Development of a Hammer Mill with Double Sieving Screens

Ojomo A. Oluymemisi and Fawohunre A. Jerome

Abstract—A hammer mill with double sieving device was designed and fabricated from locally available materials for grinding grains and other agricultural products. The conceptual design was based on the principle of design by analysis. The test carried out on the machine showed that the crushing capacity of the machine is 51.5 Kwh/hr. The moisture content, machine speed and the interaction between them had significant effect on the milling power and specific energy requirement at 5 % level of significance. Milling power and specific energy requirement of the machine increased with increase in moisture content. The maximum crushing efficiency of 79.3 %, minimum milling power and specific energy requirement of 0.09 Kwh and 3.04 Kwh/mg respectively were obtained at moisture content of 8 % (wb) and machine speed of 2000 rpm. Regression models that could be used to express the relationship existing between the hammer mill performance indices, product moisture content and machine speed were established. The machine has dual purpose for either electric motor or petrol engine.

Index Terms—Development, Hammer Mill, Performance Test, Screens

I. INTRODUCTION

The grains and tubers in their unprocessed state are bulky, difficult to transport and fetch very low prices in the market [1], this is a major causes of poverty among rural farmers in the developing countries [2] and also encourage rural-urban migration [3], [4], says that the processing of agricultural products like grains, tubers and dry solid agricultural products into more valuable products must be encouraged and fostered to guarantee access to food [5], and reduce rural-urban migration and encourage sustainable development [6]. Nowadays, the development of animal and poultry production needs to exert more efforts to increase and maintain high level of feeding crop, in addition to improve the quality and the quantity by decreasing grains losses during pre-processing operation, selecting the proper diet in the acceptable phase of livestock and reduces the consumed energy. The hammer mill is used almost exclusively in preparation of broiler rations because of its simplicity, ease to operate and low maintenance cost, it has been widely spread in most of the poultry farms in Nigerian [7].

The cereals food consumed is mostly processed through grinding by either iteration or hammering means [8]. It is therefore necessary to have an efficient means of achieving such goals most especially in developing countries. The design and fabrication of hammer mill becomes imperative as that will go a long way in getting processed cereals easily within developing nations [9]. Therefore, hammer mill is a machine whose purpose is to shred or crush aggregate material into smaller pieces by the repeated blows of little hammers. It is designed for processing, grinding, and sieving all kinds of cereal grains such as maize, wheat, millet, corn, and sorghum, it can also process different kinds of dry tubers [10]. Conventionally, hammer mill operates on the principle of impact and pulverization. It consists of a rotor assembly on which swinging hammers are mounted. The rotor shaft of this mill can be placed vertically or horizontally [8], [11]. The screen is mounted below, above and/or around the hammers. The appropriate screen size is determined by the desired finish particle size and the properties such as friability and moisture content which a material will breakdown. The fineness of the particles is regulated by the use of screen of different mesh sizes [12] – [13].

II. MATERIALS AND METHOD

A. Machine Description

As shown in Fig. 1, the hammer mill consists of two major parts: a grinding component and sieving component. The hopper is the feeding chute through which agricultural products to be milled are introduced into the milling chamber. It has a rectangular opening of 330 mmx110 mm with side inclination of 38 % with the horizontal. The shaft is made of 3 mm stainless steel of 35 mm diameter. It transmits power from the pulley to the beating hammers. It is supported on the base with pillow bearings. It is supported on the base with pillow bearings. The hammers are arranged on a gang round the shaft. The hammer is made up of 8 mm stainless steel cut into rectangular bar of dimension 10 mm x 15 mm x 16 mm. The screens allow the milled agricultural products to pass through to the discharged chute. It is made of stainless steel to prevent rust and contamination of milled food. The power rating is supplied by a 3-phase electric motor.

B. Design Analysis

Determination of the Torque and Power Transmitted to the Shaft. Power transmitted to the shaft is given by [14].

\[ P = m \left( \frac{2\pi n}{60} \right)^3 r^2 \]  \hspace{1cm} (1)

Where \( P \) = power (kW), \( n \) = number of revolutions of the hammers per minutes and \( r \) = radius of gyration

The power requirement of the machines from the calculator is 3.25kw. Thus, a motor of 3.75kw was used to drive the machine. Torque at the main shaft is given by [15] using (2).
\[ T = (T_1 - T_2)R \]  
(2)

Where, \( T_1 \) = Tight side tension (N), \( T_2 \) = Slack side tension (N) and \( R \) = Radius of pulley

\[ F_h = N_h M_h \gamma_R \omega_h \]  
(4)

Where, \( F_h \) = centrifugal force, \( N_h \) = numbers of hammers, \( M_h \) = mass of material being milled, \( \gamma_R \) = radius of hammer and \( \omega_h \) = angular velocity of hammer. Assuming inelastic impact between the hammers and material, the velocity of material, \( V_m \), given by [2] using (5).

\[ V_m = \frac{2F_h \gamma_R}{M_m N_m} \]  
(5)

Where, \( V_m \) = velocity of material being milled, \( M_m \) = mass of material being milled and \( N_m \) = number of materials impacted. The minimum width of hammer, \( W_h \) to withstand the centrifugal force at impact is given by [17] using (6).

\[ W_h = \frac{d_h + \frac{F_h}{\sigma_h \gamma_R}}{2} \]  
(6)

Where, \( W_h \) = width of hammer, \( d_h \) = diameter of hammer, \( \sigma_h \) = thickness of hammer and \( \sigma_h \) = working stress on hammer.

