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Performance Evaluation of a Fabricated Palm Kernel Shells Grinding Machine

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Abstract: **Palm kernel shells (PKS) are the shell fractions left after the extraction of oil and the removal of the seed from the nuts. These are fibrous materials with heat energy/calorific value of about 5.2MWh/MT and are used in food, feed, manufacturing, and cement industries. In order to convert the materials for use in the industry in powder form, a palm kernel shells grinding machine was designed and fabricated using locally available raw materials for reducing the size of PKS to the required particles size(s). Performance evaluation on the machine fabricated was carried out in order to determine its viability for the purpose it was designed for. The aerodynamic principle allows proper materials circulation and prevents them forming layer on the sieve and in the silo. The performance evaluation of the locally fabricated palm kernel shell grinding machine shows great advantages in high productivity with a production rate of 5tonnes per day, low energy consumption, grinding velocity of 15.1m/s, grinding efficiency of 97.7%, fineness modulus of 0.39, which indicate a fine powder and a low temperature product that is favourable for feed quality, feed preservation and as well as feed storage in the silo.**

Keywords:* *Performance Evaluation, Fineness Modulus, Grinding Efficiency, Production Rate

INTRODUCTION

Palm kernel shells (PKS) had remained very popular source of energy in the rural area in third world countries and many companies also depend on palm kernel as raw materials. Palm kernel shell is the dry, fibrous and tough materials that covers the palm nut (kernel), a left over after the extraction of the oil rich outer cover and the removal of the inside soft nut, good source of biofuel with high calorific value, Figure 1(a & b). Palm Kernel Shell has the following specifications: Heat Energy/Calorific Value**:** > 4,320 kilocalories per kilogram; Inherent Moisture: < 20 %; Ash content: < 15%; Size: 4-20mm and Foreign Materials (by visual): < 2%. Large volume of palm kernel shells is inadequately disposed yearly [1].

Figure 1 (a & b) Raw Palm Kernel Shells

Nigeria is one of the world largest exporters of palm kernel product in early sixties, providing about 400,000 metric tons amounting to 65% of the world trade, which give rise to vast deposit of palm kernel shells in the country. This exportation capacity was reduced from 65% to 15% when there was an oil boom in Nigeria. Handling the vast deposit of palm kernel shells is still a major challenge in the country [2, 3]. PKS serve as organic fertilizer but because of it hard shell, it takes much longer time for converting totally to organic fertilizer.

According to Opean Energy, on an annual basis, there are about 3.2 million tons of palm kernel shells available in Indonesia and 3.1 million tons in Malaysia. Nigeria produces about 1.5million ton/a, PKS. The shells compare favourably as a boiler fuel source due to their relatively high calorific value of 4,320 kilocalories per kilogram (16 Btu per 154 pounds), abundance of supply, ease of use and per tonnage cost. It is a good quality biomass fuel with uniform size distribution, easy handling, and limited biological activity due to its low moisture content.

Palm kernel shells are versatile and have multiple uses. It can be used in its natural form for fuel at power stations, as a clean alternative to coal, to form activated carbon or to pave roads. It can replace coal to reduce emissions of EU power stations and promote enabling enterprise in developing countries where these can be sourced from [3-7]. The chemical composition of the PKS used for the test after the fabrication is as shown in Table 1.

Table 1 Chemical Composition, PKS used for the Test

Sample	Composition, %					
	Al_2O_3	SiO_2	Fe_2O_3	CaO	MgO	K_2O
PKS (Ipokia)	11.40	54.81	0.362	8.79	6.11	6.25

Based on high dependent of many companies like insecticide, cement producer, etc. development of an efficient palm kernel shell grinding machine using locally available raw materials is therefore not only necessary but very important to enhance production capacities of these industries in other to meet up with ever increases industrial demand [4, 5].

A palm kernel shell grinding machine is a unit operation designed to break a solid palm kernel shells into smaller pieces (powder) to about 425µ-75µ with reduction ratio of 25:1. The process of grinding the palm kernel shells into powder involves cracking, abrasion and size reduction of the palm kernel shells. Every unit operation in the industry has specific objective and this calls for special machines to achieve such. Having critically examined the complicated problems with the conversion of PKS to powder, attempts was made to develop and fabricate a palm kernel shells grinding machine that will have enough strength to grind the shells into powder. This study aims at the followings: (i) to develop and fabricate palm kernel shells grinding machine locally, (ii) to test and ascertain the performance of the machine (iii) to confirm the efficiency of the palm kernel shells grinding machine and (iv) to ascertain the time required to grind a measured quantity of palm kernel shells per second. The fabricated palm kernel shells grinding machine is electrically powered; parts are mechanically fabricated and assembled together to allow for necessary relative motion, feeding process, discharge operation as well as ease of maintenance.

