Available online www.ejaet.com

European Journal of Advances in Engineering and Technology, 2019, 6(6):21-29

Research Article ISSN: 2394 - 658X

# Effect of Varying Pressure on the Physical Properties of Different Sawdust Briquettes

**Nneka Juliana Ogbuagu**

*Department of Agricultural and Bioresource Engineering, Enugu State University of Science and Technology, Enugu State Nigeria*
*njogbuagu@yahoo.com, +2348067699760*

**ABSTRACT**
*This research work presents the effect of varying pressure on the physical properties of different sawdust briquettes. It is no longer news that biomass and other industrial wastes are on the in-crease and causing a lot of problems especially its effect on our environment. In developing countries like Nigeria, there are no adequate measures of disposing these wastes, hence, converting them to other useful products such as briquettes for domestic fuel becomes desirable. In this study, sawdust briquettes were produced using various sawdust species (Stool wood, Gmelina, Mahogany and Oil bean) of different grain sizes (160µm, 315µm, 425µm, 630µm and 1250µm) and a binder (starch) in percentage compositions of 89:11 respectively under varying pressures (18bar, 20bar and 22bar). The physical properties of the briquettes such as height, diameter and mass which was used to compute the volume and the bulk density were determined using scientific equipment. The results showed that the mean bulk densities of the briquettes produced are increasing for the different sawdust samples as the pressure increases. It was also noticed that as the pressure increases from 18bar to 22bar, the height of the briquettes for each of the grain sizes decreases. This is applicable to the various sawdust samples considered. The effective utilization of these agricultural by-products as high grade solid fuel can reduce environmental pollution resulting from the wastes. This work is also relevant to briquetting industries and briquetting press designers as this helps them in their design optimization.*

**Key words:** Briquettes, Sawdust, Briquette, Pressure, Physical Properties

## INTRODUCTION

Biomass energy refers to energy generated from the use of materials derived from living organisms or recently living organisms of plant and animal origin [1]. It is known to be the third largest energy resources in the world after coal and oil [2]. It would have been the largest but as the result of oil boom in the nineteenth century made nations to divert to fossil fuel as their major source of energy. Though the use of fossil fuel has dominated since the last fifty years, biomass still provides about 14% of the world's annual energy consumption [3-5].

Biomass wastes are remains or waste of renewable, biological material that can be used directly as a fuel, or converted to another form of fuel or energy product. The major and most prominent of these wastes are wood wastes, rice husk, agricultural straws, grasses, groundnut shells etc. Sawdust can be regarded among the most abundant waste in the agricultural industries in Nigeria. The waste generated from processing of wooden products is estimated to be 15% of the total 1.72 million/$m^3$ wood processed [6]. Sawdust also referred to as wood dust is waste obtained from cutting, sanding, grinding, drilling and pulverizing of wood with the aid of a saw or other tools and machineries. It is a collection of small particles of wood in different sizes and mass. Sawdust is a flammable material when ignited which makes it useable as a source of fuel [7]. In Nigeria, 9-150 million tons (MT) of these crop residues are produced annually [8, 9]. From these large quantities of agricultural residues produced in Nigeria, there is immense potential for their use for energy production. Biomass wastes if well managed, offer many advantages, the most important being that they are renewable and sustainable energy resource. They can significantly reduce net carbon emission when compared to fossil fuel. Briquetting which is also known as densification is another way of converting the biomass wastes into useful fuel for local and industrial use.

Biomass densification or compaction technologies are among the promising ways of overcoming the limitation of low bulk density in biomass wastes. Making briquettes or pellets by means of some form of mechanical pressure, reduces the volume of biomass wastes and converts them to a solid form which is easier to handle and store than the original material. Briquette production increases bulk density of the biomass wastes to about tenfold of its original bulk density. Briquettes can be used as alternative to wood fuel as the demand for wood fuel especially in the developing countries continue to rise as a result of increasing population. Biomass densification can be performed using hydraulic press, pellet mills, extrusion processes or roller presses.
This paper presents the production of briquettes from different sawdust as well as investigating the effect of varying pressures on the physical properties of the briquettes as this will tend to give insight to briquetting industries in producing efficient briquettes that will compete favorably with fossil fuel and coal as source of fuel for household and industrial purposes.

## PROBLEM STATEMENT

The management of biomass wastes is one area of energy generation that have received very little attention. Most developing countries consider residues produced during agricultural production as "waste" and so burn them on farmlands or dispose them inappropriately. In Nigeria, various wood mill had no other means of disposing huge amount of sawdust than setting them ablaze or heaped and left to decompose. Giving the fact that briquettes are made in a bid to reduce waste generation and enhance the environment from decomposing heaps of waste.

