FACULTY OF ENGINEERING
AHMADU BELLO UNIVERSITY, ZARIA
National Engineering Conference 2018

ABU NEC2018 069

DEVELOPMENT OF A MODEL FOR SELECTING THE REQUIRED COMPACTION PRESSURE OF HETEROGENEOUS BRIQUETTES OF AGRICULTURAL WASTES

[1]U. A. Essien,[2]P. K. Oke,[2] S. O. Bamisaye and [3]J. C. Anunuso

[1]Department of Material and Metallurgical Engineering, Federal University of Technology, P.M.B. 65, Minna, Nigeria.
[2]Department of Mechanical Engineering, Federal University of Technology, P.M.B. 704, Akure, Nigeria.
[3]Department of Mechatronics Engineering, Federal University of Technology, P.M.B. 65, Minna, Nigeria.

Abstract: In low pressure compaction, the application of excessive pressure during compaction often results in poor quality briquettes. This is owing to the fact that the binding materials are often squeezed out of the briquettes. An empirical model for selecting the required compaction pressure of heterogeneous briquettes of agricultural waste was developed in this research. Heterogeneous briquettes of Sawdust/Palm kernel shell were produced by mixing Sawdust and Palm kernel shell at certain varying ratios, with Cassava starch as the binder. The optimum compaction pressures of the homogeneous briquettes were 686.5 N/cm^2 and 981 N/cm^2, for sawdust and palm kernel shell, respectively. The predicted required compaction pressures of the heterogeneous briquettes, as predicted from the model, ranged from 715 N/cm^2 to 950 N/cm^2 for the briquettes. It was revealed that the respective compaction pressures at which the agricultural wastes offered good quality heterogeneous briquettes depend on the type of material and the mixing ratios of the constituent materials; this finding was the basis on which the empirical model was developed. A comparison between the calorific values and densities of heterogeneous briquettes compacted at a fix compaction pressure of 1177 N/cm^2 and those compacted at their respective predicted compaction pressures showed that good quality briquettes were obtained when compacted at the predicted compaction pressures, than at the fixed compaction pressure. The developed model will offered ease of compaction and effective utilization of materials and will be of great use in the design of variable pressure briquetting machines.

1. INTRODUCTION

The lingering energy challenge facing the developing nations means a greater danger to life and the environment since the rural populace keep resorting to the over exploitation of wood for fuel. This calls for adoption of alternative energy forms that can suit the energy demands of the rural as well as the urban populace (Essien, 2017). "Biomass (agricultural waste) has been known to offer great energy potentials that need to be tapped for energy generation. Briquetting has been one of the technologies developed to tap these great energy potentials. Briquetting involves collecting combustible materials that are not usable due to a lack of density, and compressing them into a solid fuel of a convenient shape that can be burned like wood or charcoal" (Essien, 2017). Martin *et al.* (2008) reported that Briquettes provide cleaner emission than wood and other dried plants usually used for obtaining rural energy supply and they can be used in stoves and boilers.

Based on compaction pressure, briquetting process can be classified into to: low pressure compaction (0.2 – 5 MPa), Intermediate pressure compaction (5 – 100 MPa) and high pressure compaction (above 100 MPa). Intermediate pressure machines may or may not require binders, depending upon the material whilst low-pressure machines invariably require binders (FAO, 2017).

Considering agricultural waste briquettes for burning as fuel, there are many factors such as compaction pressure, moisture content, etc., that greatly influence the quality and other properties of briquettes. For instance, during compaction in low pressure compaction, applying excessive compaction pressure often result in squeezing out the binding material which will in turn affect the density and the quality of the briquettes (Essien, 2017). Križan *et al*. (2009), opined that briquettes quality is evaluated mainly by briquette density since it is very important from the viewpoint of manipulation, burning speed, briquette stability, etc. "A careful consideration of these factors is very important in adapting briquetting technology as an alternative energy source" (Essien, 2017).

Chirchir *et al*. (2013) investigated the effect of binder types and amount on physical and combustion characteristics. Cow dung, molasses and clay were used as binders. The ratio of the binders to the briquetting materials were varied at 10%, 15% and 25%. It was reported that the binder types and ratios had effect on the density, calorific values, ignition and burning time which were also reported to be increasing with the increased amount of binder. Also on binder type, Adegoke and Muhamed (2002) in their work reported that cassava starch is a better bonding agent than cassava glue.

Ismaila *et al*. (2013) worked on 14 selected biomass (agricultural wastes) and reported that the investigation of the effect of particle size on the High Heating Value (HHV's) indicates that finely ground particles (about 125µm) had low calorific values as the grinding resulted in a loss of some heat and made the samples vulnerable to air oxidation.

