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Design And Fabrication Of Palm Kernel Shells Grinding Machine

B. S. Yahaya, M. O. Fabiyi, E. S. Apeh, And E. S. Ochei
Engineering Materials Research Department, Nigerian Building and Road Research Institute, KM 10 Idiroko Road, Ota, Ogun State, Nigeria
Corresponding Author: B. S. Yahaya

ABSTRACT: *Palm kernel shells (PKS) grinding machine was designed and fabricated for use in the processing of materials for the production of pozzolana cement. One of the materials used for the production of pozzolana cement is palm kernel shell, which serve as fuel in the kiln during calcining of the nodulized clay and subsequently became binder after ball milling. There is need to grind the palm kernel shells to the required particle size (<425microns) before mixing it with (powdery) or ground clay. The design by calculations, drawing and fabrication was carried out at the Workshop Bay of the Engineering Materials Research Department, Nigerian Building and Road Research Institute, Ota, Ogun State, Nigeria. The materials were locally sourced for the fabrication. The designed and fabricated palm kernel shells grinding machine has a grinding efficiency of 97.7%, particle size < 425microns and grinding capacity of 625 kg/hr. It is dust free and self-cleaning with proper air circulation that allows the palm kernel shells powder in the silo to be retained.*
KEYWORDS - *Grinding Efficiency, Grinding Machine, Palm Kernel Shells, Powder, Pozzolana Cement*

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I. INTRODUCTION

There is need to harness and convert available mineral resources in the country through technological advancement of designing and fabricating the processing equipments/machineries locally for their application in the various industries. The technological advancement of any nation have been influenced and uplifted by the extent to which it can usefully harness and convert its minerals and local resources into household products and as such, the need to design an implements for their production[1]. The use of biomaterials in general and agro-waste in particular is a subject of great interest nowadays not only from the technological and scientific points of view, but also socially, and economically, in terms of employment, cost and environmental issues. Nigeria is endowed with a lot of minerals and agro-based resources that could be used in the development of environmental-friendly composite materials such as Eco-pad used in modern vehicle braking systems, pozzolana cement for low cost housing, etc.

Nigeria is the world largest exporters of palm kernel product in early sixties, providing about 400,000 metric tons of palm kernels, amounting to 65% of the world trade. Nigeria palm kernel nut export reduced drastically within seventies, from 65 to15% when there was an oil boom, as of 2011, Nigeria was the third-largest producer, with more than 2.5 million hectares(6.2×10 acres) under cultivation of palm kernel leaving behind large quantity of palm kernel shell after the processing. Grinding is the process of breaking down of materials, leading to separating, sizing, or classifying aggregate materials into various sizes. Rock crushed or ground to produce uniform aggregate sizes for construction purposes are examples of source processing. Similarly, clay materials are crushed or ground for a specific purpose but some materials are tougher than each other and as such, using the same technique or machine will not be feasible.

Grinding of palm kernel shell which is tougher than stone or clay takes into consideration of a unique grinding media. An efficient palm kernel shells grinding machine is therefore not only necessary but also important to facilitate the process of palm kernel shells grinding in order to meet up with ever increasing industrial demand of the product. Based on high dependent of many companies like insecticides, cement, vegetable oil, body cream, soap industries, etc. on palm kernel products [2-4].

Grinding may serve the following purposes in engineering: increase of the surface area of a solid, manufacturing of a solid with a desired grain size and pulping of resources. A grinding machine is a unit operation designed to break a solid material into smaller pieces. There are different types of grinding machines for various materials processing as shown above. Grinding of solid matters occurs under mechanical forces that trench the structure by overcoming the interior bonding forces. After grinding, the state of the solid is changed; the grain size, the grain size disposition and of which the grain shape are also affected. PKS are good source of bio-fuel with low moisture content, high calorific value of 4500Kcal/Kg and 18.8GJ/MT which account for its high heating value [8] and thus its relevance in the production of pozzolana cement [5-8].

