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DESIGN, FABRICATION AND PERFORMANCE EVALUATION OF A MAGNETIC SIEVE GRINDING MACHINE

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ABSTRACT

The use of grinding machine is one of the simplest methods of processing agricultural raw materials alternative to the traditional methods of grain/tuber processing using stone, mortar and pestle. However, machines constructed using metal plates results in tearing and wearing away of the materials of construction. The effect of this is the contamination of the processed foodstuff. This is known to have negative health implications when accumulated and consumed in large quantities. In this study, a magnetic sieve grinding machine was designed, constructed and the performance evaluation undertaken in order to remove the toxic metal filing contaminants that cause the health hazard in food when consumed. The machine consists of a 0.04m3 capacity hopper, a machine housing, a blower with 13.35m/s air speed, a cyclone, set of hammers that effect the size reduction of the materials been fed, 12cm width rotor pulley, a shaft of 50cm in length and a magnetic sieve that separate metal filings from the grounded food stuff. The machine is powered by a 5.96 kW diesel engine. Performance evaluation showed that 10.5g of the machine parts were worn out after 10hours of grinding. The throughput capacity and the efficiency of the machine are 600kg/hr and 87.5% respectively. Thus, from the results of the investigation, the objectives of the study were achieved. The use of the magnetic sieve grinding machine by local food processors will help reduce the rate of food contaminations during post-harvest processing of biomaterials and also safeguard people's health through food security.

Keywords- *Contamination, metal filings, extraction, grinding, machine.*

I. INTRODUCTION

The production of cassava in Nigeria has not been fully exploited due to inadequate processing technology as obtained in other developing countries (Liberty and Dzivama, 2013). This is because agricultural materials are often present in sizes that are too large to be used and they must be reduced in size. It is frequently necessary to reduce for different purposes the size of solid materials in many food processes such as expression and extraction depending on whether the material is a solid or a liquid. The operation of a size reduction can be divided into two major categories. In the case of solids, the operations are called grinding and cutting. While in the case of liquid materials, the process is defined as emulsification or atomization (Earle, 1983).

Grinding and cutting reduce the size of solid materials by mechanical action, dividing them into smaller particles. Grinding of agricultural materials is one of the oldest cultural techniques of humanity. All civilizations that feed more or less exclusively from cereals were forced to develop technology for grinding grain crops. Perhaps the most extensive application of grinding in the food industry is in the milling of the grains to make flour, but it is used in many other processes, such as in the grinding of corn, for the manufacture of corn starch, grinding of millet, grinding of cassava. In all traditional civilizations, grinding is the domain of women. There are two different techniques used in effecting size reduction of grains. The grinding done by pounding the grains (mortar and pestle) and the grinding done by crushing the grains between two stones (grinding stone). The method of pestle and mortar is the widely used in the West-African country. Before grinding, women usually soak the seeds and then let them either sit overnight or for several hours in the sun, which allows the homogenization of the moisture inside the grains. The advantage of the use of mortar and pestle is versatility. The flour thus obtained contains between 22 to 26% water. Its rapid fermentation will not permit storage beyond one or two days. The pounding work is demanding and tiring. In Senegal, an average daily efficiency of 4kg/hr per woman which is an order of magnitude. Knowing that a woman grinds approximately 4 to 6kg of grain per day, this hard work will take her more than hour of pounding per day. (FAO, 1986). Traditional grinding stones used to grind whole or decorticated grain to flour usually consists of a small stone which is held in the hand and a larger flat stone which is placed on the ground. Grain which should be fairly dry is crushed and pulverized by the backward and forward movement of the hand-held stone on the lower stone. The work is very laborious, and it is hard work for anyone to grind more than 2kg of four in an hour. In a traditional process used in many countries of Africa and Asia, decorticated grain is crushed to coarse flour either with a pestle and mortar or between stones (FAO, 1981).