Other parameters like particle sizes, mixing ratio etc. also influence the quality and calorific value of briquettes; calorific value was found to increase with a decreasing palm kernel shell grain sizes (Olugbade and Mohammed, 2015).

The objective of this study was to develop an empirical model for predicting the required compaction pressure of heterogeneous briquettes of sawdust/Palm kernel shell, based on their known mixing ratios. The developed model will offer ease of compaction, effective utilization of materials, and good quality briquettes.

2. MATERIALS AND METHOD

2.1 Materials selection

Sawdust and palm kernel shell were the agricultural wastes selected for this study. “These agricultural wastes offer good prospects as biomass fuel and are readily available in Akure and its surroundings” (Essien 2017). Locally made cassava starch was the binding material used. The equipment used in this research include a hydraulic piston press from the Central Engineering Workshop, Federal University of Technology, Akure (with sixteen mould chambers, 40 mm diameter by 140 mm height; with chamber volume of 1.76×10^{-4} m), a digital weighing balance, an e2K Bomb Calorimeter, and tape rule.

2.2 Materials preparation

The palm kernel shell was ground and sieved to a particle size of ≤ 2 mm. To restrict the effect of particle sizes the sawdust was also sieved to particle size of ≤ 2 mm. The ratio of binder was chosen at 25% the mass of the briquette (Wakchaure and Sharma, 2007; Chirchir *et al.*, 2013).

2.3 Preparation of the homogeneous briquettes

Five samples of homogeneous briquette from each of the agricultural wastes were made and compacted at varying pressures of 98 N/cm^2, 294 N/cm^2, 686 N/cm^2, 981 N/cm^2, and 1177 N/cm^2, respectively. The values and the units for the selected compaction pressures were based on the calibration of the available briquetting machine, and the pressures were selected to be within and a little above the ranges of low pressure compaction, 0.2 MPa – 5 MPa (FAO, 2017). Cylindrical briquettes with center holes were produced in this study. The mass, height, external diameter and the internal diameter of the different briquettes produced were taken immediately after ejection from the compaction chamber and the briquettes were left to dry for 19 days at an ambient temperature and relative humidity of 22 ± 3^{o}C and 75 ± 5% respectively (Olorunnisola, 2007; Sotannde *et al.*, 2010), after which their masses, heights, external diameters and internal diameters were again taken. The calorific values of the different sample briquettes were determined using an e2K Bomb Calorimeter. The calorific value test was carried out at the Central Research Laboratory, Federal University of Technology Akure. The density of the different sample briquettes were determined using equation (1).

$$Density = \frac{Mass}{Volume} \qquad (1)$$

The relaxed density or spring back density, which is the density of the briquette obtained after the briquette has remained stable, was calculated as the ratio of the briquette’s weight to the new volume. The relax density of the briquettes was determined after nineteen days (Olorunnisola, 2007; Sotannde *et al.*, 2010). The density ratio was calculated as the ratio of relaxed density to maximum density, as in equation (2) (Olugbade and Mohammed, 2015).

$$Density\ Ratio = \frac{Relax\ Density}{Maximum\ Density} \qquad (2)$$

Where: Maximum Density is the compressed density of a briquette immediately after ejection from the briquetting machine. “The density ratio was taken to explain the percentage humidity lost in drying the briquettes” (Essien, 2017).

2.4 Development of the model

Based on the calorific values obtained, the determined density values and observations made in the course of the first stage o the study, the data selected for developing the model were:

i. the optimum compaction pressures at which the briquettes of the different materials offered the optimum calorific values and optimum densities, and the expected mixing ratios of the different materials of the composite briquettes to be produced.

2.4.1 Assumptions of the Model

The model was developed based on the following assumptions (Essien, 2017):

i. The model is a deterministic model (i.e. random variations are ignored and same outcome from a given starting point is always predicted).

ii.

iii. Other factors that affect calorific value as well as the briquette quality, based on density, are kept constant.

iv.

v. The compaction pressure of a composite or heterogeneous briquette is a function of the percentage composition of the constituent agricultural wastes.

vi.

2.4.2 Implicit Assumption of the model

According to Essien (2017)

i. The compaction pressure of Y% by mass of agricultural waste ‘A’ in a composite briquette is less than the compaction pressure of 100% by mass of agricultural waste ‘A’ compacted alone.

ii.

iii. The compaction pressure of a composite briquette produced from Y_1% by mass of agricultural waste A and Y_2% by mass of agricultural waste ‘B’ is the algebraic sum of the individual compaction pressures at which the different agricultural wastes at their respective percentage by mass could be compacted separately.

iv.