Design is the transformation of concepts and ideas into useful machinery [9]. The designed and fabricated palm kernel shell grinding machine is of hammer mill type of which the hammers are mounted on a shaft in the chamber for the milling operation. The hammers revolve at high speed in the chamber and as the hammers hit the dry shells repeatedly, the materials are reduced to the required particle size. The machine is incorporated with an adjustable separator for possible particle size regulation during the grinding operation. It is powered with 75hp electric motor of 1,440 rpm. This paper on the design and fabrication of PKS grinding machine tend to harness and encourage the use of locally available raw materials and boost capacity building in the area of machine construction for their application in relevant fields.

II. MATERIALS AND METHODS

This research was carried out at the workshop bay of Engineering Materials Research Department, Nigerian Building and Road Research Institute (NBRRI), National Laboratory Complex, Ota, Ogun State. All materials are locally sourced. The procedures in the design and fabrication of the Palm Kernel Shells grinding machine are as discussed below:

2.1 Theoretical Design and Materials Selection

The design by calculation was carried out using AutoCAD software after which the fabrication was carried out at the Workshop Bay of Engineering Materials Research Department, NBRRI. The materials for the construction of the machine are: the shaft, pulley, belt, electric motor, the bearing, the mild steel plates, angle bars and mild steel cylindrical tube. These materials were selected based on their properties and areas of applications. By hand feeling; it was found that palm kernel shell when dried to moisture content of 5% (wt) cannot be crushed into powder with the human fingers [9] thus; the power required for its grinding is high.

2.1.1 Selection of Electric Motor

In selecting the required electric motor for powering the pulley, the power requirement of the grinding machine was considered. To determine the right power to be transmitted to the shaft for effective grinding operations, the force and velocity of the belts were considered according to [1].

$$P = F \times V \quad (1)$$

Where,

P is the power, F is the force, v is the velocity,

$$F = T_1 - T_2 \text{ , and} \quad (2)$$

$$V = \pi N D \quad (3)$$

Equation 1 will now be

$$P = (T_1 - T_2)\pi N D \quad (4)$$

Where,

T_1 = the tension in the tight side of the belt (T_1 = SA), T_2 = the tension in the slack side of the belt, N = the number of revolution per minute, D=the diameter of the pulley, S is the maximum permissible stress and A is the cross sectional area of the belt.

2.1.2 Selection of Transmission Drives

Belt drives are also called flexible machine elements. Flexible machine elements are used for a large number of industrial applications, such as conveying system (transporting coal, mineral ores, feeds, etc.), transmission of power (running of various industrial appliances using prime movers like electric motors, I.C. Engine, etc.). Belt drives has got an inherent advantage that, it can absorb a good amount of shock and vibration. It can take care of some degree of misalignment between the driven and the driver pulley and long distance power transmission, in comparison to other transmission systems, is possible. Based on the advantages stated above, the belts and pulley system was adopted [10].

2.1.3 Design for Pulley or Sheave

There are two types of belt drives; an open belt drive and a crossed belt drive as shown in Fig. 1 and Fig. 2. In both drives, a belt is wrapped around the pulleys. The driving pulleys transmit motion to the belt and the motion of the belt in turn will give a rotation to the driven pulley. In open belt drive system the rotation of both the pulleys is in the same direction, whereas, for crossed belt drive system, opposite direction of rotation is observed. Open belt drive was adopted in this design because of the direction of rotation.

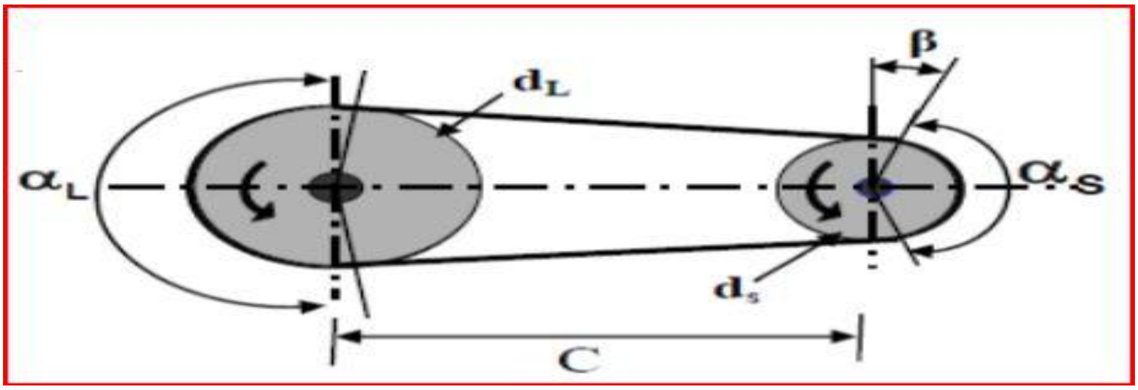

Fig. 1: Open Belt System [10]

