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Development of a combined hammer and attrition mill

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Abstract

A combined hammer and attention mill was designed and fabricated. The developed hammer and attrition mill is a multipurpose machine that can be used to reduce the size of various agricultural materials. This machine focused on how to combine the three forces used in size reduction in a single machine. The machine has two chambers. The upper chamber which is the hammer mill that uses the impact force to crush the material until it is small enough to pass through the screen. The lower chamber which is the attrition mill uses shear force to fine grind the already crushed material. The machine is driven by an electric motor of 7.5kW at a speed of 1440rpm. It has an average capacity and an average throughput efficiency of 47.2kg/hr and 98.4% respectively.

Keywords: Hammer, attrition, impact force, shear force and size reduction, multipurpose.

1.0 INTRODUCTION

A nation that does not develop agricultural sector cannot be economically buoyant. Agriculture has the great potential and prospect for a rapid transformation of the nation. The agricultural sectors have always made vital contribution to the national development and enhance poverty reduction (alleviation) in developing nations. In Nigeria, most livestock feed is milled manually using obsolete machine as a result of the high initial cost of acquiring modern equipment. The development and use of simple machine for the processing of agriculture material is very essential in making agriculture and agricultural related business to be very lucrative. It will not only enhance mechanized agriculture in the rural community but also improve income by increasing the commercial values and the quality of the processed materials. Improved mechanized agriculture helps to reduce tiredness and increase productivity. Size reduction is the breaking of solid material into smaller particles by the application of mechanical forces without any change in the chemical properties of the materials. It involves cutting, grinding, slicing, crushing and milling of the materials. This is an important process in handling agricultural materials because it aids the extraction of desired constituents from a composite structure, it helps in range of definite size for specific projects requirement. It also increases the surface of the solid, which is of assistance in many rate processing. More so, intimate mixing or blending is usually easier with smaller size range of particle. Crushing is often applied to the reduction of coarse material down to size of about 3mm.

Grinding is the term commonly used for the production of powered materials, it is associated with attrition mill. Attrition mill also called burr or plate mill consists essentially of two roughened plates, one stationary and the other rotating. The material is fed between the plates and the material is reduced by shear. Over heating reduces the effectiveness of the grinder. The plates are designed for a variety of jobs and are usually made of chilled cast iron. The type of plates and the spacing control the fineness of reduction, the spacing screw is spring loaded so that the space will increase in case of an overload or if a foreign object enters the mill. Of the various types of grinding equipment available, hammer mills are the best known equipment used for the milling/grinding (Moiceanu et al, 2012). Studies by Adekomaya and Samuel (2014), Ajaka and Adesina (2014) showed hammer mills constructed from locally sourced materials with semi-circular or circular screens and their efficiencies. Hammer mills are used in milling and are operated at high speed ranging from 1200 – 2500 rpm, and a power requirement between the ranges of 4 – 8 kW (Don and Maloney, 1996). The output obtained using hammer mills may be attributed to the impact forces developed by the arms of the hammer mills rotating at a speed. The hammer tried on screen mill and cutters produce uniformly sized granules. Hammer and cage impact mill use fixed or swinging hardened steel hammer chains or a cage for coarse crushing to fine milling. Hammer crushers and cage mill are available in vertical and horizontal rotor configurations. Three types of forces involved size reduction are compressive, impact and attrition shear force and these three forces are being utilized in this machine. The material used as case study was maize. The machine uses both the principle of the hammer mill and attrition.

2.0 MATERIALS AND METHODS

The selection of materials and methods of construction of the combined hammer and attrition mill machine are based on the preliminary investigation and design.

The following considerations and assumptions were made for designing the machine:

- The driving shaft of the milling chambers and material must be able to withstand the combined torsion and bending moment based on maximum shear theory.
- The maximum load on the hopper must not exceed 20N considering the attrition mill's hopper volume capacity to be handled per batch of loading.

2.1 Design Considerations

In order to obtain high efficiency, and reliability, the machine parts were designed and selected based on the following:

- Cost of production of the machine.
- The machine should be multi-purpose in order to be able to reduce the size of various agricultural produce.
- The machine should be made from locally sourced materials for ease of maintenance.
- The machine should reduce time and labour input by using two (2) different size reduction principles since two (2) size reduction principles have been combined in one machine.
- The machine should save time.