Determination of the Shaft Diameter: To calculate the shaft speed, the following parameters are used, according to [2].

\[ D_1/D_2 = N_2/N_1 \]  
(7)

Where, \( D_1 \) and \( N_1 \) = diameter (m) and revolution (rpm) of the smaller pulley respectively and \( D_2 \) and \( N_2 \) = diameter (m) and revolution (rpm) of the larger pulley respectively.

To obtain the speed of the driving and driven shafts, (8) and (9) were used according to [12].

\[ v_1 = \frac{\pi D_1 N_1}{60} \]  
(8)

\[ v_2 = \frac{\pi D_2 N_2}{60} \]  
(9)

C. Performance Test

The developed machine was installed on a concrete platform. Moisture content of the maize used for the test was determined according to ASABE standard 5358.2 [18]. The moisture content required for the study ranged from 8 to 16% at wet basis. To arrive at predetermined moisture content, a calculated amount of water was sprayed on the material using the method suggested by [19]. A calculated amount of water was added and mixed thoroughly with a specified amount of maize in a bowl.

\[ M_w = \frac{M_i (M_{wi} - M_{wf})}{1 - M_{wf}} \]  
(10)

Where,

\( M_w \) = Mass of water added to maize, g
\( M_i \) = Initial mass of maize, g
\( M_{wf} \) = Adjusted moisture content of the grind (wet basis) fraction
\( M_{wi} \) = Initial moisture content of the grind (wet basis) fraction

Twenty kilograms of maize was purchased from local market in the town and was cleaned by removing stone and debris. Twelve samples were prepared each weighing 5kg each were tested at three machine speed of 1400rpm, 1800rpm, and 2000rpm by varying the pulley diameter. Five levels of moisture content namely 8% 10% 12%, 14% and 16% at wet basis were employed to determine the effect of machine speeds and moisture content on the particle size distribution: crushing efficiency, crushing capacity, milling power and the specific energy requirement of the machine using the equation as suggested by [2], [20] – [21].

Crushing Efficiency (CE) was determined using (11).

\[ CE = \frac{\text{Mass of output material}}{\text{Mass of input material}} \times 100 \% \]  
(11)

Crushing Capacity (CC) was determined using (12).
\[ C_C = \frac{\text{Mass of output material}}{\text{Time}} \]  \hspace{1cm} (12)

Milling Power (MP) was determined using (13).

\[ M_P = \sqrt{\frac{\text{Power}}{1000}} \cdot \xi \cdot \cos \theta \]  \hspace{1cm} (13)

Where:
- \( I \) = Electric current in Amperes (A).
- \( \xi \) = Mechanical Efficiency, (85%).
- \( V \) = Potential strength (voltage) equal 220V
- \( \cos \theta \) = Power factor, (0.84).

The Specific Energy Requirement (SER) was determined using (14).

\[ S_{SR} = \frac{\text{The consumed power}}{\text{Actual milling capacity}} \]  \hspace{1cm} (14)

III. RESULTS AND DISCUSSION

The hammer mill test results obtained are presented in Table I; Fig. 2 to 5. Table I is the F - ratio statistical analysis of the effect of machine speed and moisture content on milling power, specific energy requirement, crushing capacity and crushing efficiency of the hammer mill respectively. The result of the test in Table I shows that moisture content and machine speed significantly affected the quantity of maize milled at 5% level of significant. The ANOVA of power required for milling as presented in Table I showed that interaction between moisture content and milling power has significant effects on the quantity of maize milled at 5% level.

![Fig. 2. Effect of machine speed and moisture content on Milling power](http://dx.doi.org/10.24018/ejers.2020.5.5.1763)

**Fig. 2.** Effect of machine speed and moisture content on MILLING power

The crushing capacity of the milling machine is significantly affected by moisture content, machine speed and the interaction between them at 5% level of significance as shown in Table I. The result presented in Fig. 3 showed that the specific energy of the machine increased with increase in moisture content and also, increase in the specific energy resulted in decrease in the machine speed. At machine speed of 2000 rpm and moisture content of 8% the specific energy requirement of the machine was 3.04 kWh/mg. However, the relationship existing between the specific energy, moisture content and machine speed could be expressed with equation given by [10].

\[ SE_R = 12.14 + 0.78mc - 0.07ms \]  \hspace{1cm} (16)

