RELATIONSHIP AMONG POROSITY, ANGLE OF REPOSE AND BULK DENSITY OF SAWDUST OF SELECTED WOOD SPECIES

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Abstract

This research evaluated the relationship among porosity, Angle of Repose (AoR) and bulk density of soft and hardwoods' sawdust from Illoabuchi Saw mill, Port Harcourt. Angle of repose or the critical angle of repose of a granular material is the steepest angle of descent or dip relative to the horizontal plane where the wood dusts are piled without slumping. Porosity or void fraction is the measure of the void or empty space in a material and is a fraction of the volume of voids over the total volume between zero or as a percentage between zero and hundred. Hardwood species sampled were Triplochiton scleroxylon, Milicia excelsa, Nuclea diderrichii, Khaya grandifoliolaand four softwood were Fiscus elastica, Helia cilliata, Gossweillodendron balsamiferum and Floater. Tangent trigonometric ratio was used to measure the angle of stability of dust after oven drying. The result showed that hardwood sawdust had higher AoR compared with sawdust from softwood saw dust and their AoRs differed significantly ($P<0.05$): Milicia excelsa had the highest AoR (24.60^o) followed by followed by Khaya grandifoliola (23.20^o) and Triplochiton scleroxylon (22.71^o) while the least AoR of 22.40^o was recorded in Nuclea diderrichii while. Helia cilliata recorded the highest AoR of 22.00^o Gossweillodendronbalsamiferum had 19.74^o, Fiscus elastic had (18.40^o) and Floater had the lowest of 7.60^o. The bulk density of the wood dust is a factor that affects the stability of both hard and soft wood species and the research shows that a direct relationship exist between bulk density and angle of repose: the regression coefficient $r^2=0.5018$ and 0.4963 respectively which indicates 50% dependency in both classes of wood. Porosity which is the volume of pore spaces also affects AoR of wood dust: an inverse relationship exists between porosity and AoR. More research on angle of repose and porosity of sawdust should be carried out. This is because literature shows that very little research has been done in this area in wood materials to enhance utilization, durability and stability wood-based products.

Keywords: *Angle of Repose, Porosity, Tangent, Bulk Density*

Introduction

The abundance of granular materials used in several fields along with their broad applications, requires a comprehensive understanding of both macro and micro mechanical behaviour (Richard *et al.,* 2005): angle of repose (structural properties) does affect the behaviour of granular materials (Duran, 2000). According to Liu (2011), angle of repose is defined as the angle that differentiates the transition between phases of granular material. One of the most commonly used definition of angle of repose is that it is the steepest slope of an undefined mater measured from the horizontal plane on which the material is heaped upon (Mehta and Barker, 1994).The angle of repose or the critical angle of repose of a granular material is the steepest angle of descent or dip relative to the horizontal plane to which the material can pile without slumping (Mehta and Barker, 1994).

The angle of repose belongs to a relatively contemporary field of study, and further investigation is needed to broaden the limited information available in this field. The angle of repose has been utilized in many applications including the transportation and storage of goods, Aeolian formations, slope stability, avalanches, barchan dune formation, concrete slump testing, bulk cargo, mass wasting, oceanic trench, retaining walls, sand volcanos, screen, rotary kiln, mountaineering, simulation model calibration, pharmacology, physics, geology, agricultural engineering, mining engineering and geotechnical engineering.

Porosity or void fraction is the measure of the void or empty space in a material and is a fraction of the volume of voids over the total volume between zero or as a percentage between zero and hundred (Hewitt, 1997). Porosity of wood materials is inversely proportional to angle of repose of particulate like micro-waste or wood materials (David-Sarogoro, 2019). Saw dust or wood dust is composed of fine wood particles is a by-product or waste product of wood work operations such as sawing, milling, planning, routing, drilling and sanding. These operations can be performed by wood working machinery, portable power tools (Green, 2005). According to World Health Organization; two wood waste products, dust and chips formed at the working surface during wood working operations such as milling, sawing and sanding which shatter lignified wood cells and breakout whole cell and group of cells, shattering wood cells creates dust while breaking out of whole groups of wood cells creates chips. The more cells shattering occur, the finer the dust particles that are produced. Wood wastes are divided into micro and macro wastes; wood pulverized dust-saw dust (wood dust) often particulate and chips or shavings respectively (David-Sarogoro, 2019).