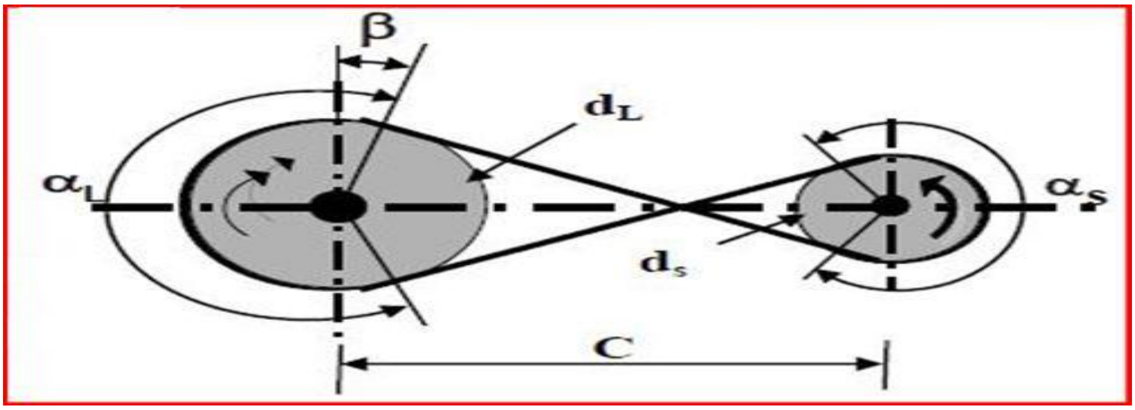

Fig. 2: Cross Belt System [10]

The rotor's pulley diameter was selected using the equation for speed ratio as shown in Eq. (5) according [1]:

$$D_r = \frac{D_m N_m}{N_r} \qquad (5)$$

Where,

N_m = Rotational speed of electric motor = 1,440 rpm, D_m = Measured diameter of motor's pulley = 200mm, N_r = Rotational speed of rotor (rpm) = 1,080 rpm

The speed of the rotor was chosen as 1,080 rpm due to the pneumatic conveying of materials in the palm kernel shells grinding machine. The speed must be high enough to generate air of velocity greater than the critical velocity of the palm kernel shells powder to be conveyed and discharged upwards.

2.2 Belt Design

Belts are used to transmit power from one shaft to another by means of pulleys which rotate at the same speed or at different speeds. The amount of power transmitted depends upon the velocity of the belt, the tension under which the belt is placed on the pulleys, the arc of contact between the belt and the smaller Pulley, and the conditions under which the belt is used [11]. V-belts were selected over flat and round belts because of the amount of power to be transmitted, the distance between the two pulleys, speed of operation and cost efficient.

2.2.1 Selection of Belt Type

The speed of the driving and driven shafts, speed reduction ratio, power to be transmitted, centre distance between the shafts, positive drive requirements, shafts layout, space available, and service conditions are the factors to be considered in selecting belt drive. Based on the power to be transmitted (55kw) and according to the Indian standards (IS: 2494-1974), V-belt type C was selected using Table 1.