2.2 Mode of operation of the combined hammer and attrition mill

The machine consists of two chambers, the upper chamber, which is the hammer mill that operates with the principle of the impact force and the lower chamber, which is the attrition mill that uses principle of shear force. Broken materials from the hammer mill move directly and enter into the attrition mill through its hopper and further grinding of the materials to smaller particle size takes place.

2.3 Design Calculations

2.3.1 Design for the Shaft of Hammer Mill

Power = Torque x Speed

P = T×W

T = P/W

But $W = \frac{2\pi N}{60}$ (N = 1200 rpm, Don and Maloney, 1996)

$W = \frac{2 \, x \, 3.142 \, x \, 1200}{60}$

W =120 rad/s

$T = \frac{7000}{120}$ (P = 7 kW, Don and Maloney, 1996)

T = 58.3 N/m^2

T_{all} = 0.27× Ys(Ys = 200 N/mm^2)

T_{all} = 0.27 × 200

= 54N/mm^2

$$\tau_{max} = \frac{16\,T}{\pi D^3}$$

$$D^3 = \frac{16T}{\pi \tau_{max}}$$

$$D^3 = \frac{16 \, x \, 58.3 \, x \, 10^3}{3.142 \, x \, 54}$$

D^3 = 5487

D = 17.64mm

Say 30 mm

2.3.2 Hopper Design (No Load)

The hopper is in the shape of a pyramid and it was calculated using equation 1 given by Khurmi (2009)

$$V_{hopper} = \frac{1}{3}[(\text{volume of the outer frustrum}) - \frac{1}{3}(\text{volume of the inner frustrum})] \quad (1)$$

$$V_{hopper} = \frac{1}{3}(Ah_o - Ah_i)$$

Where:

V_{hopper} = Volume of hopper, m^3

A = Area of base m^2

$H_{o,}$ H_i = Height of outer and inner hopper respectively, m

$$V = \frac{1}{3}[(0.303^2 \times 0.38) - (0.15^2 \times 0.1)] - \frac{1}{3}[(0.3005^2 \times 0.38) - (0.1475^2 \times 0.1)]$$

$$V = 0.010879 - 0.0107128$$

$$V = 1.66 \times 10^{-4} m^3$$

The hopper weight (W_h) was calculated using equation 2 given by Khurmi (2009)

$W_h = \rho \times V_{xg}$ (2)

$W_h = 7850 \times 1.66 \times 10^{-4} \times 10$

$W_h = 13.03N$

The bell pepper weight (W_p) is given by Khurmi (2009)

$W_p = \rho \times V_{xg}$

Where:

W_p = weight of maize, N

ρ = density of maize, kg/m^3 (760 kg/m^3) (Jiban *et al.*, 2018)

g = acceleration due to gravity, m/s^2

$W_p = 760 \times 1.66 \times 10^{-4} \times 10$

$W_p = 1.3N$

Where:

W_h = Weight of the hopper, N

2.3.3 Hopper Design (Under Load)

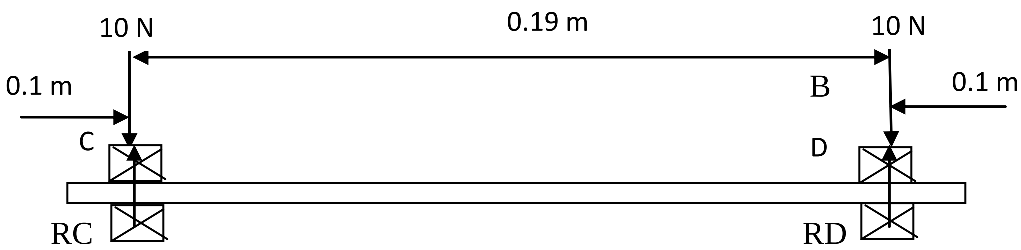
Weight on the hopper under load (W_L) was calculated using equation 3.