Wood dust is a form of particulate matter or particulate is a component of particle board. The role of lignin is to bind the wood cells or fibers together thus, enabling dimensional stability. The process of making wood dust or saw dust de-lignified wood thus making it dimensionally unstable, this demands urgent attention if the products are to be used further. The increasing demand for wood product such as furniture cabinet, beams has increase pressure on the forest, accelerating the rate of deforestation. This has necessitated engineered wood product, using wood wastes or composites of which saw dust is part. The use of dimensionally stabled wood cell products, determining the angle of repose of saw dust which in most case is inversely proportional to porosity will help to ascertain the stability of wood. Porosity of surface soil typically decreases as particle size increases which is due to soil aggregate formation in a finer textured surface when subject to soil biological processes (Glasbey, 1991). The stability of wood grains is of utmost importance because variability of species is a major factor militating against wood both within and between species. The angle of repose belongs to a relatively contemporary field of study and further investigation is needed to broaden the limited information available in this field.

This study determined the relationship between porosity, bulk density and stability (angle of repose) of sawdust of some soft and hard species from Iloabuchi Sawmill.

Materials and Methods

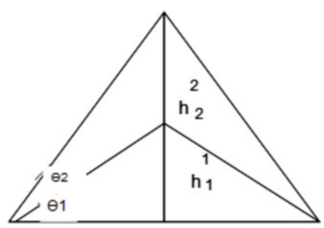
Study Area

This research work was carried out in Iloabuchi sawmill in Obio-Akpor Local Government Areas, Port Harcourt, Rivers State on Longitude 6°44'N and 7°33'N and Lat. 4 °38'E and 5°4'E. it is a cosmopolitan city and has witnessed the influx of professionals of different nationals due to the exploration of crude oil (the liquid Black Gold) and associated industries. All these haveled to a high population and urbanization (Igbudu, 2019).

Determination of Angle of Repose of Species Specific Hard and Soft Wood

Saw dust or wood dust of selected hard and soft wood species was collected from Iloabuchi sawmill and mounted on poly bags for five days at room temperature (37°C) and standard pressure. Initial and final weights of saw dust were done using weighing balance. A meter rule was used to take the initial height of the heaped sawdust (in pyramidal form) of selected wood species in centimeters (cm). Plywood (2cm by 2cm) was used to wedge the dust particles so as to ascertain the degree of sloping. The various samples were oven dried at a temperature of 40°C for the final reading of height weight and angle to be taken. The initial angle was also recorded and the final reading of height weight and angle was subtracted from the initial readings (Igbudu, 2019).

The trigonometric ratio Tangent of angle between the slope edge and base of the heap as opposite divided by adjacent (base) was used as the basis for determining the angle of repose measured using the compass after the final height measurements (Igbudu, 2019).



D1 D2

$$\text{Tan } \Theta = \frac{Opposite}{Adjacent}$$

$$\text{Tan } \Theta_1 = \frac{h_1}{D_1}$$ Equation ……. (i) (Igbudu, 2019).