Table 1: Dimensions of standard V-belts [12]

Types of belt	Power ranges in kw	Minimum pitch diameter of pulley (D) mm	Top width (b) mm	Thickness (t) mm
A	0.7-3.7	75	13	8
B	2-15	125	17	11
C	7.5-75	200	22	14
D	20-150	355	32	19
E	30-350	500	38	23

2.2.2 Calculation of Belt Length

The effective belt length is the length of the neutral layer of an un-tensioned belt. It is identical with the fabrication length. The belts were employed to transfer power through rotational motion from one shaft to another and so the right length of belt must be employed to transmit the required energy. The centre to centre distance between the large pulley and small pulley used in this design was measured and is equal to 117mm. The length of the desired belt is given by [1] as shown in equation (6),

$$L = \frac{\pi}{2}(D_1 + D_2) + 2x + \frac{(D_1 + D_2)^2}{4x} \quad (6)$$

Where,

L = Length of belt, D_1 = Big sheave diameter = D_m(200mm), D_2 = Small sheave diameter = D_r(160mm), x = Centre to centre distance of pulleys(117mm)

These parameters are represented in Fig. 3 below:

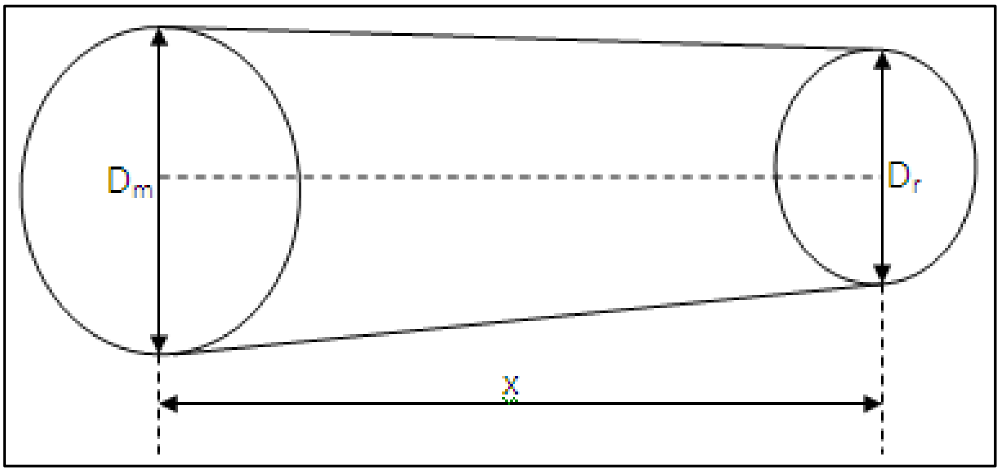

Fig.3: Open belt drive

2.3 Shaft Design

A shaft is a rotating member used for the transmission of power. It is integral with an engine, motor or prime mover and is of suitable size, shape and projection to allow its easy connection to other shafts. The most important factor to consider in shaft design is the diameter of the shaft. The calculated diameter of the shaft was selected based on the power requirement of the machine. The shaft of the palm kernel shell grinding machine which is constantly under a twisting moment rotates the belts, hammers, separator and fan. For a shaft subjected to twisting moment only, the diameter of the shaft was obtained by using the torsion equation given in Eq. (7) according to [1]:

$$T = \frac{\pi}{16} \times \tau \times d^3 \quad (7)$$

Where,

T = Twisting moment (Nm), τ = Torsion shear stress (N/m^2) = 42 MPa [12].

d = Diameter of shaft (m)

According to [12], the equation for determination of twisting moment (T) for a belt drive is shown in Eq. (8):

$$T = (T_1 - T_2)R \quad (8)$$

Where,

T_1 = Tight side tension (N), T_2= Slack side tension (N), R = Radius of pulley (m)

2.3.1 Determination of Belts Tension

Power transmission is a function of belt tension. However, also increasing with tension is stress (load) on the belts and bearings. The ideal belt is that of the lowest tension that does not slip in high loads. Belt tensions should also be adjusted to belt type, size, speed, and pulley diameters. Belt tension is determined by measuring the force to deflect the belt in a given distance per inch of pulley. From Eq. (9), the tight side tension was given as:

$$T_1 = T_m - T_c \quad (9)$$

Where,

T_m = Maximum tension in belt (N)

T_c = Centrifugal tension (applicable for belt running at high speed).

$$T_m = Maximum\ Stress(\sigma) \times Cross\ Sectional\ Area\ of\ Belt(a)$$

$$T_m = \sigma a \quad (10)$$

2.3.2 Determination of Belts Cross-Sectional Area

The cross-sectional area of the belt was calculated by considering Fig. 4. From Table 1, top width, b = 22 mm; thickness, t = 14mm and by calculation, the bottom width (x) was got as 6.6 mm.