W_L = Weight of the hopper (W_h) + Weight of maize (W_p) (3)

$W_L = 13.03N + 1.3N$

$W_L = 14.33N = 14N$

2.3.4 Design of Hopper Shaft



W = 10 N (half of the hopper capacity/weight)

L = 0.1 m = 100 mm

X = 0.19 m

Maximum bending moment acts at C and D

M = W x L

= 10 x 0.1 = 1 Nm.

2.3.5 Torque Requirement Design

Torque was calculated using equation 4 given by Khurmi (2009)

Torque = Force x shaft radius (4)

= 14 x 0.1 = 1.4Nm

2.3.6 Design of Power

Power was calculated using equation 5 given by Khurmi (2009)

Power = $2\pi NT$ (5)

Where:

π = Constant (3.142)

N = Number of revolution, rpm

T = Torque, Nm

Number of revolutions (N) = 150 (Necmiye *et al.*, 2010)

Power = 2 x 3.142 x 150 x 1.4

= 1319.64W

= 1.3kW

2.3.7 Shaft Diameter Design

Shaft diameter was determined using equation 6 given by Krutz *et al.* (1984)

$$d^3 = \frac{16}{\pi S_s}\sqrt{(K_m M)^2 + (K_T T)^2} \qquad (6)$$

Where

M = maximum bending moment, Nm

T = maximum torque, Nm

S_s = allowable shear stress = 41.379 x 10^6 N/m^2

K_m and K_T = Shock loading factors

d = shaft diameter, m

$$d^3 = \frac{5.1}{S_s}\sqrt{(K_m M)^2 + (K_T T)^2}$$

$$d^3 = \frac{5.1}{41.379 \times 10^6}\sqrt{(2.0 \times 1)^2 + (1.5 \times 1.4)^2}$$

$$d^3 = 1.2 \times 10^{-7} \times \sqrt{(2)^2 + (2.1)^2}$$

$$d^3 = 3.567 \times 10^{-7}$$

$$d = 0.0071m$$

$$d = 0.01m$$

2.3.8 Taper Screw Auger Design

Taper screw auger was obtained using equation 7 given by Lower *et al.* (1994)

$$\text{CFTHR} = \frac{(D^2 - d^2)P_a \ x \ N_s}{215 \ X \ 10^{-4}} \qquad (7)$$

Where:

CFTHR = Material being moved by a full auger, m^3/h

D = Diameter of the screw, m

d = Diameter of the shaft, m

P_a = Pitch of the auger, usually the same as D, m

N_s = Speed of the shaft, rpm.

$$\text{CFTHR} = \frac{(0.2)^2 - (0.01)^2 \ x \ 0.2 \ x \ 100}{215 \ X \ 10^{-4}}$$

$= \frac{(0.04-0.0001) \, x \, 20}{215 \, X \, 10^{-4}}$

$= \frac{0.798}{215 \, X \, 10^{-4}}$

$= 37.1m^3/h$

2.3.9 Calculation for Diameter of Pulley and Length of Belt for Hammer Mill

$N_mD_m = N_hD_h$

But $D_h = \frac{N_m D_m}{N_h}$

$W = \frac{1440 \, x \, 120}{1200}$

$D_h = 144$ mm

Choose diameter of 145mm

Hammer mill limit of center to Center

$$\frac{D_1 + D_2}{2} + 120mm < C < 2(D_1 + D_2)$$

$$\frac{120+145}{2} + 120 < C < 2(120 + 145)$$

132.5 + 120 < C < 2(265)