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Motorised mills were introduced as a result of the drudgery involved in grain grinding. Grinding machines are machines that use the principles of abrasion, compression, attrition/shearing, impact or friction forces to effect size reduction in Agricultural raw materials. The basic principle behind most of our local grinding machines is friction. In order to effect size reduction, the two frictional surfaces of the grinding machines have to come together to crush the material between them (Maduako, 2005).

When two metallic surfaces rub against each other, there is the production of metallic filings. The grinding disc is usually made from cast iron. Thus during grinding iron filings are produced when two disc surfaces rub against each other. Exposures to metal filings are man-made in nature and occur on a daily basis in minute amounts. The day to day metal to metal wear of the frictional faces, loose machine parts and broken parts of grinding mills contaminate our flour with metal filings (Normanyo et al., 2010). Iron filings produced as part of the grounded food as a result of the grinding plates rubbing each other have some long term health effects on the human body. All metals are soluble to some extent in water. While excessive amount of any metal may present health hazard, only those metals that are harmful in relatively small amounts are commonly labelled toxic. "Dose makes the poison" other metals fall into the non-toxic group (Adetundeet al, 2010). The accumulation of metal filings in the human body system for a long time results to many of the lung and abdominal problems of the alimentary canal. Recently, it was discovered that, the frictional plates of the local Burr mills wear out too frequently. These plates are made up of heavily welded metal consisting of a lot of alloys and cast iron. The grounded flour meals have been implicated in many of the health problems of the alimentary canal of humanity in our local communities due to the accumulation of very fine metal filings. This is a very serious situation that needs attention. (Hoseney,1994).

II. MATERIALS AND METHODS

The selection of materials and methods of construction of the magnetic sieve grinding machine are based on the preliminary investigation, design and the drawing of the machine components carried out.

Description of the Machine

The magnetic sieve grinding machine is of hammer mill type. In this case, there is hammer-like projection mounted on a shaft. The hammer revolves at high speed and grinds the materials fed into pieces by beating. Moreover, the machine can grind only the dry materials.

The machine is incorporated with a magnetic sieving mechanism to ensure fineness of the grounded material and separation of metal filings from the flour. The magnetic sieve is made up of wire cloth with aperture sizes ranging from 870μm to 2mm and circular magnets arranged beneath the sieve, spaced 4cm with each other. The machine is powered by the use of eight Horsepower (5.96kW) diesel engine with a speed of 850 rpm.

The entire construction is brought about by locally sourced material thereby making the cost not prohibitive. The machine elements are easily accessible and detachable to facilitate assembling and maintenance process. Although the machine is sufficiently rugged to function properly for a reasonable long period, it is cheap enough to be economically feasible. The pictorial view of the machine with components labelled is presented in fig.1 below.