$$= h_1 \div \frac{D_1}{2} = h_1 \times \frac{2}{D_1} = \frac{2h_1}{D_1}$$

$$\text{Tan } \Theta_2 = \frac{h_2}{\frac{D_2}{2}} = h_2 \div \frac{D_2}{2} = h_2 \times \frac{2}{D_2}$$

$$\frac{2h_2}{D_2}$$

$$\text{Angle of Repose} = D_2 - D_1 \left\{ h \times {}^{2}\!/_{d2} \right\} \text{ (Igbudu, 2019).}$$

$$\text{Angle of Repose} \quad \frac{2h_2}{D_2} - \frac{2h_1}{D_1}$$

Determining Porosity or Void Ratio of Species Specific Hard and Soft Wood

To determine the porosity of saw dust of selected wood species, the volume of the pore spaces which is the space occupied by water and air was obtained by taking the reading of the total volume of saw dust before air drying and after oven drying; final volume of the particles was recorded. The initial volume minus final volume equals the volume of the pore spaces. To determine the total porosity of wood dust, the volume of the pore spaces will be divided by the bulk volume or total volume. The bulk volume is the volume of the pore spaces plus volume of solid while volume of the pore spaces is in volume of air plus volume of water.

$$\text{Porosity} = \frac{Vp(Va+Vw)}{Vb(Vp+Vs)}$$

Where: Vp = volume of pore spaces; Vb = bulk volume; Vs = volume of solid; Va = volume of air; Vw = volume of water

Bulk Density

This was determined by measuring the weight of the saw dust with weighing balance and dividing by the bulk volume from porosity measurement.

$$\text{Bulk Density} = \frac{Weight(g)}{Volume(cm3)}$$

Experimental Design and Statistical Analysis

The experiment was laid out in a Completely Randomized Design (CRD) with eight (8) treatments, replicated thrice. Data analyzed by one-way Analysis of Variance (ANOVA) using SPSS software as described by Steel and Torrie (1980). Duncan Multiple Range Test of probability of 5% (DMRT).

Results

The angle of repose (AoR) of the four sampled hard wood species differ significantly (P<0.05): *Milicia excelsa* had the highest AoR (24.60°) followed by followed by *Khaya grandifoliola* with 23.20° and *Triplochiton scleroxylon* with 22.71° while the least AoR of 22.40°was recorded in *Nuclea diderrichii* (Table 1).

Table 1: Hard Wood Species (Angle of Repose)

Species	Initial Height cm	Final Height cm	Initial Diameter cm	Final Diameter cm	Initial Angle (Δ1)	Final Angle (Δ2)	Instability Δ1 - Δ2
Trplochiton scleroxylon (obeche or African white wood)	185.00	166.00	15.00	15.00	24.67°	22.71°	1.96°
Milicia excelsa	185.00	153.00	15.00	15.00	24.67°	24.60°	0.07°
Nuclea diderrichii (opepe)	185.00	168.00	15.00	15.00	24.67°	22.40°	2.27°
Khaya grandifoliola (Benin mahogany)	185.00	174.00	15.00	15.00	24.67°	23.20°	1.47°

Separation of Means of Hardwood Species

Species	Hardwood
Milicia excelsa (iroko)	24.60[a]
Triplochiton scleroxylon (obeche or African white wood)	22.71[b]
Nuclea diderrichii (opepe)	22.40[c]
Khaya grandifoliola (Benin mahogany)	23.20[c]

Means with the different letters are significantly different (P≤05) at DMRT

The AoF of the four sampled softwood species vary significantly (P<0.05). *Helia ciliate* had the highest AoF (22.00°), followed by *Gossweilerodendron balsamiferum* with 19.74° and *Ficus elastica* with 18.40°, the lowest AoR was recorded in Floater (Table 2). Similarly, as was observed in the hard woods, *Helia ciliate* was the most stable saw dust with the lowest instability index (II) of 2.67° and Floater, the most unstable with 7.07°.