## AIM AND OBJECTIVES OF THE STUDY

The aim of this study is to investigate the potential of briquette made from different sawdust. While the specific objectives are to determine the physical properties and the effect of varying pressures on the properties of these sawdust briquette.

## LITERATURE REVIEW

Many researchers have worked on the densification of sawdust briquettes, [10] worked on physical and combustion properties of briquettes produced from sawdust of three hardwood species and different organic binders. The purpose of his study was to assess the calorific value of briquettes produced from mixed sawdust of three tropical hardwood species (Afzelia Africana, Terminalia superba, Melicia elcelsa) bonded with different binding agents (starch, cow dung and wood ash). In another similar work, [11] studied behaviour of beech sawdust during densification into a solid biofuel. It was observed that the impact of technological variables (compression pressure and compression temperature) and Material variables (particle size and moisture content) affects significantly the quality indicators especially the mechanical indicators of quality (briquette density, mechanical durability, etc.) during biomass densification. Study on densification of sawdust of tropical hardwoods and maize cobs at room temperature using low compacting pressure without a binder was also carried out [12]. The study determined the optimum conditions for producing briquettes from sawdust of selected timber species and maize cobs at low compacting pressure and room temperature without a binder. The findings of densifying maize cobs and sawdust of six selected tropical hardwood timber species at room temperature (25 $^{o}$C) using low compacting pressure (CP) varied from 10 MPa to 50 MPa, without a binder. Effect of compacting pressure on the mechanical and combustion properties o sawdust briquettes were also studied [13]. The sawdust briquette was produced using styrofoam adhesive as binder. It was found there is great effect of changing the compression pressures on combustion and mechanical properties of the briquettes within the range of pressure studied. In another research [14], a project focused on the development of briquettes from the waste wood (sawdust). This was carried out because there are lot of wastes resulting from timber industries. The produced briquettes showed positive features as obtained from the results of the comparison between the briquette and firewood, and these includes, easy to light, improved cooking time and less consumption of fuel.
In summary, the review shows that global researches today are mostly focused on ways of converting bio-wastes into sustainable sources of fuel for both domestic and industrial use. More especially, there are a lot of wood sawdust generated all over the countries and has constituted environmental hazards. These residues from saw mills can be collected and densified into solid fuels. It is based on these potentials of biomass usage that this work was conceived.

## MATERIAL AND METHODS

This study was carried out using the facilities in the material laboratory of Enugu State University of Science and Technology and that of Scientific Equipment Development Institute, Enugu State both in Nigeria.

### Material

The materials used for this investigation are sawdust gotten from various wood species (i.e. Stool wood, Gmelina arborea, Mahogany and Oil bean. These samples were obtained from two major sources namely; Timber wood market, Enugu and Saw Mill Abakpa - Nike, Enugu respectively. The binder used was cold water starch (Renew). The pictures of the samples and binders are shown in Fig. 1.

**Fig. 1** Sawdust at Timber wood market, Enugu

The equipment used are; 5 different sieve sizes (160µm, 315µm, 425µm, 630µm and 1250µm), beaker, digital weighing balance, hydraulic briquetting press, measuring cylinder, crucible, hammer mill, plastic bowl, flash dryer, mixer.

**Raw Material Preparation**

The sawdust used were sieved to different grain sizes (160µm, 315µm, 425µm, 630µm, 1250µm respectively) of the various wood samples for the experiment. The percentage mixture of the different grain sizes for each sample with the binder was in the ratio of 89:11 in volume. The moisture content (MC) of each sample before briquetting was 15%. Furthermore, we designated the different wood species A, B, C, and D respectively. Finally, the samples were separated under 3 different groups (considering the varying pressures i.e. 18 bar, 20 bar and 22 bar). See Fig. 2.

**Fig. 2** Sample preparation for the four materials

**Briquette Production and Quality Evaluation**

The sawdust was poured into a flash dryer which reduces the moisture content to 7% at 250 – 300 °C for 50 minutes for the samples.

**Group 1 (for 18 bars):** Each sawdust particle size was fed into a bowl and mixed with binder (starch) in percentage compositions of 89:11 respectively. The agitating process was done in a mixer to enhance proper blending prior compaction. A steel cylindrical crucible (die) of dimension 82mm height and 50mm in diameter was used for this project. The die was freely filled with known amount of weight of each sample mixture and positioned in the hydraulic briquetting press machine for compression. The piston was actuated to compress the samples and the pressure was monitored at 18 bar using the pressure gauge. After pressure was applied at a time to the material in the die, the briquette formed was extruded.

Prior the release of applied pressure, each briquette of different particle size was replicated for the various sawdust wood species according to the level of process variables. The briquettes produced were allowed to dry in the sun for two days and then assessed for their physical properties. See fig 3.