252.5 < C < 530mm

Assume C = 500mm

Length of belt of hammer mill

$$L = 2C + \frac{\pi(D_1 + D_2)}{2} + \frac{(D_2 - D_1)^2}{4C}$$

$$= 1000 + \frac{\pi(265)}{2} + \frac{(145-120)^2}{2000}$$

= 1000 + 416.315 + 0.312

L = 1416.94mm

Say 1430mm

2.3.10 Calculation for Pulley Diameter and Length of Belt of Attrition Mill

$N_mD_m = N_aD_a$

$$D_a = \frac{N_m D_m}{N_a}$$

$$W = \frac{1440 \, x \, 120}{600}$$

$D_a = 288$mm

Choose 290mm

Limit of Center to Center

$$\frac{D_1 + D_2}{2} + 120mm < C < 2(D_1 + D_2)$$

$$\frac{120+290}{2} + 120 < C < 2(120 + 290)$$

205 + 120 < C< 820

325 < C < 820

Assume C = 500mm

Length of belt Attrition Mill

$$L = 2C + \frac{\pi(D_1 + D_2)}{2} + \frac{(D_2 - D_1)^2}{4C}$$

$$L = 2 \, x \, 500 + 1.571(120 + 290) + \frac{(290-120)^2}{4 \, x \, 500}$$

L = 1000 + 644.11 + 14.45

L = 1658.56

Use = 1640mm

2.3.11 Number of Belt for Hammer Mill

$V_b = 0.15 \times N \times \frac{2\pi}{60}$

$V_b = 0.15 \times 1200 \times \frac{2\pi}{60}$

= 18.25m/s

$V_b = 19ms^{-1}$

$\text{Sin } \beta = \frac{D_2 - D_1}{2C}$

$= \frac{145 \, x \, 120}{2 \, x \, 500}$

$\text{Sin } \beta = \frac{25}{1000} = 0.025$

$\beta = \text{Sin}^{-1} 0.025$

$\beta = 1.4$

e = 180 ± 1.4

$e_1 = 180 + 1.4 = 181.4^0$

$e_2 = 180 + 1.4 = 178.6^0$

$P_d = \frac{Kp}{K_eK_L}$ $(K_e = 1, K_L = 0.9$

$P_d = \frac{1.2 \times 3.75 \times 1.36}{1 \times 0.9}$

$P_d = \frac{6.12}{0.9} = 6.8$

2.3.12 Number of Belt for Attrition Mill

$V_b = 0.15 \times N \times \frac{2\pi}{60}$

$V_b = 0.15 \times 2 \times 3.142 \times \frac{2}{60}$

$V_b = 9.43m/s$

$\text{Sin } \beta = \frac{D_2 - D_1}{2C}$

$= \frac{288-120}{2 \times 500} = \frac{168}{1000}$

Sin β = 0.168

$\beta = \sin^{-1} 0.168$

β = 10.74

e = 180 ± 10.47

$e_1 = 180 + 10.47 = 190.74^0$

$e_2 = 180 + 10.47 = 169.26^0$

$P_d = \frac{K_p}{K_e K_L}$ $(K_e = 1, K_L = 0.9)$

$$P_d = \frac{1.2 \times 3 \times 1.36}{1 \times 0.9}$$

$$P_d = \frac{4.896}{0.9} = 5.44$$

The combined hammer and attrition mill is shown in Fig. 1.

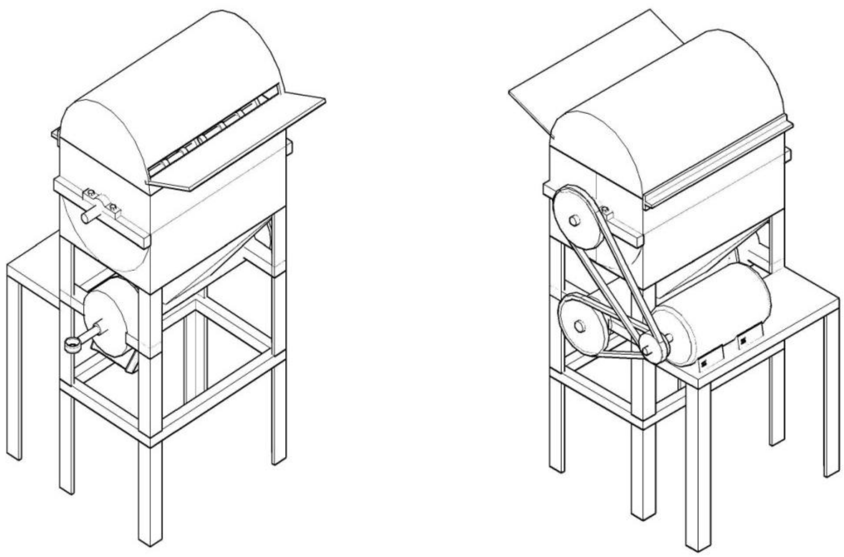


Figure 1: Diagrams of the combined hammer and attrition mill.