Thus,

$$Area\ of\ belt(a) = (area\ of\ triangle\ 1) + (area\ of\ rectangle\ 2) + (area\ of\ triangle\ 3)$$

$$= \frac{t}{2}\left(\frac{b-x}{2}\right) + xt + \frac{t}{2}\left(\frac{b-x}{2}\right) \quad (11)$$

$$a = \left[\frac{b-x}{2}\right] t = xt \quad (12)$$

Maximum allowable stress of belt, F = 2.8MPa [12]

Also, centrifugal tension, T_c was determined using Eq. (13):

$$T_c = mv^2 \quad (13)$$

Where,

m = mass of belt per unit length. It was calculated using:

$$m = \sigma a \quad (14)$$

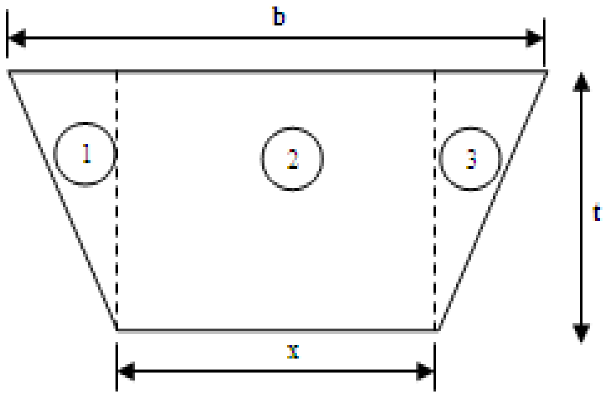

Figure 4: Cross-section of V-belt

Table 2: Density of belt materials [12]

Materials of belt	Mass density in Kg/m^3
Leather	1000
Canvass	1220
Rubber	1140
Balata	1110
Single woven	1170
Double woven	1250

Also,

V = linear speed of belt is given as [10]:

$$V = \frac{\pi DN}{60} \quad (15)$$

D = density of belt material (Rubber)

From Table 2, the density of a rubber material belt was found to be 1140kg/m^3

For a V-belt drive, the tension ratio is given by the Eq. (16) as:

$$\frac{T_1 - T_c}{T_2 - T_c} = e^{\mu\theta cosec\alpha\ /2} \ [1] \quad (16)$$

Where,

μ = Coefficient of friction between belt and pulley, θ = Angle of wrap (radian)

α = Groove angle = 34º

From Table 3, the coefficient of friction between belt (rubber) and pulley (dry cast iron) was taken as 0.30. By considering the small pulley, which is the driver, the angle of wrap, θ, was calculated using Eq. (17) according to [1]:

$$\theta = \left\{180 - 2\sin^{-1}\left[\frac{D_1 - D_2}{2x}\right]\right\}\frac{\pi}{180} rad \quad (17)$$

2.3.3 Power Transmitted by Belt

Power is defined as unit of energy per unit time. Power transmission is the movement of energy from its place of generation to a location where it is applied to perform useful work. The power transmitted to the shaft that causes the shaft to rotate is calculated using equation 18 below;

$$P_b = (T_1 - T_2)V \quad (18)$$

Where,

P_b is the power transmitted by the belt, T_1 is the tension in the slack side of the belt, T_2 is the tension in the tight side of the belt and V is the velocity of the belt.

Table 3: Coefficient of friction between belt and pulley [13]

Pulley material **Cast iron, steel**					
Belt materials	Dry	Wet	Greasy	Wood	Leather face
Leather oak tanned	0.25	0.2	0.15	0.3	0.38
Leather chrome tanned	0.35	0.32	0.22	0.4	0.48
Canvass-stitched	0.20	0.15	0.12	0.23	0.40
Rubber	0.30	0.18	-	0.32	0.40
Balata	0.32	0.20	-	0.32	0.40

2.3.4 Number of Belts Required

To transmit the require power from the electric motor, the right number of belts must be used. The number of belts required to transmit 55kw power from electric motor was calculated using Eq. (19) as:

$$n = \frac{Motor\ Power}{Power\ per\ belt} \text{ [12]} \quad (19)$$

2.4 Selection of Bearing

Bearings are highly engineered, precision-made components that enable machinery to move at extremely high speeds and carry remarkable loads with ease and efficiency. There are different types of bearings that serve different purposes. The ball roller bearing was prefer over the cylindrical and needle roller bearing, tapered roller bearing, and spherical roller bearing because of its high speed, low friction, light to medium loading and light[14]. Ball roller bearing of standard designation P216 was selected for the PKS 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 P216 signifies medium series bearing with bore (inside diameter) of 90 mm [12].