Table 2: Softwood Species (Angle of Repose)

Species	Initial Height cm	Final Height cm	Initial Angle (Δ1)	Final Angle (Δ2)	Instability Δ1 - Δ2
Fiscus elastica(Bush rubber)	185.00	138.00	24.67°	18.40°	6.27°
Heliacilliata (Abura)	185.00	165.23	24.67°	22.00°	2.67°
Gossweillodendron balsamiferum (Agba)	185.00	148.03	24.67°	19.74°	5.20°
Floater	185.00	132.60	24.67°	17.60°	7.07°

Separation of Means of Softwood Species

Species	Softwood
Fiscus elastica(Bush rubber)	22.00[a]
Heliacilliata (Abura)	19.74[b]
Gossweillodendronbalsamiferum (Agba)	18.40[c]
Floater	17.60[c]

Means with the different letters are significantly different (P<05) at DMRT

The four hard wood species have a greater angle of repose than the four soft wood species(Figure 1). It was also observed that variations occurred between the sampled hard wood species but greater variations occurred between the sampled soft wood species.

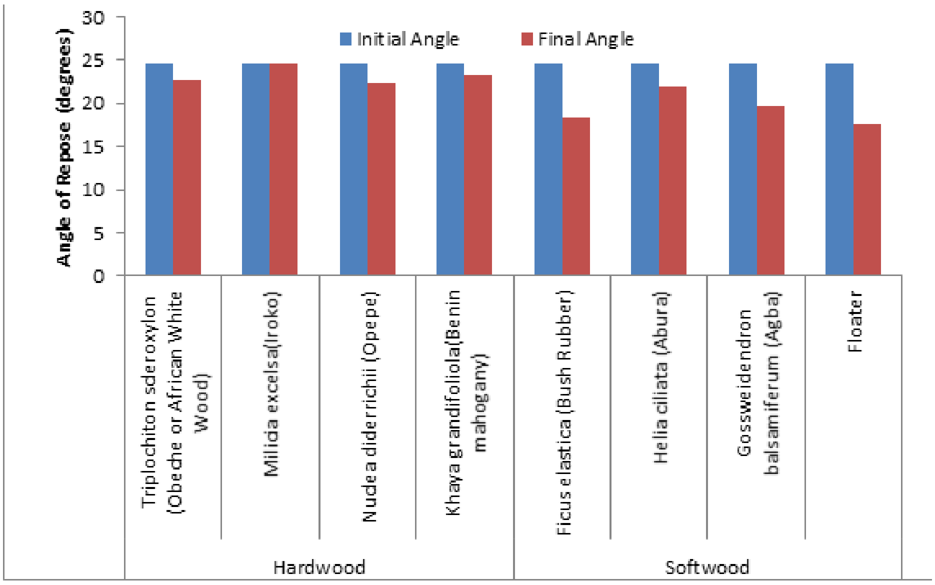


Figure 1: Angle of Repose of Hard and Softwood Species

There was an inverse relationship existing between porosity and angle of repose. Floater with the least AoRhad the largest pore spaces (0.41%) followed by *Ficus elastica* with 0.32%, Helia sp. with 0.39% *and Gossweilerodendronbalsamiferum* had the least porosity of 0.29% amongst softwoods while *Miliciaexcelsa*had highest porosity of 0.24% followed by*Nucleadiderrichii*with 0.21%, *Khaya grandifoliola* with 0.17% and the lowest 0.15% in *Triplochiton scleroxylon* dust (Figure 2).

