Journal of Energy Technologies and Policy
ISSN 2224-3232 (Paper) ISSN 2225-0573 (Online)
Vol.4, No.4, 2014

Design and Development of a Petrol-powered Hammer mill for rural Nigerian Farmers.

Adekomaya, S.O., and Samuel,O.D
Department of Mechanical Engineering, Olabisi Onabanjo University, Nigeria
*Corresponding Author: oludaisiyetunde@gmail.com

Abstract

A conventional hammer mill is a device consisting of a rotating head with free- swinging hammers, which reduce rock, grains or similarly hard objects to a predetermined size through a perforated screen, hammer mills can be used for grinding grain into fine flour or into coarse meal for animal feed production.

This project is focused on the design, development, and testing of a hammer mill that has a small scale production capability. The conceptual design was based on the principle of design by analysis. The methodology adopted was to examine the most critical defects of conventional hammer mills and provide solutions. The major components of the new hammer mill are Inlet tray, Throat, Magnetic chamber, Rotor, Crushing chamber, Hammer mill body, Hammers/Beaters, Screen, Bearings, Discharge, Table or stand, Mechanical drive, Pulleys.

The preliminary tests carried out on the new hammer mill confirm that this mill is capable of performing the same function as that of the huge hammer mills used in the industries, as well as the same function as the conventional hammer mill which usually produce coarse, medium and fine particles, thus quality control and monitoring is needed.

Keywords: Design, Hammer mill, Grains, Particles.

1. Introduction

Most of the existing hammer mill machines are designed for very large scale production by the multi-national companies such as breweries, feed mills and flour mills. But due to the recent sensitization of the public on the need for self-employment/entrepreneurship, there is an increase in the small scale companies. Thus, there is a very high demand for small scale hammer mill machines. The major area of focus of this design is to strengthen the productivity of farmers in rural settlements in Nigeria which has high numbers of farmers who are into grains/cereal processing but it was discovered that, they were not really actualizing the required profit as they ought to because after harvesting their products they will have to sell it to people who owns a feed mill for further processing in which these people will just pay them a token.

1.1 Shortcomings of convectional hammer mills

1.1.1 As a result of wear and corrosion the sieve screen holes enlarge or burst thereby allowing larger than desired particles to pass through,

1.1.2 After several hours of hammer mill operation, the sieve screen holes are clogged thereby reducing its efficiency and capacity.

1.1.3 Wet materials become elastic and therefore absorb most of the impact energy of the hammer without breaking. This reduces the efficiency of conventional hammer mills.

1.1.4 Adequately broken particles can be collected when they fall through the sieve hole by gravity. Due to the relatively large gap between the hammers and the screen, this will be inadequate and therefore clearly inefficient.

1.1.4 Materials being crushed by conventional hammer mills cannot be recycled until they are reduced to the required size before trying to force them through the sieve holes. This is probably the greatest cause of burst holes.

1.2 Respective solutions proferred

1.2.1 Eliminate sieve screens. Introduce an endless sieve that is a dimensionally controlled “open gate”.

1.2.2 The solution to problem 1 eliminates problem 2

1.2.3 Introduce a fan to induce forced convection and rapid drying of material

1.2.4 Solution 3 eliminates problem 4 as pressurized air can lift particles of sufficient sizes through great distances. This is observed in tornadoes and cyclones.

1.2.5 A mechanical separator, which rotates at the same speed as the shaft ensures that all solid particles above certain sizes are blown back into the hammer mill chamber until they are ground or broken by impact into fine particles.

2. Materials And Method

Conceptual design: The conceptual design was based on the principle of design by analysis (Nortion, 2006). The methodology was to introduce special features into the hammer mill so that certain lapses noticed in the convectional hammer mill is reduced to a bearable level.