2.5 Principles of Operation of Machine

Size reduction and pneumatic conveying principles were considered during the design and fabrication of the PKS grinding machine. These principles were employed in designing the grinding and the conveying action.

2.5.1 Principle of Size Reduction

The PKS grinding machine applies the principle of shear and impact in the reduction of size of the dried palm kernel shell. The energy required to produce the small change (dx) in the size of the dried palm kernel shell was obtained by using eq. (20) [5, 15]:

$$\frac{dE}{dx} = \frac{K}{X^n} \quad (20)$$

Where,

K = a constant, n = an exponent, dE is the change in energy and dx is the change in size of PKS

For fine grinding, Rittinger's law (n = 2) was applied on eq. (20) to yield eq. (21), [15]:

$$\frac{dE}{dx} = \frac{-K_1}{X_2} \quad (21)$$

By substituting variables and integrating Eq. (21) between x_2 and x_1, the energy equation was developed as shown by Eq. (22):

$$E = K_1\left[\frac{1}{X_2} - \frac{1}{X_1}\right] \quad (22)$$

Where,

X_1= Average initial size of the material, X_2= Average final size of the product

E= Energy per unit mass, k_1= Rittinger's constant

2.5.2 Principle of Pneumatic Conveying

Pneumatic conveyors are mostly suited for small seeds and products in powdery form, such as rice and flour [15]. Due to light weight of the PKS powder, pneumatic system consisting of a fan which increases the speed of the air transport was incorporated to the machine's rotor. The fan at the end of the grinding chamber sucks in the air at a velocity higher than the terminal velocity of the product. The high speed air makes the product to flow in the air stream through a pipe into the silo. The design of the pneumatic conveyor was based on the aerodynamic properties of the material-velocity, determined by blowing the material with domestic fan and determining the distance moved per unit time. The moving air has to overcome some resistance before it will be able to lift the material. This resistance was obtained by Eq. (23) according to [16]:

$$f_D = \frac{1}{2C_D A_P \rho_f V2} \quad (23)$$

Where,
f_D = Resistance (drag force) (N), C_D = Overall drag coefficient
A_p = Projected area normal to the motion direction (m^2), ρ_f = Density of air (kg/m^3)
V = Relative velocity of the PKS powder (m/s).
The PKS powder is moved by the air as soon as the relative velocity becomes equal to the terminal velocity of the PKS powder. The terminal velocity was obtained by eq. (24), [16]:

$$V_T = \sqrt{\left[\frac{2W(\rho_P - \rho_f)}{(C_D A_P \rho_P \rho_f)}\right]} \quad (24)$$

Where,
ρ_p = Density of PKS powder (kg/m3), D_p = Air density (kg/m3)
V_T = Terminal velocity (m/s), W = Weight of particle (N)
A_p = Average projected area (m3)

2.6 Theoretical Throughput Capacity and Power Requirement

Throughput is the movement of inputs and outputs through a production process. This is the measured processing speed of a machine expressed as total output in a unit period (usually an hour) under normal operating conditions. It includes operator caused delays and therefore, differs from the machine vendor's rated speed, which is often the machine's best output capability under optimum operating conditions. It is the rate at which a system achieves its goals [17].

2.6.1 Throughput Capacity:

The throughput capacity is the quantity of material moved or produced per unit time. It can be volumetric or gravimetric. The volumetric throughput capacity was obtained by Eq. (25) as stated by [12]:

$$Q = VA\Phi \quad (25)$$

Where,
V = Velocity of air (m/s), A = Area available for flow of material (m^2)
Φ = Coefficient of filling.