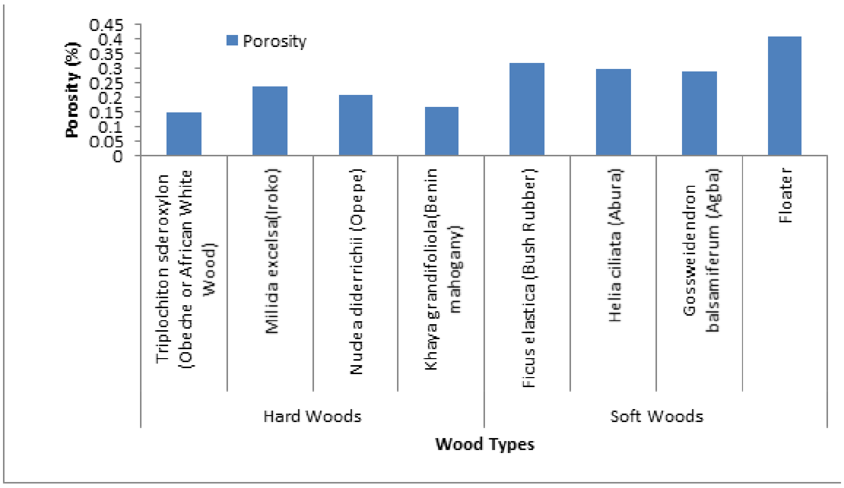


Figure 2: Porosity of Hard and Soft Wood Species

It was established that a regression of bulk density on angle of repose of hardwood and softwood species is dependent on bulk density (Fig 3). A direct relationship exists between bulk density and angle of the repose of both soft and hard wood species(r^2=0.5018 and 0.4963).

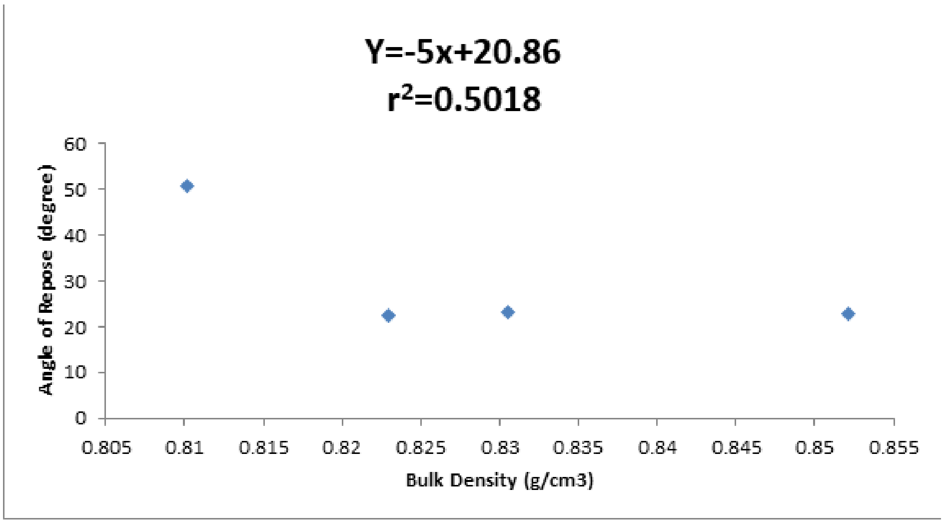


Figure: 3: Regression of Bulk Density on AoR of Hardwood Sawdust

Discussion

The angle of repose (AoR) of the four sampled hard wood species differs significantly (P<0.05): *Miliciaexcelsa* had the highest AoR (24.60°) followed by followed by *Khaya grandifoliola* with 23.20° and *Triplochiton scleroxylon* with 22.71° while the least AoR of 22.40° was recorded in *Nuclea diderrichii* (Table 1). This implies that the higher the AoR, higher the stability of wood dust of these sampled hard woods; *Milicia excelsa* was the most stable and *Nuclea diderrichii* the most unstable. This agrees with Igbudu (2019) observed angle of repose or the critical angle of repose of *Milicia excelsa* was the most stable and *Nuclea diderrichii* the most unstable.

The AoF of the four sampled softwood species vary significantly (P<0.05). *Helia ciliate* had the highest AoF (22.00o) followed by *Gossweilerodendron balsamiferum* with 19.74o and *Ficus elsatica* with 18.40°, the lowest AoR was recorded in Floater. It was observed in hard woods above, *Helia ciliate* was the most stable saw dust with the lowest instability index (II) of 2.67° and Floater, the most unstable with 7.07° (Igbudu, 2019).