MATERIAL AND METHOD

Materials

Description of the Palm Kernel Shell Grinding Machine

The palm kernel shell grinding machine was designed and fabricated at the workshop bay of the Engineering Materials Research Department, Nigerian Building and Road Research Institute, National Laboratory Complex, Ota, Ogun State, Nigeria. The machine is made of three main sections: grinding chamber which comprises the [hopper, suction fan, separator, electric motor and the hammers]; the silo; and the air filter bags. The overall dimension of the machine is 4.9m x 1.9m x 3.48m. The machine is powered by a 75 hp electric motor with an operating speed of 1,180rpm. The following materials; mild steel sheet, metal rods, angle iron, steel pipe, blade, rubber materials, bearing, casing, bolts, nuts, pulleys, belts and electric motor were used in the development of the machine. The hopper unit was made of mild steel. It is trapezoidal in shape. At the base of the hopper lies the grinding chamber which house the hammers that does the size reduction. The suction fan helps to draw the fine grinded palm kernel shells particles into the silo. The silo helps to store the grinded palm kernel shells till when it will be discharged for usage and the air filter bags helps to keep the environment clean by trapping very fine PKS particles from being release to the environment.

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Design Consideration and Materials Selection
Design of the Machine

In carrying out the design of the machine, the velocity of the palm kernel shell towards the hard wall, rotor speed, palm kernel shells size, weight, etc, and feed rate of the palm kernel shells were factors that were considered. Research were carried out to determine the average size, average mass, velocity require to grind the palm kernel shell and the average volume of the palm kernel shell to aid the design and fabrication of the machine. The grinding area will be subjected to constant abrasion, centrifugal forces, torque and wears due to forces impacted on the surface by the kernel shells and the rotating forces of the hammers. For this reason, the area was lined with mild steel sheet of 10mm thickness (the base casing) and 8mm thickness (upper casing). The choice of mild steel is based on its resistance to shock, wear and abrasion, as well as weldability and good work-hardening properties.

Mass of the Kernel Nut
Samples of palm kernel shells were collected from Ipokia, Ogun State, Nigeria. The palm kernel shells diameter was measured using a venire calliper at the Engineering Materials Research Department of the Institute; the mass of each shell was measured using an electronic weighing balance at the soil laboratory of the Institute. The various measurements taken are as shown in Table 2.

Performance Evaluation of the Machine
The evaluation of the palm kernel shell grinding machine was carried out at the Pozzolana Cement Pilot Plant, National Laboratory Complex, Nigerian Building and Road Research Institute, Ota, Ogun State, Nigeria. Palm kernel shells obtained from Ipokia, Ogun State, were used for the evaluation performance test (grinding of the shells). The factors considered for the evaluation include: grinding capacity, grinding efficiency, grinding velocity, fineness test, modulus of fineness, sieve analysis and particle size distribution.

The Machine Output Capacity (M_C)
This is the rate at which the palm kernel shell grinding machine grinds the palm kernel shells loaded into it and is calculated as:

$$M_c = \frac{Q}{t} \quad [3] \qquad (1)$$

where,

M_C = Machine capacity (powder produced/min)

Q = Quantity of PKS powder produced

t = Time for grinding the PKS (min)

The Grinding Efficiency (G_E)

This is defined as the percentage by output of viable quantity of grinded PKS over the total quantity of PKS produced. It is calculated using equation 2 [3]:

$$G_E = \frac{T-X}{T} \qquad (2)$$

where,

G_E = Grinding efficiency (%)

T = Total quantity of PKS input

X = Total quantity of PKS output

Grinding Velocity (G_V)

This is the speed at which the grinding hammers rotate and grinds the palm kernel shells into PKS powder and it is expressed as [3]:

$$G_V = \frac{\pi DN}{60} \qquad (3)$$

where,

G_V = Grinding velocity (m/s)

D = Diameter of the machine pulley

N = Speed of rotation of the machine pulley

Fineness Modulus

Fineness Modulus (FM) defines the fineness or coarseness of materials. A small number indicates fine materials; a large number indicates coarse materials and it is calculated thus [7]:

$$FM = \frac{Sum\ of\ Cumulative\ \%\ Retained\ on\ Selected\ Sieves}{100} \quad (4)$$

Sieve Analysis

Sieve analysis was carried out on the palm kernel shells powder produced from the locally fabricated palm kernel shells grinding machine to determine its grinding efficiency. A representative sample of 200g was used for the sieve analysis. A total of six (6) different sieve sizes (425µm, 300 µm, 200 µm, 125 µm, 100 µm, and 75 µm) were used for this analysis. The stack of sieves was subjected to the vibratory action of the sieve shaker for one hour. The palm kernel shells powder retained on each sieve was then weighed in order to determine the particle sizes distribution of the palm kernel shells powder. The analysis was done for three (3) different batch samples and the mean value was calculated, the result is as shown in Table 7.

RESULTS AND DISCUSSION

RESULTS

The results of the evaluation of the palm kernel shells grinding machine is as stated below. Table 3 shows the particle size distribution analysis of the palm kernel shells powder. The result shows that bulk of the palm kernel shells powder passed through the 425µm sieve, which is the required particle size, an indication of the grinding efficiency of the palm kernel shells grinding machine. Table 4 is the grinding efficiency of the PKS grinding machine for three different batch samples. The grinding efficiency of the PKS grinding machine was calculated to be 0.979 using equation 2.