**Group 2 (for 20 bars):** Again, each sawdust particle size was fed into a bowl and mixed with binder (starch) in percentage compositions of 89:11 respectively. The same procedure for Group 1 was utilized for Group 2 in making the briquettes save for the pressure being monitored at 20 bar.

**Group 3 (for 22 bars):** Again, each sawdust particle size was fed into a bowl and mixed with binder (starch) in percentage compositions of 89:11 respectively. The same procedure for Group 1 was utilized for Group 3 in making the briquettes save for the pressure being monitored at 22 bar.

**Fig. 3** Sample briquettes produced

**Data Collection**

The length, mass, diameters of the briquettes were determined. These measurements were used to compute the volume and density of each of the samples of briquettes produced for the various groups.

Again, data were also collected on the physical properties of briquettes produced from the sawdust. The methods and formulas used are given below.

Density: The weights of briquettes were determined using digital weighing balance in the laboratory. Then, the volumes of briquettes were determined by a simple calculation based on the direct measurement of length and diameter of the briquettes.

The Formula: D (kg/m$^3$ or g/cm$^3$) = M/V; Where; D = Density, M = Mass, V = Volume.

## RESULTS AND DISCUSSIONS

**Physical Characteristics of the Briquettes**

The briquettes were produced using a hydraulic press briquetting machine, as shown in cross-section in Fig. 4. The outer surface of the briquettes was carbonized and solid with no holes at the center. The briquettes from the both samples of the sawdust assumed a brown coloration. The plots Fig. 5-12 was used to explain the physical properties of the stool wood, Gmelina, Mahagony and Oil bean sawdust respectively at varying pressures. The ANOVA are presented in Table 1-.4 for the materials.

**Fig. 4** Hydraulic briquetting machine

**Stool Wood Sawdust**

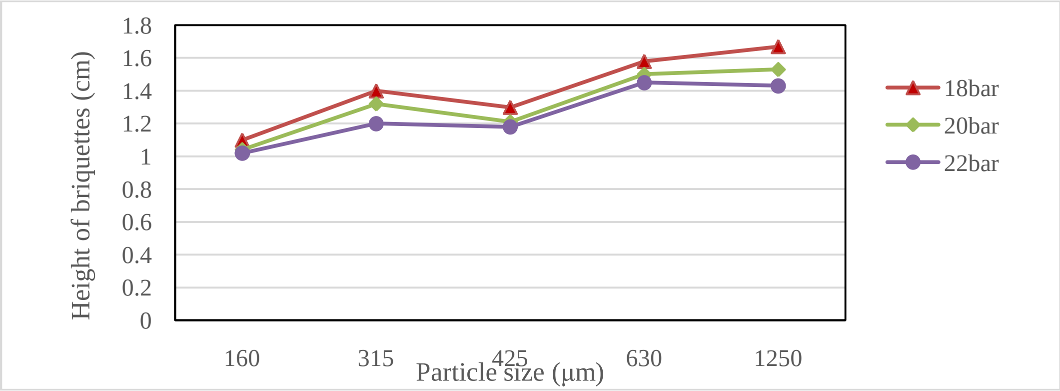


**Fig. 5** Plot of height of briquettes against grain sizes at varying pressures (stool wood)

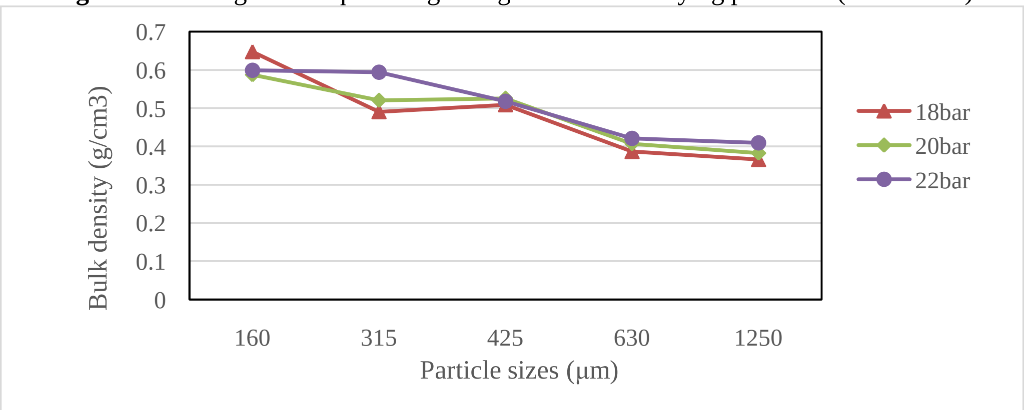


**Fig. 6** Plot of bulk density against grain sizes at varying pressure (Stool wood)

**Table -1 ANOVA for effect of pressure and particle on Stool wood sawdust**

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---|---|---|---|---|---|---|
| Pressure | 0.002281 | 2 | 0.00114 | 1.279573 | 0.329492 | 4.45897 |
| Particle size | 0.106786 | 4 | 0.026696 | 29.955 | 7.29E-05 | 3.837853 |
| Error | 0.00713 | 8 | 0.000891 | | | |
| Total | 0.116196 | 14 | | | | |