2.6.2 Determination of Area of Flow

The area of flow of the material is the area within the grinding chamber. The aerodynamics of the Area of Flow is given by the equation below,

$$A = \frac{\pi}{4}\left[\left(D^2 - d_1^2\right) + \left(D^2 - d_2^2\right)\right] - n(Lt) \quad (26)$$

Where,
D = Diameter of grinding chamber, d_1 = Diameter of disk, d_2 = Diameter of shaft
n = Number of hammers, L = Length of hammer, t = Thickness of hammer

2.6.3 Determination of Velocity of Air

Velocity of air was obtained by Eq. (27), [12]:

$$V = \frac{\pi DNK}{60} \quad (27)$$

Where,
N = Rotational speed of rotor (rpm), D = Diameter of fan (in), K = Number of fan blade
The gravimetric throughput capacity was obtained by Eq. (28), [12]:

$$Q_g = Q\rho_f \quad (28)$$

Where,
ρ_f = Density of air = 1.239 kg/m^3

2.6.4 Power Requirement

The power requirement is the amount of power required to power the palm kernel shell grinding machine for effective grinding result. The power requirement of the PKS machine was obtained by Eq. (29), [12]:

$$P = Q_g H f \qquad (29)$$

Where,

Qρ = gravimetric throughput capacity, H = Height of lift, f = Power factor

1.7 Efficiency Test of the Palm Kernel Shells Grinding Machine

After the successful fabrication and test running of the PKS grinding machine, efficiency test was carried put on the Palm Kernel shell to determine the throughput capacity and every other specification. 500Kg of dried PKS was grinded for 30 min. The ground PKS powder was collected in an air tight sack. A representative sample of 200g of the PKS powder was collected. The collected sample was poured into a set of sieves (425µm, 300µm, 200µm, 125µm, 100µm and 75µm) and was vibrated with a mechanical sieve shaker for 45 min at the soil laboratory of the Nigerian Building and Road Research Institute, National Laboratory Complex, Ota. The quantity of PKS powder that passes through each sieve was weighed using a semi-automatic weighing balance. The test was repeated for three (3) different operations using the same mass of PKS powder and operating the machine at the same speed and power. The result is tabulated in Table 4.

III. RESULTS AND DISCUSSION

The result of the efficiency test is as shown in Table 4. The Grinding Efficiency of the PKS grinding machine is given by eq. (30):

$$G_E = \frac{chang\,e\ in\ diemeter}{original\ \ diameter} \times 100 \qquad (30)$$

Table 4: Average Grinding Efficiency

Test Number	Grinding Efficiency, G_E (%)
1	**97.7**
2	**97.9**
3	**97.5**

The grinding efficiency was calculated for three tests and the average grinding efficiency was obtained as shown below

$$Grinding\ Efficiency = \left(\frac{G_E1+G_E2+G_E3}{3}\right) \qquad (31)$$

Thus, for the three test samples

$$Average\ Grinding\ Efficiency = \left(\frac{97.7 + 97.9 + 97.5}{3}\right) = 97.7\%$$

3.2 DISCUSSION

The design by fabrication of the Palm Kernel Shells grinding machine was based on the principle of size reduction and pneumatic conveying principle. The fabricated Palm Kernel Shells grinding machine has a grinding efficiency of 97.7% (reduction capacity) with good aerodynamic pneumatically principles that help in proper circulation of the products (PKS powder) which keeps the PKS powder intact in the silo. The fineness modulus test carried out on the PKS powder produced by the locally fabricated Palm Kernel Shell grinding machine was obtained as 0.39. A fineness modulus of 2.10 and below signifies fine powder [18]. The fabricated PKS machine is powered by a 55kw electric motor with a rotor speed of 1080rpm; the machine is dust free and self-cleaning.

IV. CONCLUSION

The Palm Kernel Shell grinding machine was designed, fabricated, tested and found to have an average grinding efficiency of 97.7%. Also, the fineness modulus of the powder produced was found to be 0.39. Thus, the PKS grinding machine when operated within the designed parameters will produce powder of fineness 0.39, which is better than that of the existing mill (hammer mill) at the institute. The materials for the fabrication were sourced locally to harness the vast deposit of palm kernel shells raw materials in the country and promote indigenous application of technological development of machine for use in their various operations.

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