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Design, Modification and Performance Evaluation of Household Hammer Mill

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Abstract: *A Hammer mill is machine whose purpose is to shred or crush aggregate material into smaller pieces by the repeated blows of little hammers. After the machine was designed and fabricated from locally available materials, the crushing chamber of the machine was open, hammer with two (2) beaters was fixed into the shaft, and the machine was started. 500g of maize sample was fed into the crushing chamber of the machine through the feed hopper. The time taken and fuel consumption to crush the sample (i.e. the sample to fully discharged) was recorded. The weight of the sample before and after crushing was also recorded. The process was repeated for guinea corn using hammer with 4 and 6 beaters respectively. The results obtained during milling operations of the (3) different hammers (2, 4 and 6 beaters) shows that the highest milling efficiency can be found when using hammer with two (2) beaters with an efficiency of 84.7% and 90.3% for both maize and guinea corn respectively. The average milling time and fuel consumption at the speed of 3400 r.p.m. for both maize and guinea corn are 23.97 secs, 8.9 ml and 21.97 secs, 7.63 ml respectively. In conclusion, the performance evaluation shows that the speed and the number of beaters has a significant effect on the machine performance.*

Key words: *Hammer mill, Fuel consumption, Grinding. Beaters, crushing chamber*

1.0 Introduction

Most of our staple foods in Nigeria are cereals and dried tubers. These products need to be processed before storage, transported and consumed. The major processing method is size reduction after drying. Dabbour et al. (2015) reported that grinding is one of the most important and energy-consuming processes in cereal industry, and that this process consumes from 70% of total power during the feed production and up to 90% for wheat flour milling. The grinding energy requirements depend on kinematical and geometrical parameters of the grinding machine and physical properties of the ground material (Dabbour et al. 2015). Ajaka and Adesina, (2014) evaluated a small laboratory hammer mill with minerals (dolomite and granite). Their results however indicated that the new machine can perform better in terms of products with improved design. The objectives of grinding grain are to increase digestibility or palatability, and to facilitate mixing with other constituents of the ration (Culpin, 1982). There are different methods of grinding these products depending on the level of development in the area. According to Culpin (1982), grinding of grain has been practiced since very early times, when a device resembling a pestle and motor was employed in the production of meals for human consumption. The first mills were modification of this device, in which grains were fed through an opening in a disc-shaped stone which was cause to rotate upon another. The gradual development of this type of mill over thousand years has led to the evolution of the buhr-stone mills. Buhr-stone mills are so termed because of the grooves (buhrs) which are cut on the grinding faces of the two disc-shaped stones. As one stone revolves upon the other, grain fed in at the centre passes towards the periphery being gradually ground in the process. Gujja (2016) modified the conventional hammer mills base on their short comings, such as the enlargement of screen holes due to wear, corrosion, clogging which reduces the efficiency of the hammer mill, wet materials become elastic and therefore absorb most of the impact energy of the hammer without breaking the grain among others. The solution proffered to these problems include: changing of sieve screen with endless sieve that is dimensionally controlled, introduction of fan to induced forced convection and rapid drying of material. This greatly increased the efficiency of the machine but incorporation of several parts to the machine made it complex that skilled personnel is required to performed maintenance on the machine and this can be hardly found in the rural areas, hence the machine is not suitable to be used in the rural area. In very remote areas the use of the traditional grinding stone or pestle and mortar is very common, while in some villages and cities the commercial grinding machine (grinding plates discs) were used. These commercial hammer mills are too bulky and very expensive to run and they are designed for very large scale production or big companies such as breweries, feed mills and flour mills. Due to the recent sensitization of the public on the need for self-employment/ entrepreneurship, small scale industries that need smaller hammer mills are increasing in number. Therefore, this study investigates the effect of the number of beaters on performance of a small household hammer mill capable of handling small quantities of product at a very low cost.

2.0 Materials and Methods

2.1 Machine Description and Operation

The hammer mill consists of feed hopper which is connected to the crushing chamber through the seed inlet throat. The crushing chamber that houses the hammer and the sieve is connected to the discharge chute. The two components were mounted on the main frame and a compression ignition (CI) engine was mounted on the frame. The hammer was mounted on the shaft of the C.I engine which passes through the crushing chamber. Plate 1 shows the photograph of the machine

Plate 1: Photograph of the hammer mil

2.2 Experimental Setup

The materials that was used for the performance evaluations of the machine are maize (zea mays Linn) and guinea corn (sorghum bicolor L. Moench). Other testing apparatus are digital tachometer (to measure the angular velocity), stop watch (to measure the time), weighing balance (10 kg) and burette (500ml) (to measure fuel consumed). The crushing chamber of the machine was opened and the required hammer was mounted on the shaft. The fuel hose was removed from the fuel tank and was connected to a burette for accurate measurement of fuel consumed during the machine's operation. The burette was filled with fuel (petrol) above the calibration on the burette.