Stool wood sawdust is recognized as soft wood and is affected by pressure because of its high compressibility, porosity and lower mechanical properties. Remarkably, [15] categorically stated that hardness of wood is a function of the heaviness or density of the wood and the amount of wood material compared to air spaces it contain. It can be observed from Fig.5 that for the three pressures analyzed, height of briquettes reduces with reduction in particle size and briquette of lower height was obtained at 22bar. Similarly, bulk density of Stool wood sawdust briquettes increased from 0.409 to 600 g/cm$^3$ with reduction in particle size from 1250 to 160µm at 22bar, (Fig. 6). This is because of the compressibility of the Stool wood sawdust briquette when subjected to high pressure. Relating to wood properties, [16] described every wood species as having effect to its drying and other related properties. Thus, less dense wood has the tendency to be greatly affected by higher force when compared to higher dense materials. This can be attributed to the inter particle spaces and walls collapse due to the high porosity of the particulates thereby increasing the bulkiness of the loose materials. Observing the trend of bulk density as particle size is reduced from 1250 to 630µm and 425 to 315µm, the percentage increase is very low (< 11%) as when compared to colossal increase of 46% (22 bar), 54% (20bar), and 77% (18 bar) from 1250µm to 160µm. Peak increment was attained each after two sieve mesh. It is an indication that gradual decrease in particle size may not produce drastic increase in bulk density at a given pressure. However, Table 4.1 shows high significant difference of particle size on bulk density of the stool wood briquette (F-test of 29.955 > F-crit. of 3.83) but no significant difference of pressure on bulk density (F-test of 1.27<F-crit. of 4.45). Absence of significant difference of pressure on bulk density of the briquette can be attributed to fewer treatment levels of pressure during briquette production and it signifies that Stool wood material attains more density at slightest pressure application. Their resistance to force is low and because of this, their intermolecular walls are easily broken and collapses easily. Very high significance difference of particle size on bulk density at probability level, <0.01% (7.29 x10$^5$) is an indication that fine particles are more densed than coarse materials. Thus particle size is an important factor in examining the performance of densification process.