Inlet tray/Hopper: This is the pathway through which the material to grinded will be pour into the hammer mill. The inlet tray was fabricated with a 3mm thickness metal plate (Mild steel). The tray was braced on the sides by 1inch by inch angle iron of the same dimension. Inside the tray we have a gate which is used in regulating the flow of feed into the crushing chamber of the hammer mill.

Throat: This provides the passage for the material to be grind into the crushing chamber. This was also fabricated with 3mm thickness metal plate.

Magnetic chamber: The magnetic chamber will be filled with high attraction magnets which will help in trapping all ferrous material from the product to be grinded in order to prevent it from entering into the crushing chamber.

Rotor: This is shaft of 30mm diameter that is holding 3 circular discs of diameter 90mm and is these circular discs that are carrying the hammers/beaters.

Crushing chamber: This is unit houses the rotor that holds the beaters and the screen for sieving.

Hammer mill body: This was made of 3mm thickness plate with dimension 400mm length & 215mm width & height 420mm. The hammer mill body is made in such a way that it can easily be assembled & disassembled.

Hammers/Beaters: The hammers/beaters are a rectangular 3mm thickness metal that does the grinding of material. It is 85 x 30mm in dimension with a drill hole of 12mm at 30mm interval from both ends.

Screen: The screen act as a sieve for grinded materials before it will be finally discharged. It was fabricated with 6mm thickness metal plate with many drilled hole which will act as the sieve for the grinded material.

Bearings: The bearings provide sliding motion between the main shaft and the shaft holding the hammers.

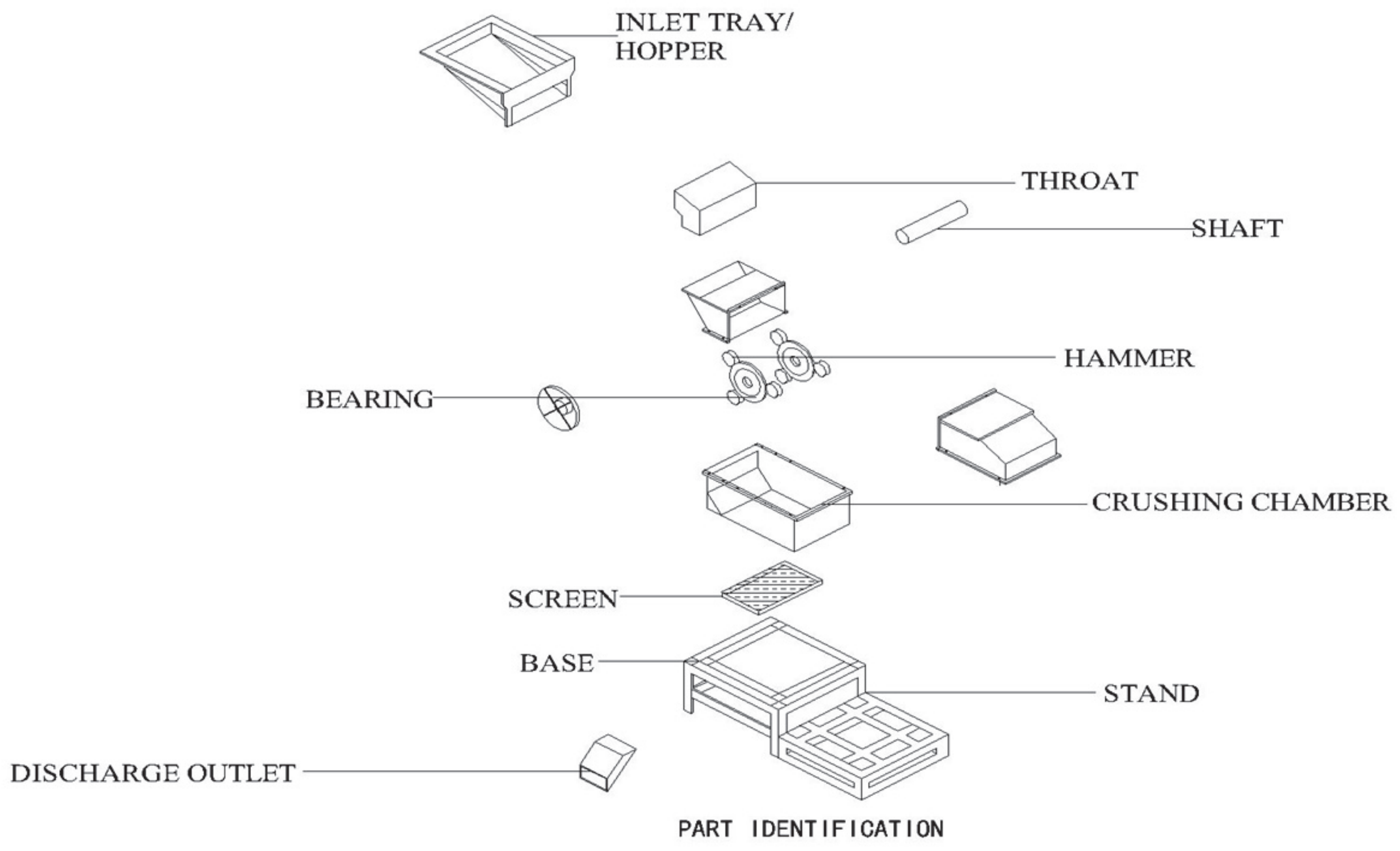
Discharge: This is the section through which the grinded material will be passed out it will also be made with a 3mm thickness metal sheet.

