill Book Company New York, 1988, p. 210-243.

[3] Perry R. H., *Chemical engineering handbook*, 7th edition, McGraw-Hill New York, pp. 18, 65-123, 1997.

[4] Pulsegroove J. W., *Tropical crops dicotyledon*, Longman Green Haslow and London, pp. 199-232, 1968.

[5] Woolrich W. R., Carpenter E. L., *Many problems beset vegetable oil producers*, Funds and Industries, Vol. 6, 1933, p. 260.