**Gmelina Wood Sawdust**

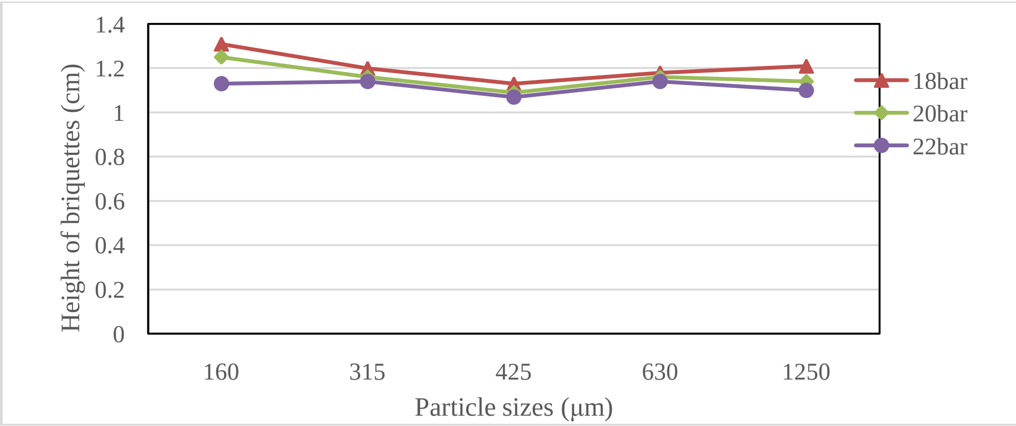


**Fig. 7** Plot of height of briquettes against grain sizes at varying pressures (Gmelina)

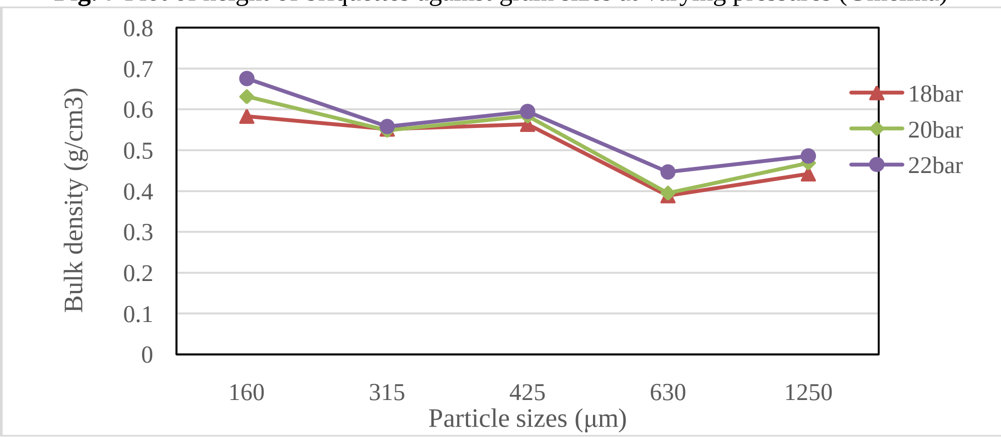


**Fig. 8** Plot of bulk density against grain sizes at varying pressures (Gmelina)

**Table -2 ANOVA for effect of pressure and particle on Gmelina**

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---|---|---|---|---|---|---|
| **Pressure** | 0.005498 | 2 | 0.002749 | 9.122876 | 0.008632 | 4.45897 |
| **Particle size** | 0.094903 | 4 | 0.023726 | 78.74351 | 1.84E-06 | 3.837853 |
| **Error** | 0.00241 | 8 | 0.000301 | | | |
| **Total** | 0.102811 | 14 | | | | |

For Gmelina sawdust, briquette's height was higher at 160µm (1.3cm) and reduces (1.2cm) as the particle size increases (Fig. 7). However, its bulk density (Fig. 8) maintained the same trend as Stool wood sawdust thus every analysis attributed to stool wood are applicable to Gmelina. It was also noticed that bulk density at the three pressures was highest (0.68g/cm$^3$) at 160µm followed by 425µm (0.56 g/cm$^3$) as indicated in Fig. 4.30. This is as a result of mild hardness of Gmelina (4270N) when compared Stool wood sawdust (1820 N) [17,18].From ANOVA in Table 4.2, within the pressure levels analyzed, there was significant difference (F-test of 9.12 > F-crit. of 4.45) on the bulk density of Gmelina sawdust at probability level <1% and also very high significant difference (F-test of 78.74 > F-crit. of 3.83) of particle sizes at probability level <0.001% on the bulk density of Gmelina sawdust briquettes. This however inform us that difference in wood properties has effect on compression process.