![Fig. 3. Effect of machine speed and moisture content on Specific Energy requirement](http://dx.doi.org/10.24018/ejers.2020.5.5.1763)

**Fig. 3.** Effect of machine speed and moisture content on Specific Energy requirement

\[ C_C = 14.17 + 0.92mc + 0.09ms \]  \hspace{1cm} (17)

Although the effect of moisture content and its interaction with machine speed reached statistical significance, the actual size of their effect was found to be smaller than that of the machine speed. The milling power increased with increase in moisture content to a maximum value as shown in Fig. 2. Also, Fig. 2 showed that the milling power decreased with increase in moisture content as the machine speed increases. At machine speed of 2000 rpm and moisture content of 8% the machine consumes the least power of 0.09 kW. The machine speed made the strongest unique contribution to the milling power of the machine. The relationship existing between power consumed by the machine, moisture content and machine speed is given by [10] as shown in (15).

\[ M_P = 0.15 + 0.01mc + 0.035ms \]  \hspace{1cm} (15)

The specific energy of the milling machine is significantly affected by moisture content, machine speed and the interaction between them at 5% level of significance as shown in Table I. The result presented in Fig. 3 showed that the specific energy of the machine increased with increase in moisture content and also, increase in the specific energy resulted in decrease in the machine speed. At machine speed of 2000 rpm and moisture content of 8% the specific energy requirement of the machine was 3.04 kWh/mg. However, the relationship existing between the specific energy, moisture content and machine speed could be expressed with equation given by [10].

\[ SE_R = 12.14 + 0.78mc - 0.07ms \]  \hspace{1cm} (16)

![Fig. 2. Effect of machine speed and moisture content on Milling power](http://dx.doi.org/10.24018/ejers.2020.5.5.1763)

**Fig. 2.** Effect of machine speed and moisture content on MILLING power

The crushing capacity of the milling machine is significantly affected by moisture content, machine speed and the interaction between them at 5% level of significance as shown in Table I while Fig. 4 shows that the crushing capacity of the machine decreases with increase in moisture content and also, crushing capacity decreases with increase in moisture content and decrease in the machine speed. At machine speed of 2000 rpm and moisture content of 8% the crushing capacity of the machine was 51.2 kg/hr. The relationship existing between crushing capacity of the machine, moisture content and machine speed could be expressed by the equation 17, given by [10].

\[ C_C = 14.17 + 0.92mc + 0.09ms \]  \hspace{1cm} (17)

![Fig. 3. Effect of machine speed and moisture content on Specific Energy requirement](http://dx.doi.org/10.24018/ejers.2020.5.5.1763)

**Fig. 3.** Effect of machine speed and moisture content on Specific Energy requirement

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Also, the crushing efficiency of the milling machine is significantly affected by moisture content, machine speed and the interaction between them at 5% level of significance as shown in Table I. Fig. 5 shows that the efficiency of the machine decreased with increase in moisture content and also, increase in the crushing efficiency resulted in increase in the machine speed. At machine speed of 2000 rpm and moisture content of 8%, the machine has optimum efficiency of 79.3%. The relationship existing between crushing efficiency the machine, moisture content and machine speed could be expressed by the (18), given by [10].

\[ C_E = 3.85 + 0.03mc + 0.06ms \]  

(18)

Fig. 4. Effect of crushing speed and moisture content on crushing capacity

Fig. 5. Effect of machine speed and moisture content on crushing efficiency

IV. CONCLUSION

Based on the performance test conducted on the hammer mill, optimum crushing efficiency of 79.3% and crushing capacity of 51.2 kg/hr were obtained. Also, moisture content, machine speed and the interaction between them had significant effect on the performance indices. The milling power and the specific energy requirement increase with increase in the moisture content of the agricultural product. The relationship existing between the performance indices and machine speed were found to be adequately expressed by regression equations.

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Ojomo A. Oluymesi holds Bachelor of Engineering in Agricultural Engineering, Master of Engineering in Crop processing and storage Engineering and Doctor of Philosophy in crop processing and storage Engineering from Federal University of Technology Akure, Ondo State, Nigeria. He is presently a Chief Lecturer in the Department of Agricultural and Bio-environmental Engineering Technology in Rufus Giwa Polytechnic, Owo, Ondo State, Nigeria. His research interests cut across machine design and fabrication for processing of agricultural crops. He has more than twenty publications in different reputable journal houses. He is a member of various professional bodies such as COREN, NIAE, NSE, and ASABE.
Fawohunre A. Jerome is a Lecturer in the Department of Agricultural and Bio-environmental Engineering, with teaching and research experience of about 15 years. He holds a Bachelor of Engineering from University of Agriculture, Makurdi, Benue State, Nigeria; Master of Engineering in processing and storage Engineering from Federal University of Agriculture Abeokuta, Ogun State, Nigeria. He has over twenty publications, which cut across crop processing machines. He is a member of various professional bodies such as COREN, NIAE, NSE, and IRDI.