Table or stand: This is the platform on which the whole machine is mounted. It was made with mild steel I-beam. It was made of 2 inches by 2 inches angle iron. It is the base to which the hammer mill body and the prime mover is bolted

Mechanical drive: A 5.5Hp, 3600rpm petrol engine was used as the prime mover of the machine through belt transmission.

Pulleys: Two pulleys were used for this machine which was the driver and the driven pulleys respectively. The driver pulley is mounted on the mechanical drive engine while the driven pulley is mounted on the rotor of the hammer mill machine.

Fig. 1: Component part of hammer mill



2.1. Design considerations.

2.1.1. Determination of the Shaft Speed

The transmission system used is belt transmission via a pulley (specifically v-belt selection) using a mechanical drive petrol engine of 3600rpm with pulley of diameter 130mm (D_1) and the diameter on that of the rotor is 198mm (D_2).

Thus to calculate the shaft speed, the following parameters are used:

$\frac{D_1}{D_2} = \frac{N_2}{N_1}$ ………………………(1) [John and Stephens 1984]

$$N_2 = \frac{D_1 N_1}{D_2}$$

Where

N_1 = revolution of the smaller pulley, rpm.

N_2 = revolution of the larger pulley, rpm.

This shaft speed is only obtained when there is no slip condition of the belt over the pulley. When slip and creep condition is present, the value (3600 rpm) is reduced by 4% (Spolt 1988)

2.1.2. Determination of the Belt Contact Angle

The belt contact angle is given by

$\sin\beta = \frac{(R-r)}{C}$ ……………………… (2) [Hollowenko et al, 2004]

Where

R = radius of the large pulley, mm

r = radius of the smaller pulley, mm

The angles of wrap for the pulleys are given by

$\alpha 1 = 180 - 2\sin^{-1}\left(\frac{R-r}{C}\right)$……… (3) [Hollowenko et al, 2004]

$\alpha 2 = 180 + 2\sin^{-1}\left(\frac{R-r}{C}\right)$……… (4) [Hollowenko et al, 2004]

Where

α_1 = angle of wrap for the smaller pulley, deg

α_2 = angle of wrap for the larger pulley, deg

Comparing the capacities, $e^{\mu a/\sin ½}$ θ of the pulley,

Where μ = coefficient of friction between the belt and the pulley = 0.25 (assumption);

θ = angle of groove ranges from $30^0$to 40^0. Assume θ = 40^0 (Joseph E. Shigley, Choles R.Mischke: Mechanical Engineering Design, 2001) and

Using μ = 0.25; Θ = 40^o

For the smaller pulley $e^{0.25 \times 3.04/\sin 20}$ = 9.22

For the larger pulley $e^{0.25 \times 3.04/\sin 20}$ = 10.68

Since that of smaller pulley is smaller, the smaller pulley governs the design.