It was also observed that variations occurred between the sampled hard wood species but greater variations occurred between the sampled soft wood species. There is proof that variability is a characteristic feature of tree crops between species, the different wood species will also behave differently because of the variation in angle of repose. This implies that the dimensional stability of the different wood species differs greatly: hardwood tree species are more stable dimensionally than softwood species which might be due to the larger and more stable particulates of hard wood compared to soft wood grains-dust. This agrees with Stahl and Konietzky (2011) observed that the angle of repose decreases slightly when the amount of granular material or number of particles increased. This result was also verified by physical experiments, and similar findings have also been reported by Coetzee (2016).

It is observed that an inverse relationship exists between porosity and angle of repose, this means that the higher the pore spaces, the lower the angle of reposes and higher the angle of repose the smaller pore spaces vice versa. This agrees with Botz*et al.* (2003) that the angle of repose decreases when the spherical sand in antlions pits particle diameter increases: the angle of repose decrease when the particle size of the sand increased. It was also observed the four hard wood species sampled had higher angle of repose compared to the four soft wood species sampled. This shows that hard wood species are denser and less porous compared to soft wood species. Dimensional instability is a characteristic feature of wood and it product is indeed a disadvantage.

Moreover, considering the particle size distribution, as the mean particle size increases using interferometer and a Sympatec Qic Pic laser scanner, the average roughness was found to be 0.38 $\pm$ 0.19µm. Similar work was conducted by Yang *et al.,* (2009) using the power spectrum method. Miural *et al.* (1997) noticed that when the roughness of the base, which the sand was piled on, increased, the angle of repose also increased; consequently, forming a heap on a frictionless base in nearly impossible. Similarly, Zaalouk and Zabady (2009) proved that for different types of wheat, the angle of repose increases with the roughness of the base. Liu (2011) provided similar results for sand. Additionally, Altuhafi *et al.* (2016) noticed that the normalized elastic shear modulus increased with the surface roughness of natural sand and correlated the shape descriptors with the stiffness and critical state parameters of the soil. The various factors affecting angle of repose as seen in literature was observed in both hard and soft wood. This implies that angle of repose of sawdust can be determined thus the application of angle of repose is not limited to engineering.

A direct relationship exists between bulk density and angle of the repose of both soft and hard wood species. Though, the regression coefficient (r^2=0.5018 and 0.4963) of this relationship indicates 50% dependency in both classes of wood. This means that the bulk density of the wood species played major role in determining angle of repose: an increase in bulk density leads to a corresponding increase in the angle repose and a decrease in bulk density results in a corresponding decrease on angle repose. This implies that a direct relationship exists between bulk density and angle of the repose of both soft and hard wood species. Though, the regression coefficient (r^2=0.5018 and 0.4963) of this relationship indicates 50% dependency in both classes of wood. In addition, the heterogeneity and stratification of a mixture have been found, unsurprisingly, to affect the angle of repose in sand. Chik, *et al.* (2016) reported that the angle of repose for a mixture with predominantly coarse sand is greater than that for a mixture with predominantly fine sand. On a smooth base, the angle of repose is minimized for both coarse and fine-grained sands, and the failure mode takes the form of lateral spreading.

Conclusion

This study has established that angle of repose is inversely proportional to porosity of saw dust: the higher the angle the higher the wood density and the smaller the pore spaces hence porosity. Though, variation exists among different wood saw dust so their angle of repose thus stability of based on the purpose of use (end use) particularly in engineered wood product where stability and durability are very important. The four hard wood species and four soft wood species sampled and the difference in angle of repose and porosity shows variations exist between and within wood species. This research work also proves that angle of repose of sawdust is not only a function of moisture content alone. Other factors such as particle size and roughness affects angle of repose of sawdust.

Application of angle of repose is not limited to engineering. Sawdust which in most case is regarded as waste but is be useful in the manufacturing of wood based products. This will help reduce the pressure on the forest due to rising population because more dimensionally stable Engineered wood-based panel products can be made thereby conserving the forest and help save wild life species.The research work also shows that hard wood species are generally more stable than softwood species; in addition, *Helia ciliata* which is seen or classified under softwood is also stable compared to other soft wood species sampled. So wood dust from *Helia ciliata* is recommended for use in the production of wood based panel products that are engineered. More research on angle of repose and porosity of saw dust should be carried out. This is because literature shows that very little research has been done in this area in wood materials to enhance utilization, durability and stability wood-based products.