2.3 Theoretical Design Consideration

The design was carried out on the basis of the safety of the operator. Some other major hazards which may arise in the course of crushing was properly put in to consideration. The deflection of the hammers while in operations was considered in the design. Swimming instead of stiff hammers was used to avoid the rotor or the hammers from getting stocked in case a hammer comes in contact with a material that it cannot break at first impact.

2.4 Design Analyses

2.4.1 Power Transmission System

The transmission of one power of machine part to the other could be done through the use of belts, chains, belts, gears, axle, shafts etc. In this machine, power was transmitted through a diesel powered engine to the shaft. The power required to operate the machine was determined from the equation.

$P = f \times v$……………………………………………....eqn 2.1

Where;

P= power required in watt

F= force acting on the machine in Newton

V= velocity in meter per second.

2.4.2 Transmission Shaft

Shaft is a rotating machine element which is used to transmit power from one point to another

Points to consider:

a. Standard size of the shaft
b. Stresses in shafts and shear stresses due to the transmission of torque (i.e due to torsional load)
c. Maximum permissible working stresses for transmission shaft.

Power transmitted by the shaft (in watt) is given by the relation:

$P=\frac{2\pi N}{60}$ ……………………………………………eqn 2.2

Where;
p=power transmitted by the shaft in (in watt)
N= speed of the shaft in r. p. m
T= twisting moment (in N-m)

2.4.3 Shaft Design

Mass of shaft (m)= $\rho v \ldots \ldots \ldots \ldots . \ldots . \textit{eqn}$ 3.3
Where;
M= mass of the shaft (Kg)
$\rho =$ *density of the shaft* (kg/m^3)
V= volume of the shaft (in m^3)
And
V= A×l ………………………………………………………………………eqn 2.4a
Where;
v= volume of the shaft (m^3)
A= cross sectional area (m^2)
L= length of the shaft (m)
Were;
$A = \frac{\pi d^2}{4}$ ……………………………………………………………………… eqn 2.4b

According to khurmi and Gupta 2005 gave the density of mild steel as 7.83 x10^{3}g/cm^3 and diameter of a shaft having little or no axial loading: as

$d^3 = \frac{16}{\pi \sigma_s}\sqrt{(K_b\, M_b)^2 + (K_t\, M_t)^2}$ ………………………………………………… eqn 2.5a

Also; $T = \frac{\pi}{16} \times \tau \times d^3$ ……………………………………………………………eqn 2.5b

Where;
d= diameter of the shaft
K_b and K_t = the combined and fatigue factor applied to bending and torsional moments respectively:
∂_s =Allowable shear stress of the shaft (40MN/m^2 ASME CODE)

2.4.4 Determination of Weight of Hammer

$W_h = M_h . g \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . . eqn$ 2.6

it can be seen that the action of the weight of hammer shaft on the main shaft is negligible

2.4.5 Determination of the Centrifugal Force Exerted by the Hammers.

Centrifugal force exerted by the hammers can be calculated from equation as given by:

$F_c = \frac{\text{Mv}}{r}$…………………………………………eqn 2.7

The angular velocity of the hammer is given:

W= $\frac{2\pi rN}{60}$ ……………………………………….eqn 2.8

2.4.6 Determination of the Hammer Shaft Diameter.

The bending moment on the shaft is given by

$M_{b\ (max)} = \frac{wl^2}{8}$…………………………………………...eqn 2. 9

Since the bending moment that can be carried out by a beam is a measure of the strength of the beam and this depend upon the $\frac{I}{Y\mu a\theta}$

Where;

$\partial_s(allowable) = \frac{M_b Y_{max}}{I}$……………………………….eqn 2.10

$\frac{I}{Y_{max}}$= Z→ $\partial_{s(allowable)} = \frac{M_b}{Z}$……………………………..eqn 2.11

where ;

$Y_{(max)}$ = distance from the neutral axis to outer fibers (in m)