2.1.3. Determination of the Belt Tension

The belt tension is given below [Khurrmi and Gupta, 2007]

Maximum Tension in belt

$T = SA$ ……………………………(5) [7]

Centrifugal Tension in belt

$T_C = mv^2$ …………………………… (6) [7]

$T_1 = T - T_C$ ……………………………(7) [8]

To get tension in slack side using the relationship below

$2.3\log\left(\frac{T_1}{T_2}\right) = \frac{\mu\alpha_1}{\sin\theta}$ ………………………………(8) [5]

Where

T_1 = the tension in the tight side of belt, N

T_2 = the tension in the slack side of belt, N

S = the maximum permissible belt stress, MN/m^2
The allowable tensile stress for leather belting is usually 2-3.45MPa [3]
Let $s =$ 2.4MPa = 2.4 $\times\ 10^6 Pa$ [7]

M = mass per unit length of belt
Also, mass per unit belt length, $m = bt\rho$
Let ρ = belt density = 1000kgm^{-3} for leather belt [6]

A = area of belt, $A = bt$
B=Belt breadth= 12.5mm
T=belt thickness= 8mm
v = linear velocity of belt
$V = \frac{\pi dN}{60}$ [5]
N = speed of motor = N_1 =36006rpm, d= diameter of motor pulley=130mm
mv^2= centrifugal force acting on the belt

2.1.4. Determination of the Torque and Power Transmitted to the Shaft
Power required by the shaft is given by
$P = (T_1 - T_2)V$ ....(9) [3]

1hp = 0.75kw

Maximum power of petrol engine is 5.5hp and power required by engine is 5.23hp so 5.5hp was an appropriate selection.

Torque at the main shaft is given by
$T = (T_1 - T_2)R$ ....(10) [12]
2.1.5. Determination of the Hammer Weight
$W_h = m_h g$ ....(11) [10]
It can be seen that the action of the weight of hammer shaft on the main shaft is negligible.
Determination of the Centrifugal Force Exerted by the Hammer
Centrifugal force exerted by the hammer can be calculated as given by:
$Fc = \frac{mv}{r}$.......................... (12) [9]
Hammer Tip speed
$v = \frac{\pi d\ X\ rpm}{12in/ft}$ .... (13) [10]
The angular velocity of the hammer is given by
$\omega = \frac{2\pi rN}{60}$ .... (14) [11]
The centrifugal force on the hammers, F_h, is given by
$F_h = N_h m_h r_h \omega_{h^2}$.....................(15) [12]
Where,
F_h = centrifugal force
N_h = number of hammers
m_h = mass of each hammer
r_h = radius of hammer
ω_h= angular velocity of hammer
Assuming inelastic impact between the hammers and material, the velocity of material, Vm, given by
$V_m = \sqrt{\frac{2f_h r_h}{m_m N_m}}$ ....(16) . [10]
Where
V_m = velocity of material being milled
m_m = mass of material being milled

N_m = number of material impacted

The minimum width of hammer, w_h, to withstand the centrifugal force at impact is given by

$$w_h = d_h + \frac{f_h}{t_h \sigma_h} \quad \text{............................ (17)} \qquad [11]$$

Where

w_h = width of hammer

d_h = diameter of hammer

f_h = thickness of hammer

σ_h = working stress on hammer

2.1.6. Determination of the Hammer Shaft Diameter

The bending moment on the shaft is given by

$$M_{b(max)} = \frac{Wl^2}{8} \quad \text{........................ (18)} \qquad [10]$$