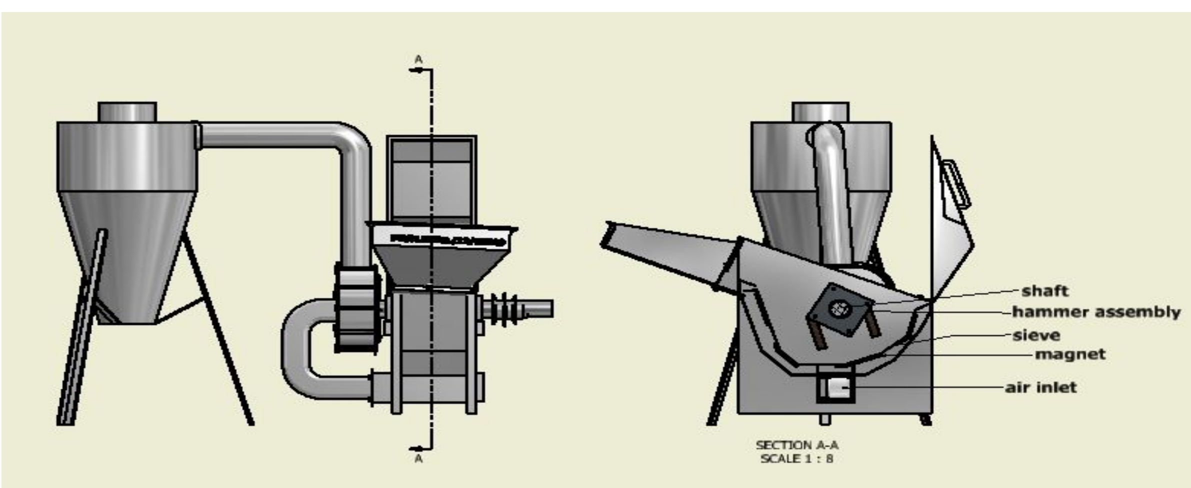

Fig.1 Cross section A-A of the Magnetic Sieve Grinding Machine

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Construction Materials

The magnetic sieve grinding machine is a size reduction machine that grinds corn, cassava, millet g/corn and so on to flour and simultaneously separating the flour from the metallic contaminants that result from tearing and wearing of the machine parts.

This machine is constructed manually with the available materials thereby making the cost not prohibitive. It is sufficiently strong and rugged to function properly for a reasonable long period.

Table 1 Construction materials

S/NO	ITEMS	QUANTITY
1.	Gauge 14 mild steel sheet	2½ sheets
2.	Gauge 16 mild steel sheet	3 sheets
3.	50cm stainless steel shaft	1 nos
4.	1mm aperture sieve	1 no
5.	Bar magnets	4 nos
6.	Bearings	2 nos
7.	3mm Angle Bar	1 no
8.	Flat Bar (5mm)	1 no
9.	Paint	1 tin
10.	Bolts, and nuts	36 nos
11.	Pulley (12cm Diameter)	1 no
12.	Grease	1 tin

The materials for the construction of the magnetic sieve grinding machine were selected on the basis of low cost, availability, resistance to corrosion, ease of operation and machining, suitability and convenience.

Method of Construction

This is the process by which various components of the machine are fabricated in stages before being assembled into a complete functional unit.

III. DESIGN ANALYSIS

a. Determination of the Torque and power transmitted to the shaft

Power transmitted to the shaft is given by

Where

T_1 = Tight side tension of the belt (N)
T_2 = Slack side tension of the belt (N)
V = shaft speed (m/s) (Spolt, 1988)

b. Determination of the Centrifugal Force Exerted by the Hammer

Centrifugal force exerted by the hammer can be calculated from equation (4.16) as given by:

The angular velocity of the hammer is given by:

Where

r = Radius of pulley over which the belt runs (m)
N = Number of rotation of pulley
M = Mass of belt per unit length (kg)
V = Linear velocity of Belt (m/s) (Nasir, 2005)

c. Determination of Hammer Shaft Diameter

The bending moment on the shaft is given by Ryder, 1996 in (Nasir, 2005).

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/y that (Ryder, 1996).

Where

Y_{max} = distance from neutral axis to outer fibres
I = Moment of Inertia
Z = Section Modulus

For a solid round bar:

d. Determination of power required by the blower

The blower consists of a round housing and fan blades mounted on a shaft. The diameter of the blower = 480mm, outer area = 1200mm x 120mm.

Air power = Q x P_s (9)

Where

Q = volumetric flow rate (m^3/s)
P_s = static pressure developed (kpa) (Owan, 2004).

e. Selection of Powered Diesel Engine

The Diesel engine selected to powered the magnetic sieve grinding machine has the following specifications:

- rotational speed, power = 5.9kW, rotational speed = 850rpm

The power transmission drives used for the machine are belt and pulley.

f. Selection of Bearing

Ball rolling contact bearing of standard designation 307 was selected for the magnetic sieve grinding machine. This selection was based on the type of load the bearing will support when at rest and during operation and also based on the diameter of the shaft.