**Mahogany Wood Sawdust**

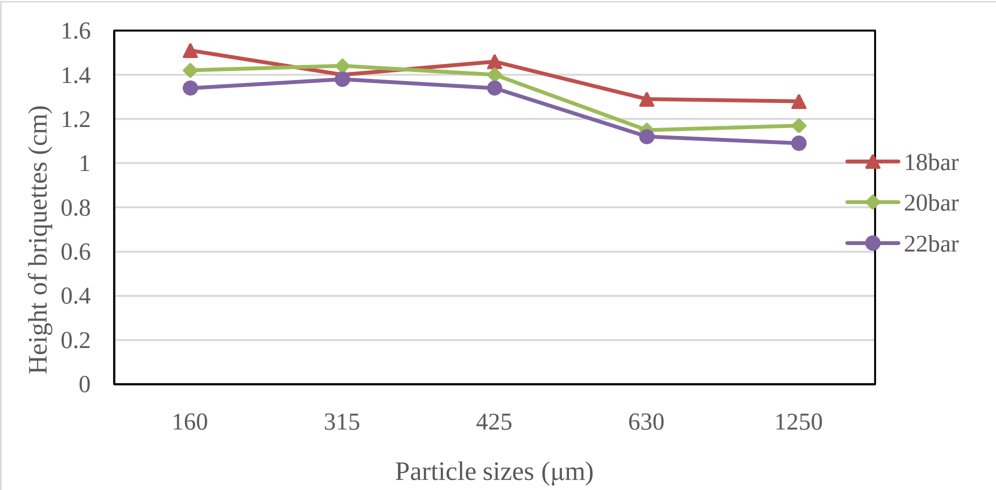


**Fig. 9** Plot of height of briquettes against grain sizes at varying pressures (Mahogany)

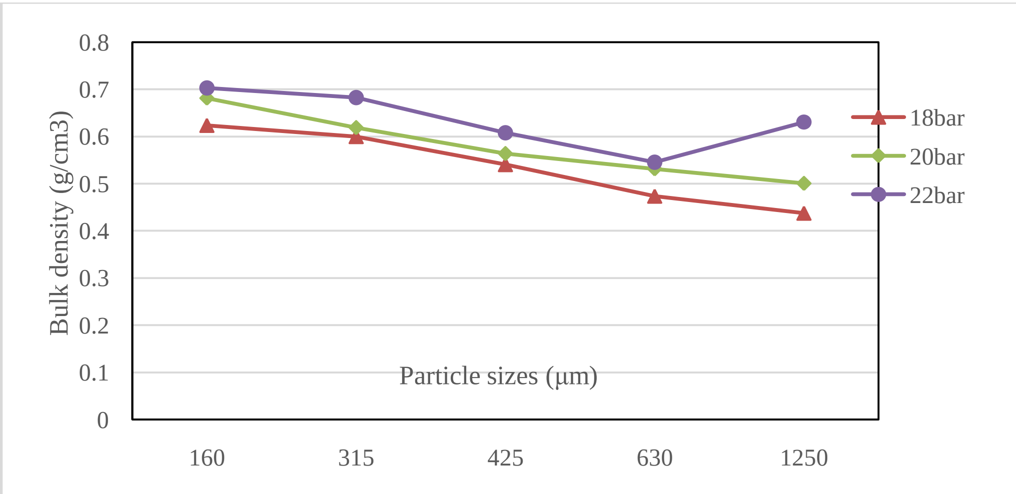


**Fig. 10** Plot of bulk density against grain sizes at varying pressures (Mahogany)

**Table -3 ANOVA for effect of pressure and particle on Mahogany**

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---|---|---|---|---|---|---|
| Pressure | 0.024506 | 2 | 0.012253 | 13.57344 | 0.002684 | 4.45897 |
| Particle size | 0.054557 | 4 | 0.013639 | 15.109 | 0.000846 | 3.837853 |
| Error | 0.007222 | 8 | 0.000903 | | | |
| Total | 0.086284 | 14 | | | | |

Height of briquettes produced from Mahogany sawdust showed similar behavior to that of Gmelina (Fig. 9) which is contrasting to the result of briquettes produced from Stool wood sawdust. This differences could be ascribed to the initial bulk density of the materials before briquetting. However, bulk density of the briquettes produced behaved in similar manner to that of Stool wood and Gmelina sawdust. Optimum bulk density of 0.703, 0.68, and 0.623 was obtained at 22, 20, and 18 bar respectively at 160µm (Fig. 10). Table 3 is the ANOVA on effect of pressure and particle size on bulk density of Mahogany sawdust. It can be seen that the pressure levels studied has high significant difference (F-test of 13.57 > F-crit. of 4.4) at <0.5% probability level and particle size has very high significant difference (F-test of 15 > F-crit. of 3.8) at <0.1% probability level. This result corresponds to other works on wood densification which state that there is high effect of particle size and pressure on bulk densities of briquettes [19, 20].