Length of the shaft is 390mm

Since the bending moment that can be carried by a beam is a measure of the strength of the beam and this depends upon, I/yμ *a* θ

$$\sigma_{s(allowable)} = \frac{M_b Y_{max}}{I} \quad \text{......(19)} \qquad [11]$$

$$\frac{I}{Ymax} = z \equiv \sigma s(allowable) = \frac{Mb}{Z} \quad \text{...... (20)} \qquad [9]$$

Where

Y_{max} = distance from neutral axis to outer fibers

I = moment of inertia

Z = Section modulus

For a solid round bar:

$$I = \frac{\pi d^4}{64} \quad \text{............................. (21)} \qquad [9]$$

$$Z = \frac{\pi d^3}{32} \quad \text{............................. (22)} \qquad [9]$$

2.1.7. Determination of the Shaft Diameter

The ASME code equation for a solid shaft having little or no axial loading is:

$$d^3 = \frac{16}{\pi \sigma_s} \sqrt{(K_b M_b)^2 + (K_t M_t)^2} \quad \text{... (23)} \qquad [9]$$

Where,

d_s = shaft diameter, m; M_b = bending moment, Nm; M_t = torsional moment, Nm;

K_b = Shock and fatigue factor for bending moment and K_t = shock and fatigue factor for torsional moment.

Since the load is suddenly applied with heavy shock, therefore,

Let K_b and K_t values be 2.0

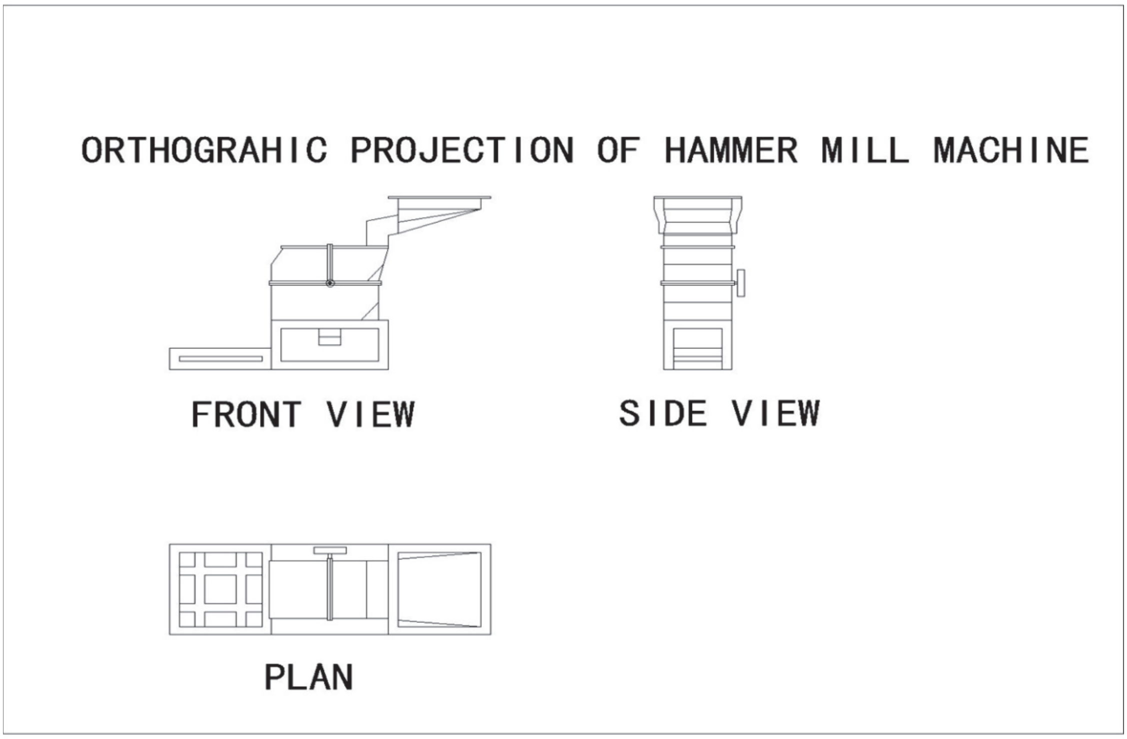


Fig. 2: Orthographic projection of hammer mill

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Note: All dimension are in mm