The designation 307 signifies medium series bearing with bore (inside diameter) of 40mm (Khurmi and Gupta, 2005).

g. Determination of velocity of air:

Velocity of air was obtained by equation (10)

Where

N = Rotational speed of Rotor (rpm)
D = diameter of fan (mm)
K = Number of fan blade

The gravimetric throughput capacity was obtained by equation (11)

Where

= Density of air= 1.239kg/m^3
(Nwaigwe et al, 2012).

h. Determination of area of flow

Area of flow, a =

Where

D = Diameter of milling chamber
d_1 = Diameter of disc
d_2 = Diameter of shaft
n = Number of hammers
L = length of the hammers
t = Thickness of hammer

i. Theoretical throughput capacity

The throughput capacity is the quantity of material moved, produced or separated per unit time. It can be volumetric or gravimetric. The volumetric throughput capacity was obtained by

Where

V = velocity of air (m/s)
A = Area available for flow of material (m^2)
θ = Coefficient of filling

j. Power requirement

The power requirement for the magnetic sieve grinding machine was obtained by equation (14)

Where

H = Height of lift
f = power factor

(Nwaigwe et al, 2012).

k. Determination of the percentage of flour passing through each sieve

The per cent of aggregate passing through each sieve was obtained by equation (15)

Where

W_{sieve} = Weight of aggregate in the sieve (kg)
W_{total}= Total weight of the aggregate (kg)

% Cumulative passing = 100% - % Cumulative Retained (16)
(Sonaye et al, 2012).

l. Determination of the amount of metal filings separated by the magnet

Set of hammers was weighed before coupling to the machine and found to be 2kg. After 10 hours of the machine operation. It was re-weighed and found to be 1.988kg. The magnets was removed and brushed out the filings. The quantity of filings gotten was re-weighed and found to be 0.0105kg (10.5g).

m. Determination of efficiency of metal fillings extraction

The extraction efficiency(%)=

Where

Q_{fm} = Quantity of metal filings attracted to the magnet (10.5g)
Q_t =Quantityof material worn out of the set of hammers (12g).

IV. PERFORMANCE EVALUATION

Performance evaluation is a vital step in the process of machine development. After the design and construction, testing is necessary in order to determine the machine performance, exposed defect and area of possible improvement, and appreciate the level of success in the research. Thus, it is important to test and run a machine to determine its work ability and efficiency.

Procedures used for the testing

Sample of corn and cassava was obtained from the market for the performance evaluation.

10kg of dry cassava chips was fed into the machine through the hopper while machine was on. The grinding was noted. The machine component was removed. It was observed that, some quantities of metal filings were magnetized by the magnets. It was brushed out and weighed. The amount of the metal filings obtained is stated in Table 2.

Table 2: Summary of Performanceof the Machine

s/no	Parameters	Values Obtained	Unit	Time taken
1	Quantity of	10	Kg	One

	dried cassava chips handled by the machine			minute
2	Throughput capacity	600	Kg	One hour
3	Initial mass of hammers	2.0	Kg	-
4	Final mass of hammers (after grinding)	1.988	Kg	10 hours
5	Percentage value of material worn out	0.012 (12g)	Kg	-
6	Percentage value of iron filings obtained on the magnets	0.0105 (10.5g)	Kg	-
7	Machine efficiency	87.5	%	-

The performance evaluation conducted for the determination of the efficiency of extraction of metal filings is presented in table 3 and also in a graphical form in fig. 2

Plate 1.Photo showing the evaluation of the machine performance

Table 3 Values obtained from the extraction of metal filings

Quantity (g)	10.5	10.51	10.5	10.49	10.5	10.5	10.51	10.5	10.51	10.49
Time (hr.)	1	2	3	4	5	6	7	8	9	10

Quantity (g)