References

Altuhafi, F. N., Coop, M. R. & Georgiannoil, V. N. (2016). Effect of particle shape on mechanical behaviour of natural sands. *Geotech. Gevenviron. Eng*. P. 142.

Bok, J. T., Loudon, C., Barger, J. B., Olafen, J. S., Steeples, D. W., Artlons, J. & Kansas, E. (2003). Effects of slope and particle size on ant common implications for chore of substrate by Soc. 76 426 - 435.

Chik, Z., Vallejo, L. E., CAN. Geotech. J. 42 (2016). Characterization of angle of repose of binary graming material, 683 – 692, https://doi.org/10.1139/104-118.

Coetzee, C. J. (2016). Calibration of the discrete element method and the effect of particle shop, powder technology, 50 - 70.

David, N. (2013).Physico-Chemical Properties as Indices to Enhance Utililization of Two Trees Lesser-Used-Species in Rivers State, Nigeria. Unpublished PhD Thesis in the Department of Forestry and Environment, University of Science and Technology, Nkpolu Port Harcourt. Pp 154.

David-Sarogoro, N. (2019). Appraisal of Starch-bonded briquettes utilization among user-respondents in Port Harcourt, Rivers State, Nigeria. *Asian Journal of Environment & Ecology*. 11(3): 1-8; Article no. AJEE.52677. ISSN: 2456-690x. www.sciencedomainjournal.org

Duran, J. (2000). Sand, powders and grains: An introduction to the physics of granular materials, Springer, New York: New York NY.

Glasbey, C. A., Horgan, G. W. & Darbyshine, J. F. (1991). "Image analysis of three-dimensional modally of pores in soil aggregates". *Journal of Soil Science,* 42(3): 497-86.

Green David (2005). "Why did bars used to put sawdust on the floor? Why don't they anymore?"

Hewitt, G. F., Shires, G. L. & Pole Zheav, Y. V. (editors) (1997). "International Encyclopedia of that and mass transfer", CRC Press.

Igbudu, R.S. (2019). Porosity and Angle Of Repose Of Saw Dust Of Wood Species From Illoabuchi Saw Mill Port Harcourt. Unpublished undergraduate project in the Department of Forestry and Environment, Rivers State University, Nkpolu Port Harcourt. Pp 71.

Liu, Z. (2011). Measuring the angle of repose of granular systems, using Hollowcylinders, M. Sc. Thesis University of Pittsburgh.

Lumay, F., Boschini, K., Traina, S., Bontempi, J. C., Remy, R. & Cloots, N. (2012). Vandawalls, measuring the flowing properties of powders and grains powder Technol, 244, 19 - 27.

Mehta, A., Barker, G. C (1994). The dynamics of sand, report, prog, Phys. 57. 383 - 416.

Miura, K. Maeda, S. &Toki, G. (1997). Method of measurement for the angle of response of and soil found, 37: 89 - 96.

Richard, P., Niwdemi, M., Delannay, R., Rbiene, P., Bideau, D. (2005). Slow relaxation and compaction of granular System, Nat, Mater, 4, 12 1-128.

Yang, F., Shi, B., Gllo, Y. (2009). Study on dynamic angle of repose of non-uniform sediment Hydrodynamics. https:// doi.org /10/ 016/ S.00/ 6058 (08) 60200-0.

Zaalouk, A. K., Zabady, F. I. (2009). Effect of moisture content on angle of repose and friction coefficient of grain. Misr. *Journal of .Agricultural Engineering*. 26418-427, http://www.mjac.eg.net/pdf/2009/Jan/22.pdf.