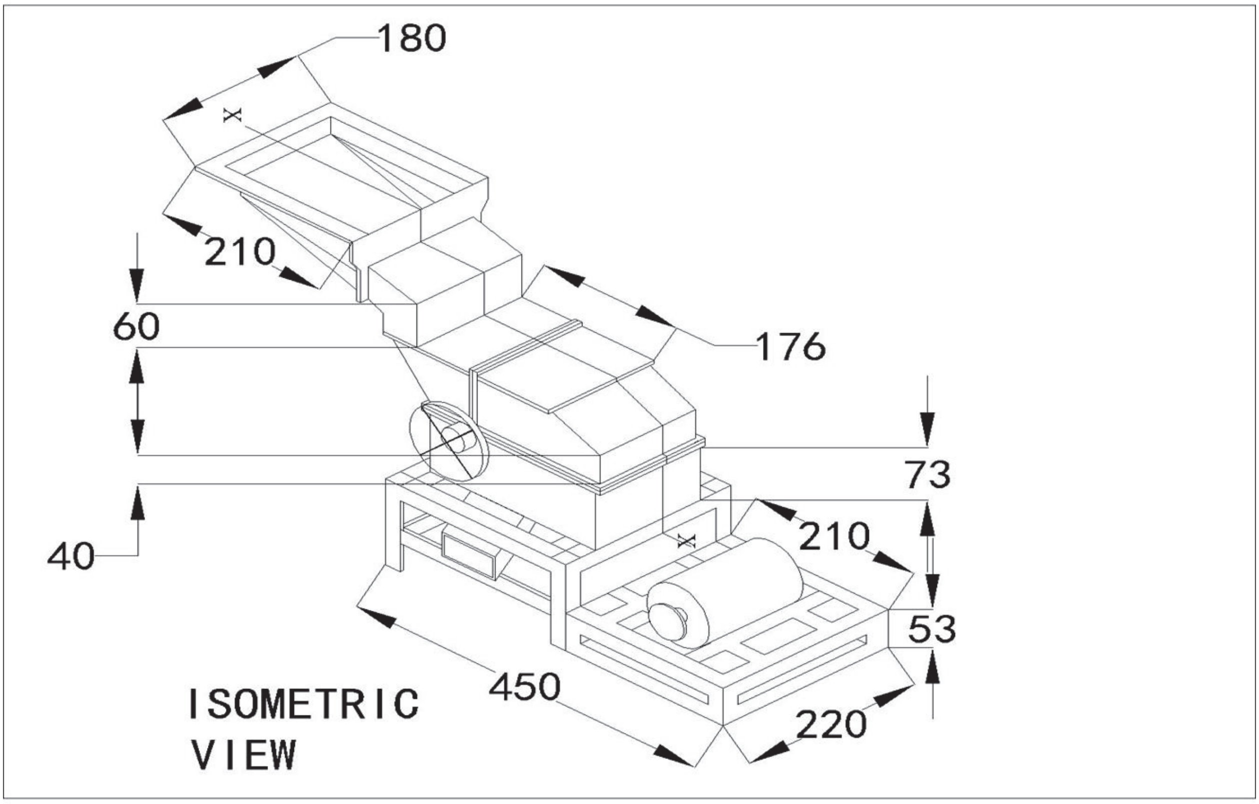

Fig 3: Isometric view of hammer mill

3. Results and Discussion

A prototype of the hammer mill has been produced. Most components of the machine were produced using locally available materials. The machine was tested using 1.2kg of dry maize and 1.2kg of dry wheat and the analysis were displayed below

3.1. Test using dry maize

A 1.2 kg of dry Maize was fed into the hopper while the gate of the hammer mill remain closed in order to prevent the maize to go into the grinding chamber before the engine is been started after which the petrol engine was started and the maize was slowly fed into the grinding chamber to prevent clogging on the screen. The time taken for grinding was noted and also the mass of the recovered maize after grinding was recorded. This was repeated for three times and average of time and mass recovered values was used for calculation.