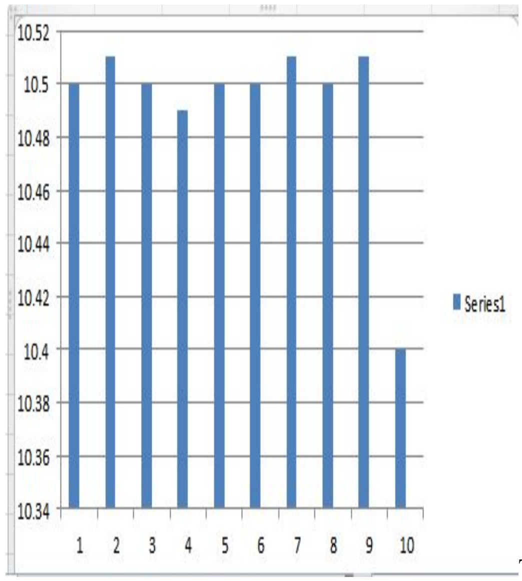

Fig2. A graph showing the quantity of metal filings (g) extracted by the machine per unit time (hr)

Fig. 2 above showed a graph of quantity of the iron filings attracted by the set of magnets in grams against time in hours. The variations in the bars are as a result of the values obtained during the performance evaluation. It can be seen that, the maximum value obtained was in the 2nd and the 9thhours and the least in the 10th hour.

V. DISCUSSIONS

Table 2 showed that, the quantity of iron filings produced by a grinding machine was found to be 10.5g after one hour of operation (grinding). Comparing the result obtained with Normanyo et al, 2010. It was discovered that grinding of agricultural materials like cassava with either burr mill or hammer mill results in tearing and wearing away of machine parts which contaminates food products. Alam et al, (2002) and Gorham,(1994) also wrote that, long time accumulation of metal filings into human body system has a negative health implication such as lung and abdominal problems of the alimentary canal.

Table 2 showed that, the magnetic sieve grinding machine based on its design, operated at a very high speed of 4,250rpm and air velocity that blows the product (flour) to the cyclone was found to be 13.35m/s which is better than Nwaigwe et al, (2012) hammer mill that is operated at only a speed of 1,080rpm since the higher the speed of a grinding machine, the higher its performance.

During the performance evaluation it was discovered that, the magnetic sieve grinding machine requires continuous feeding of the dried cassava chips. The machine was found to be dust free and the beaters do not wear when running freely.

From these results obtained, the machine is effective. It has a throughput capacity of 600kg/hr and machine efficiency of 87.5%. The efficiency proves that the machine has served its purpose.

VI. CONCLUSIONS RECOMMENDATIONS

The results obtained from the design and performance evaluation showed that, the magnetic sieve grinding machine was designed, fabricated, tested and found to have a throughput capacity 600kg/hr and efficiency of 87.5% also a speed of 4,250rpm with air velocity of 13.35m/s. From the results the following conclusions were made:

1. The machine efficiency was influenced by the strength of the magnets.
2. There was no damage by the hammers (beaters) to the magnetic sieving component at a speed of 4,250rpm.
3. The magnetic sieve was able to extract 10.5g of metal filings from the grounded cassava flour after 10 hours of operation.

Thus, with the extensive job done on the basis of the preliminary investigations, design, construction and performance evaluation as stated above. The aims and objectives of undertaken this project have been achieved. The use of the magnetic sieve grinding machine by local food processors will help reduce the rate of food contaminations during postharvest processing of biomaterials to the minimum level and also safeguard people's health through food security.

The following recommendations are considered pertinent for the maintenance of the magnetic sieve grinding machine:

i. For mass production of the machine, stainless steel materials should be used in construction.
ii. An electric motor of rated speed up to 4,250rpm, 6 -8 Hp may be used as a power source.
iii. Field trial of the machine performance may be undertaken and the experience gained should be used to optimize the design of the machine if necessary.
iv. Given the level of performance achieved. It is recommended that, this magnetic sieve grinding machine should be manufactured and popularized for adoption to avoid assimilation of contaminated food into human body system in Nigeria.

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