Table 2: Mass and Diameter of Palm Kernel Shell Samples

S/N	Mass (g)	Diameter (mm)
1	5.200	15.00
2	4.500	14.00
3	4.000	14.00
4	4.200	14.50
5	5.100	15.00
6	4.300	14.00
7	4.000	13.00
8	4.300	13.50
9	4.300	14.20
10	3.500	13.40

The procedure was repeated for three different batch samples and the different grinding efficiency of the machine is shown in Table 4.

Table 3: Particle Size Distribution

Number	Sieve size(µm)	Mean Weight of PKS Retained (g)	Particle Size Distribution (%)
1	+425	77.00	38.5
2	-425+300	21.10	10.55
3	-300+200	21.76	10.88
4	-200+125	22.22	11.11
5	-125+100	8.13	4.07
6	-100+75	10.53	5.25
7	Pan	37.46	18.73

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$$G_E = \frac{T-X}{T} = \frac{0.0204-425\times10^{-6}}{0.0204} = 0.979$$

Table 4: Average Grinding Efficiency

Test number	Grinding efficiency, G_E (%)
1	97.7
2	97.9
3	97.5

The average grinding efficiency of the palm kernel shell grinding machine is calculated below:

$$Average\ Grinding\ Efficiency = \frac{97.7+97.9+97.5}{3} = 97.7\%$$

The machine output capacity is calculated as thus:

$$M_c = \frac{Q}{t} = \frac{37500}{60} = 625kg/hr$$

The grinding velocity of the locally fabricated palm kernel shell grinding machine is as calculated below:

$$G_V = \frac{\pi DN}{60} = \frac{\pi\times200\times1440}{60} = 15.1m/s$$

The result of the fineness and modulus of fineness carried out on the palm kernel shell powder is shown in Table 5, Table 6, and while Table 7 is the grain size distribution of grinded PKS.

Table 5: Result of Fineness Test on the Grinded Palm Kernel shell

Test Number	Sieve size	Retained size (g)
1	+425 µm	77.00
2	-425µm+300 µm	21.10
3	-300 µm+200 µm	21.76
4	-200 µm+125 µm	22.22
5	-125 µm+100 µm	8.13
6	-100 µ m+75 µm	10.53
Pan	-75 µm	39.28

Table 6: Modulus of Fineness

Test Number	Sieve Size (g)	Weight of PKS Retained (g)	Percentage of weight retained (%)	Cumulative %, PKS
1	426µm	77.00	38.5	38.5
2	Pan	63.00	61.5	100

Table 7: Grain Size Distribution of Grinded PKS

Sieve Size	% Retained	Cumulative % Retained
+425 µm	38.5	38.5
-425µm+300 µm	10.55	49.05
-300 µm+200 µm	10.88	59.93
-200 µm+125 µm	11.11	71.04
-125 µm+100 µm	4.07	75.11
-100 µ m+75 µm	5.25	80.36
Pan	18.73	100

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Modulus of Fineness and Uniformity Index

The result of the fineness test carried out on the Palm Kernel Shell powder produced by the Palm Kernel Shell grinding machine is shown in Table 5.

Total weight of sample = 200g

Time of vibration = 45 minutes

$$\%\, retained\ in\ sieve = \frac{weight\ of\ retained\ sample}{total\ weight\ of\ sample} \times 100$$

$$FinenessModulus\ (FM) = \frac{Sum\ of\ Cummulative\ \%\ Retained\ on\ Selected\ Sieves}{100}$$

$$FM = \frac{38.5}{100} = 0.39$$

DISCUSSION

The result of the performance evaluation test carried out on the fabricated palm kernel shells grinding machine using local raw materials as indicated in Table 3 shows that there was great size reduction in the initial size of the palm kernel shell with 97.7% (average grinding efficiency) reduction in size. It can be seen from Table 5 that, the bulk of the palm kernel shells powder passed through 425µm sieve which implies that, bulk of the palm kernel shells powder can be used for the desired purpose. It was also observed that, 77g (38.5%) of the 200g that was used for the analysis was retained on the 425µm, which suggest that, PKS has a high resistance to crushing and grinding [8], finer grains can be achieved by adjusting the sieve on the palm kernel shells grinding machine to obtain the desired grain sizes at all time. The palm kernel shells grinding machine has a grinding capacity of 625kg/hr (5 tonnes per day) with grinding velocity of 15.1m/s which means, the machine can be used for low, medium and large scale industrial purpose [9]. From the fineness test carried out on the PKS powder produced by the machine, the fineness modulus was obtained as 0.39. A fineness modulus of 2.10 and below signifies fine powder [10], which implies that, the quality of workdone by the locally fabricated palm kernel shells grinding machine is satisfactory.

CONCLUSION

A palm kernel shells grinding machine with an adjustable/removable sieving device has been designed and fabricated, the performance evaluation was carried out and the results obtained shows that, it satisfied both the energy and production criteria of the process with minimal cost. The evaluation shows that, the machine can also serve as a universal hammer mill, as it has the capacity to grind any materials that have strength in the range of the palm kernel shells and below. It is also suitable for small, medium and large scale production with a grinding capacity of 5 tonnes per day.

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