3.2. Test using Dry wheat

The same procedure was reported using 1.2kg of dry wheat

Table 1**:** Hammer mill test results using maize

Trial	Mass of maize before grinding (kg)	Mass of maize after grinding (kg)	Time taken (mins)
1	1.20	1.15	1.20
2	1.20	1.10	1.29
3	1.20	1.10	1.26
Average	1.20	1.12	1.25

Average mass of the dry maize before grinding = 1.2 kg

Average mass of the dry maize after grinding = 1.12 kg

Average time taken =1.25 min

$$\text{crushing Effiency } C_{eff} = \frac{\text{mass of recovered material}}{\text{mass of input material}} \times 100$$

$$crushing\ Efficiency\ C_{eff} = \frac{1.12}{1.2} \text{ X } 100$$

=93%

$$\text{losses} = \frac{m_b - m_a}{m_b}$$

$$\text{where } m_b = \text{mass before grinding}$$

$$m_b = \text{mass after grinding}$$

$$\text{losses} = \frac{1.2-1.12}{1.2} = 0.07$$

Table 2 hammer mill test results using dry wheat

Trial	Mass of maize before grinding (kg)	Mass of maize after grinding (kg)	Time taken (mins)
1	1.20	1.10	2.20
2	1.20	1.15	2.16
3	1.20	1.15	2.17
Average	1.20	1.13	2.18

Average mass of the dry wheat before grinding = 1.2 kg
Average mass of the dry wheat after grinding = 1.13 kg
Average time taken =2.18mins

$$\text{crushing Effiency } C_{eff} = \frac{\text{mass of recovered material}}{\text{mass of input material}} \times 100$$

$$crushing\ Efficiency\ C_{eff} = \frac{1.13}{1.2} \text{ X } 100$$

=94%

$$\text{losses} = \frac{m_b - m_a}{m_b}$$

$$\text{where } m_b = \text{mass before grinding}$$

$$m_b = \text{mass after grinding}$$

$$\text{losses} = \frac{1.2-1.13}{1.2} = 0.06$$

3.3. Discussion

From the result of the test, the crushing efficiency of the machine was found to be 93 and 94% for dry maize and dry wheat, respectively. The slight difference may be because of smaller sizes of wheat to maize which will require more time to be grind. It is clear from the crushing capacity and efficiency above that the performance of the machine is satisfactorily. The loss obtained was due to the sticking of the powdery materials to the wall of the crushing hammer and some strains that did not pass though the screen.

The total cost of the fabricated hammer mill is about 200USD including both manufacturing cost and overhead cost whereas the cost of the imported type is about 400USD. This amount is affordable for the average Nigerian farmers.

4. Conclusion

. The environmental pollution associated with the use of conventional hammer mills is virtually eliminated in the new hammer mill. Thus there is no health hazard experienced by the operator of the new machine. Furthermore, the new hammer mill would reduce processing losses, produces flour with longer shelf life (dry flour), enhances greater consumer choice, ensures new markets for domestic cereals and legume crops, reflects a more effective response to changing market requirements and increases food security for Nigeria.

Though the production of fine grain was achieved as required, coarse, medium and fine particles where still produced to be re-run for finer and more uniform particle size produced by the conventional hammer mill a recommendation to tackle this is producing a hammer mill

5. **Aknowlegment**.

The author wishes to appreciate the contribution of Mr.B. Oredope and Mr.B.Sodiq in the design, fabrication and preliminary testing of the petrol-powered hammer mill.

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