**Oil Bean Wood Sawdust**

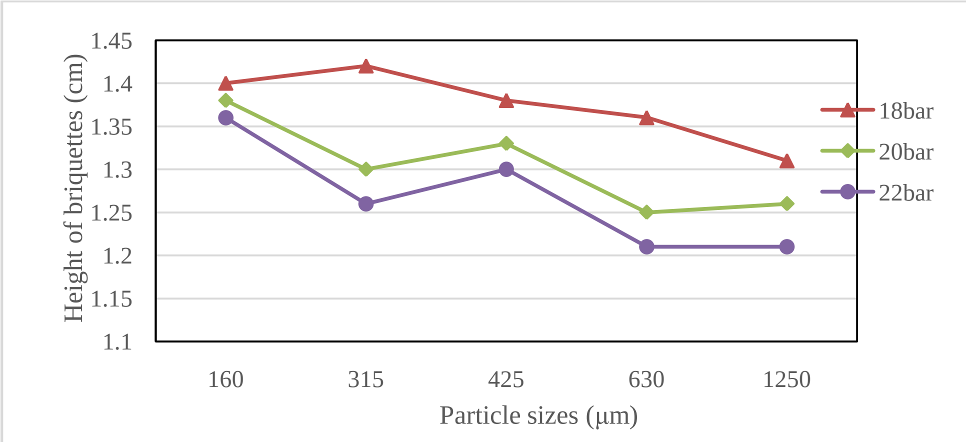


**Fig. 11** Plot of height of briquettes against grain sizes at varying pressures (Oil bean)

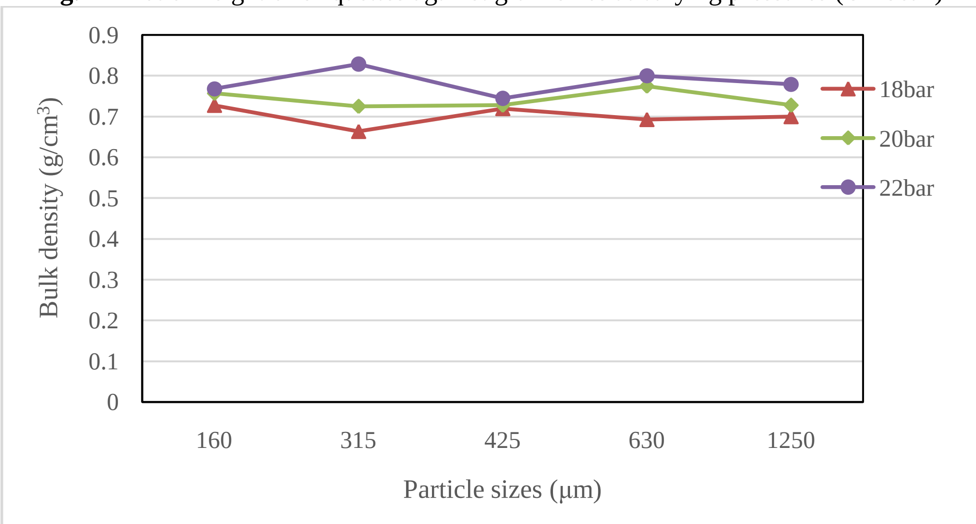


**Fig. 12** Plot of bulk density against grain sizes at varying pressures (oil bean)

**Table -4 ANOVA for effect of pressure and particle on Oil bean**

| **Source of Variation** | **SS** | **df** | **MS** | **F** | **P-value** | **F crit** |
|---|---|---|---|---|---|---|
| Pressure | 0.017278 | 2 | 0.008639 | 9.520969 | 0.00766 | 4.45897 |
| Particle size | 0.001327 | 4 | 0.000332 | 0.365672 | 0.826723 | 3.837853 |
| Error | 0.007259 | 8 | 0.000907 | | | |
| Total | 0.025865 | 14 | | | | |

From Fig. 11, there was fluctuation in trend as it concern height of briquettes produced from oil bean sawdust at 20 and 22bar. It is supposed that at 20 and 22bar, the pressure exerted on the material are not sufficient to harmonize the binding of the loose material steadily. This reaction of the material to this effect is seen as the material behaving as an elastic material. For this reason, it is therefore possible that height of the briquettes produced increased at 425µm (1.33 and 1.3cm), reduced for 315µm (1.26 and 1.3cm), increased again at 160µm (1.38 and 1.36cm) for 20 and 22bar respectively. However, there is increase in height from 1.31 to 1.42cm as particle size decreases from 1250 to 315µm at 18bar. This explanation could be affiliated with the inconsistent differences in height between 18-20bar. Similar performance was exhibited in bulk density as presented in Fig. 12. Though 22bar produced high densed briquettes (0.7-0.8g/$cm^3$) like in other materials but it was difficult distinguish the relationship in terms of particle size. The results obtained on density is higher than those recorded in other works for other materials at similar pressure and particle size [21, 22]. The ANOVA indicate significant effect (F-test of 9.5 > F-crit. of 4.45) of pressure at <5% probability level and no significant effect (F-test of 0.36 < F-crit. of 3.8) of particle size at <1% on bulk density of oil bean briquette (Table 4). Meanwhile, it was understood that because of the hardness (11,020N) of the Oil bean sawdust, it must have affected the compression of the material such that during compression, the material rebound at the force application which must have resulted to insignificance of pressure of the bulk density of the oil bean briquette. This result contrasted [23, 24] reports on pressure application which explained that mechanical strength increases as the briquetting pressure increases as a result of the plastic deformation. It could be described that maximum pressure was attained and beyond which there was no significant gain in cohesion as observed in [25].

## CONCLUSION

Effect of pressure and particle size of different biomass materials reveals significant difference on bulk density of the materials depending on the material composition. The role of bulk density in the efficiency of transportation and storage of briquettes is very vital as it influence the engineering design of transport equipment, storage and conversion process. Low density has characterized most lignocellulosic and fibrous materials such as sawdust thus they have a lot of void spaces throughout its structure that are filled up with air. After reducing the size of the particles, the fine particles releases the air inside and then increase density.

## REFERENCE

[1]. UNEP (2013) "Technologies for Converting Waste Agricultural Biomass to Energy, United Nations Environmental Programme Division of Technologies", Industry and Economic International environmental Technology Centre Osaka.

[2]. JS Tumuluru, C.T Wright, KL Kenny, and JR Hess, A Review on Biomass Densification Technologies for Energy Application, Idaho National Laboratory Biofuels and Renewable Energy Technologies Department, Energy Systems and Technologies Division Idaho, 2010.

[3]. P. Purohit, Ak Tripathi, TC Kandel, Energetic of Coal Substitution by Briquettes of Agricultural Residues, *Journal ofEnergy*,2006, Vol 131.