3.0 RESULTS AND DISCUSSION

Tests were carried out by introducing 2, 4 and 6 kg of maize into the machine. Tables 1, 2, 3 and 4 show the result obtained when the ground materials were introduced into sieve of various sizes. The quantities of materials retained on each sieve were as shown in the Tables.

Results of Test

Table 1: The particle size range for 2kg of milled maize

Sieve size (mm)	Materials retained (g)	Materials retained (%)
1.00	50	2.5
0.80	100	5.0
0.63	400	20.0
0.40	650	32.5
0.20	700	35.5
0.10	50	2.5

Time taken is 3 minutes. It can be concluded that 37.5% of the materials milled fit into the range of fine.

Table 2: The particle size range for 4kg of milled sized maize

Sieve size (mm)	Materials retained in (g)	Materials retained (%)
1.00	150	3.75
0.80	350	8.75
0.63	700	17.50
0.40	600	15.00
0.20	1750	43.75
0.10	400	10.00

Time taken is 50 minutes, 30 seconds. It can be observed that 43.75% of the milled product falls under fine.

Table 3: The particle size range for 6kg of milled maize

Sieve size (mm)	Materials retained (g)	Materials retained (%)
1.00	300	5.00
0.80	800	13.33
0.63	1000	16.67
0.40	1500	25.00
0.20	2100	35.00
0.10	200	3.30

It took 8 minutes to mill the materials. It can be observed that 35% of the milled product falls under fine

Table 4: The particle size range for 2 kg of dried milled cassava

Sieve size (mm)	Materials retained (g)	Materials retained (%)
1.00	-	-
0.80	-	-
0.60	200	10.0
0.40	300	15.0
0.20	1300	65.0
0.10	150	7.5

Time taken for milling is 2 minutes. It can be observed that 65% of the milled product falls under fine.

4.0 Discussion

Maize can be used for many purposes depending on the particle size required. From Tables 1, 2 and 3, with sieve opening of between 1.2 – 0.66 mm, the total percentage retained on these sieves were 27.5, 30 and 35 for 2, 4 and 6 kg maize respectively. This range is known as the Grit fraction and the materials in this range are used for the production of corn flakes, beer and for the imitation of rice. This means that the maize granules obtained can only be used for the production of these items. Comparing the percentages retained for 2, 4 and 6 kg maize, and if it is for the production of these items, the operation for 6 kg maize with 35% retention is suggested. Again, from Tables 1, 2 and 3 with sieve size opening of 0.6 – 0.2 mm, the total retention percentage was 68, 58.8 and 60% respectively for 2, 4 and 6 kg maize respectively. The particles in this sieve size range are for the production of maize meals e.g. maize bread, maize muffins, some extruded maize snack products etc. the test with 2 kg maize had highest percentage retention. This operation is thus suggested for the production of maize meals. For the sieve size opening of less than 0.2 mm, the percentage retained was 2.5, 10 and 3.3% respectively for 2, 4 and 6 kg maize. The particles obtained were for the production of maize flour e.g. for pan cake mixes, baby foods, cookies, biscuits, ice cream cones etc. the percentages of particles retained were low. It is therefore not suggested for the production of particles for maize flour. From the analysis above, the machine though designed to produce particle size of less than 1.2mm, it has been able to perform even better than anticipated. It has an average capacity of 47.2kg/hr and an average throughput efficiency of 98.4%

5.0 Conclusion

A combined hammer mill and attrition mill was designed, fabricated and tested at the Agricultural and Bio-Environmental Engineering Department, Lagos State Polytechnic. The machine has a capacity of 40 kg/hr and performs the dual role of hammer mill and attrition mill. This prototype has been tested and found to be highly efficient. The performance of the machine was adjudged satisfactory by the departmental board of Agricultural Engineering. The machine is currently being designed for commercial production.

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