$I = moment\ of\ inertia$ (In m^4)

Z= section modulus. (In m^3)

For a solid round bar:

I= $\frac{\pi d^4}{64}$………………………………………..eqn 2.12

Z= $\frac{\pi d^3}{32}$…………………………………………...eqn 2.13

2.5 Performance Evaluation

The performance evaluation was carried out following similar procedures described by Mohammed et al. (2015) and Hadi et al. (2017). Fifty kilogram (50 kg) each of the two samples (maize and guinea corn) were bought from Maiduguri Monday market. The samples were cleaned by removing unwanted matters. The cleaned samples were subdivided into fragments of 500 g each and were kept for evaluation. The storage moisture contents of both stored sample (maize and guinea corn) were determined using the method described by Oluwole et al. (2016) and were found to be 13% and 14% respectfully. 500 g of maize was poured into the hopper and the machine was switched on by starting the spark ignition engine that powers the machine. The speed was adjusted and measured with a tachometer, as the machine reaches the required ope+rating speed, the gate at the hopper throat was opened to allow the samples to flow into the crushing chamber and the initial reading on the burette and initial time were taken and recorded. At the end of the operation, the final time, burette reading (fuel consumed) and mass of crushed sample were taken and recorded. This was replicated 3 times for both samples (maize and guinea corn) at 3 different speeds (2600, 3000, and 3400 rpm) and using 3 different hammers (2, 4 and 6 beaters). The results obtained were tabulated and the milling efficiency and specific fuel consumption (sfc) were calculated. The milling efficiency of the machine was obtained from Equation (1)

$$\eta_m = \frac{m_a}{m_b} x100\% \text{ ……………………………………………………….eqn.2.12}$$

Where η_m is the milling efficiency

m_a = is the mass of sample after milling (g)

m_b = is the mass of sample before milling (g)

3.0 Results and Discussions

The results of the milling test carried out on the hammer mill machine are:

Table 3.1: Milling Operation of Maize and Guinea Corn Using Hammer with two Beaters

Hammer :

	$\omega 1$ (2600 r.p.m)				$\omega 1$ (3000 r.p.m)			$\omega 1$ (3400 r.p.m)		
	S/N	t(s)	F_c(ml)	η_m(%)	t(s)	F_c(ml)	η_m%	t(s)	F_c(ml)	η_m%
Maize	1	59	8.5	78	31.30	8.30	82	25.42	8.9	88
	2	55	8.0	81	29.10	8.20	81	24.00	8.9	84
	3	50	7.8	80	27.45	80.00	80	22.48	8.8	82
	AV	54.7	8.1	79.7	29.28	8.20	81	23.97	8.9	84.7
Guinea Corn	1	46.98	7.50	84	28.30	7.2	82	23.55	7.8	92
	2	45.76	6.50	86	26.77	7.0	78	22.14	7.6	90
	3	41.39	6.30	76	25.10	6.8	90	20.22	7.5	89
	AV	44.71	6.76	82	26.72	7.0	83.3	21.97	7.63	90.3

Where $\boldsymbol{\omega}$ is the angular velocity, t_s is the milling time in second, F_c is the fuel consumption in millilitre, η_m is the milling efficiency

The result shows that as the speed increases the milling time decreases while the fuel consumption and efficiency increases for both maize and guinea corn. At the speed of 2600 r.p.m for both maize and guinea corn the average milling time, fuel consumption and efficiencies are: 54.7secs, 8.1ml, 79.7%, and 44.71sec., 6.76ml, 82% respectively. Similarly, at the speed of 3000 r.p.m. the average milling time, fuel consumption and efficiency for both maize and guinea corn are: 29.28 secs, 8.20 ml, 81 % and 26.72 secs, 7.0 ml 83.3 % respectively. Likewise, at the speed of 3400 r.p.m. the average milling time, fuel consumption and efficiency for both maize and guinea corn are: 23.97 sec, 8.9mililitre, 84.7 % and 21.97sec, 7.63 milliliter, 90.3 % respectively.