[4]. J Werther, M Saenger, EU Hartga, T Ogada, and Z Siagi, Combustion of Agricultural Residues, *Progress in Engineering and Combustion Science*, 2000, Vol. 26, 1-27.

[5]. XY Zeng, YT Ma and LR Ma, Utilization of Straw in Biomass Energy in China, *Renewable and Sustainable Energy Revisions*, 2007, Vol. 26, 976-987.

[6]. SO Badejo, Sawmill wood residue in Nigeria and their utilization, *Proceedings of National on workshop on Forestry Management Strategies for self -sufficiency in wood production*, Ibadan 12th - 15th June, 1990.

[7]. BA Stout and G Best, Effective energy use and climate change: needs of rural areas in developing countries, *Agricultural Engineering International: the CIGR E-Journal of Scientific Research and Development*, 2001, Vol. 3, 19.

[8]. EB Agoro and NA Ogie, A Comparative Review of Biomass Resources and Biofuel Production Potential in Nigeria, *Research Journal in Engineering and Applied Science*, 2012, Vol. 1(13), 149-155.

[9]. KJ Simonyan and O Fasina, Biomass Resources and Bioenergy Potentials in Nigeria, *African Journal of Agricultural Research*, 2013, Vol. 8(40), 4975-4989.

[10]. EA Emerhi, Physical and combustion properties of briquettes produced from sawdust of three hardwood species and different organic binders, *Advances in Applied Science Research*, 2011, Vol. 2 (6), 236-246.

[11]. P Križan, M Matúš, Ľ Šooš. and J Beniak, J. (2015), "Behavior of Beech Sawdust during Densification into a Solid Biofuel, *Energies*,2015, 8, 6382-6398.

[12]. SJ Mitchual, *Densification of Sawdust of Tropical Hardwoods and Maize Cobs at Room Temperature Using Low Compacting Pressure Without a Binder*, Kwame Nkrumah University of Science and Technology, Ghana, 2014.

[13]. A Abdulrasheed, UO Aroke and M Ibrahim, Compression Pressure Effect on Mechanical & Combustion properties of Sawdust Briquette using Styrofoam adhesive as binder, *American Journal of Engineering Research*, 2015, 4 (8), 205-211.

[14]. EA Sanchez, MB Pasache and ME Garcia, Development of Briquettes from Waste Wood (Sawdust) for Use in Low-income Households in Piura, Peru, *Proceedings of the World Congress on Engineering*, London, U.K,2014, 2.

[15]. A Taylor, Hardwood and Softwood, Forest Products Extension, College of Agricultural Sciences and Natural Resources, University of Tennessee, 2003.

[16]. E Basri and N Hadjib, The Relation between Base Properties and Drying Properties of Five Priority Wood Species from West Java, *National Journal Penelitian Hasil Hutan*, 2004.

[17]. Palla, F., (2005) "Alstonia Boonei De Wild", [Internet] Record from PROTA4U. Louppe, D., Oteng-Amoako, A.A. & Brink, M. (Editors). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands.
[18]. U Kroya, Wood Species, PT. 61416, No. 173, Tunggorono, Jombang Indonesia, 2017.
[19]. JT Oladeji (2011), Agricultural and Forestry Wastes and Opportunities for their use as an Energy Source in Nigeria- an Overview, *World Rural Observations*, 2011, 107-112.
[20]. RM Davies and US Mohammed, Effect of Processing Variables on Compaction and Relaxation Ratio of Water Hyacinth Briquettes, *International Journal of Scientific Research in Knowledge*, 2013, 1(9), 308-316.
[21]. TU Onuegbu, IM Ogbu, and C Ejikeme, Comparative Analyses of Densities and Calorific Values of Wood and Briquettes Samples Prepared at Moderate Pressure and Ambient Temperature, *International Journal of Plant, Animal and Environmental Sciences*, 2012, 2 (1), 40-45.
[22]. JA Ajobo, Densification Characteristics of Groundnut Shell, *International Journal of Mechanical and Industrial Technology*, 2014, 2(1), 150-154.
[23]. Y Li and H Liu, High Pressure Densification of Wood Residues to form an Ungraded Fuel, *Biomass and Bioenergy*, 2000, 19, 177-186.
[24]. A Demirabas, S Demirbas and AH Demirbas, Briquetting Properties of Biomass Waste Materials, *Energy Sources*, 2004, 26, 83-91.
[25]. Ndiema, C. K. W., Manga, P. N., Ruttoh, C. R. (2002) "Influence of Die Pressure on Relaxation Characteristics of Briquetted Biomass" Energy Conversion and Management Vol. 43, pp. 2157-2161.