Table 3.2: Milling Operation of Maize and Guinea Corn Using Hammer with Four (4) Beaters:

	ω1 (2600 r.p.m)				**ω1 (3000 r.p.m)**			**ω1 (3400 r.p.m)**		
	S/N	t(s)	F_c(ml)	η_M(%)	t(s)	F_c(ml)	η_M(%)	t(s)	F_c(ml)	η_M(%)
M1aize	1	25.40	12.6	78	23.00	13.00	76	21.30	15.60	70
	2	24.30	12.4	78.4	23.50	13.60	72	21.00	16.00	71
	3	24.00	12.8	80	22.50	13.90	70	20.75	16.25	72
	AV	24.57	12.60	78.8	23.00	13.50	72.7	21.02	15.95	71
Gunninea Corn	1	24.50	10.00	72	22.30	11.30	70	20.80	12.25	64
	2	24.30	10.45	78	22.00	11.90	72	20.00	12.70	68
	3	24.00	10.90	77	21.60	12.20	73	19.50	13.00	63
	AV	24.27	10.45	75.7	21.97	11.80	71.7	20.10	12.65	65

The results show that as the speed increases; the fuel consumption also increases while the milling time and efficiency decreases for both maize and guinea corn. Similarly, at the speed of 2600 r.p.m, the average milling time, fuel consumption and efficiency for both maize and guinea corn are: 24.57sec, 12.60ml, 78.8% and 24.27sec, 10.45ml, 75.7% respectively. However, at the speed of 3000 r.p.m, the average milling time, fuel consumption and efficiency for both maize and guinea corn are: 23.00 sec; 13.50ml, 72.7% and 21.97 secs, 11.80ml, 71.7 % respectively. At the speed of 3400 r.p.m, the average milling time, fuel consumption and efficiency for both maize and guinea corn are; 21.02secs, 15.95m/s, 71% respectively

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Table 3.3: Milling Operation of Maize and Guinea Corn Using Hammer with Six (6) Beaters:

	ω1 (2600 r.p.m)				**ω1 (3000 r.p.m)**			**ω1 (34000 r.p.m)**		
	S/N	t(s)	F_c(ml)	η_m(%)	t(s)	F_c(ml)	η_m(%)	t(s)	F_c(ml)	η_m(%)
Maize	1	22.50	17.50	60	19.40	20.50	60	15.60	24.50	59
	2	22.30	17.70	633	20.70	20.70	62	15.00	24.30	58.4
	3	22.00	17.40	65	20.85	20.85	60	14.80	24.00	58
	AV	22.27	17.53	62.7	19.05	20.68	60.7	15.13	24.27	58.5
Guinea Corn	1	21.60	13.20	60	17.20	15.10	60	13.70	18.40	58
	2	21.00	13.00	63	17.00	15.00	59	13.50	18.25	58
	3	20.95	12.90	65	16.90	14.90	58	13.00	18.20	57
	AV	21.80	13.03	62.7	17.03	15.00	59	13.40	18.23	57.7

The above results show that as the speed increases, milling time and efficiency decreases while fuel consumptions increases for both maize and guinea corn. At the speed of 2600 r.p.m the average milling time, fuel consumptions and efficiencies for both maize and guinea corn are: 22.27secs, 17.53ml, 62.7% and 21.8secs, 13.03ml 62.7% respectively. Similarly, at the speed of 3000 r.p.m the average milling time; fuel consumptions and efficiencies, for both maize and guinea corn are: 19.05secs, 20.68ml, 60.7% and 17.03.8secs, 15.00ml and 59 % respectively. Likewise, at the speed 3400 r.p.m, the average milling time, fuel consumptions, and efficiencies for both maize and guinea corn are: 15.13secs, 24.27m/s, 58.5% and 13.40secs, 18.23 and 57.7% respectively. Base on the above results obtained, the speed and the number of beaters has significance effects on the machine performance. Therefore, hammer with two (2) beaters at the speed of 3400 r.p.m should be used because the optimum efficiencies with less comparable average milling time and fuel consumption for both maize and guinea corn are: 84.7%, 23.97sec, 8.9ml, and 90.3%, 21.97secs, 7.63ml respectively.

4. CONCLUSION

The modified household hammer mill was designed, fabricated and the performance was evaluated. At the end of the evaluation, the objective of the research was achieved. Base on the results and analysis, it has been found that the speed and the number of beaters have effects on both fuel consumption and the efficiency of the machine. The result also shows that by using hammer with (2) beater at the speed of 3400 r.p.m., the average milling time, fuel consumption and optimum efficiency for both maize and guinea corn are: 23.97secs, 8.9ml, 84.7% and 21.97secs, 7.63ml, 90.3% respectively which is the best milling operation in compared to hammer with four (4) and six (6) beater.

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