2.4.3 Parameter definition for the model

According to Essien (2017), for a composite briquette made from two different agricultural wastes say A and B let:

M_1 = compaction pressure of 100% by mass of agricultural waste A

Y_1 = percentage composition of agricultural waste A in the composite briquette (the expected mixing ratio of A in the composite)

X_1 = compaction pressure of Y_1% by mass agricultural waste A

M_2 = compaction pressure of 100% by mass of agricultural waste B

Y_2 = percentage composition of agricultural waste B in the composite briquette (the expected mixing ratio of B in the composite)

X_2 = compaction pressure of Y_2% by mass agricultural waste B

2.4.4 Derivation of the model

From the assumptions, if 100% by mass of agricultural waste ‘A’ is compacted at M_1 (N/cm²), by mathematical proportionality, Y_1% by mass of agricultural waste ‘A’ will be compacted at X_1 (N/cm²). Therefore, for heterogeneous briquettes produce from two agricultural wastes ‘A’ and ‘B’ the model was derived as shown on Table 1, to be

$$\hat{Y} = X_1 + X_2 = 0.01M_1Y_1 + 0.01M_2Y_2. \qquad (3)$$

Table 1: Model for Heterogeneous Briquettes Produced from Two Agricultural Wastes (Essien, 2017)

Agricultural Waste A		**Agricultural Waste B**	
% Composition	Pressure (N/cm²)	% Composition	Pressure (N/cm²)
100	M_1	100	M_2
Y_1	X_1	Y_2	X_2
$X_1 = \frac{M_1 \times Y_1}{100}$		$X_2 = \frac{M_2 \times Y_2}{100}$	
$X_1 = 0.01 M_1 Y_1$ (N/cm²)		$X_2 = 0.01 M_2 Y_2$ (N/cm²)	

The required compaction pressure for the heterogeneous briquette

$(A + B) = X_1 + X_2$ (N/cm²)

2.5 *Studying the developed model*

To study the developed model a multiple regression analysis of the mixing ratios and the predicted compaction pressures was carried out. Microsoft Excel was used for the analysis.

2.6 *Production of the heterogeneous briquettes*

Heterogeneous briquettes of sawdust/palm kernel shell were produced at different mixing ratios and compacted at the predicted required compaction pressures, predicted from the developed model. Their densities and calorific values were also determined.

2.7 *Verification of the developed model*

To verify the model, the heterogeneous briquettes were compacted at a particular fixed compaction pressure, 1177 N/cm², chosen to be higher than the predicted compaction pressures. The calorific values and the densities of the heterogeneous briquettes were determined. The results of the calorific values and densities of the heterogeneous briquettes, when compacted at 1177 N/cm² were compared to the results obtained when compacted at their respective predicted required compaction pressures.

3. RESULT AND DISCUSSION

3.1 Calorific value and density of the homogeneous Briquettes

Table 2: Calorific Values and Densities of the Homogeneous Briquette Samples (Essien, 2017)

Material	**Compaction Pressure (N/cm²)**	**Calorific Value (MJ/kg)**	**Density (kg/m³)**		**Density Ratio**
			Max Density	Relaxed Density	
Sawdust	1177	16.20	602.66	411.07	0.6821
	981	16.20	624.26	488.04	0.7818
	686	16.82	661.08	552.37	0.8356
	294	15.33	646.44	445.61	0.6893
	98	15.34	647.84	445.61	0.6878
Palm kernel shell	1177	18.11	1612.05	1290.12	0.8003
	981	18.34	1633.26	1320.26	0.8083
	686	18.17	1600.32	1186.34	0.7413
	294	17.98	1608.91	1239.88	0.7706
	98	17.96	1605.67	1286.88	0.8015

The result of the calorific values and densities of the homogenous briquette samples are depicted on Table 2.

From the result on Table 2, saw dust offered a better quality briquette with a calorific value of 16.82 MJ/kg, a density of 661.08 kg/m³ and a density ratio of 0.8356, at a compaction pressure of 686.5 N/cm²; while palm kernel shell offered a better quality briquette with a calorific value of 18.34 MJ/kg, a density of 1633.26 kg/m³ and a density ratio of 0.8083, at a compaction pressure of 981 N/cm².

From the result on Table 2, saw dust offered a better quality briquette with a calorific value of 16.82 MJ/kg, a density of 661.08 kg/m³ and a density ratio of 0.8356, at a compaction pressure of 686.5 N/cm²; while palm kernel shell offered a better quality briquette with a calorific value of 18.34 MJ/kg, a density of 1633.26 kg/m³ and a density ratio of 0.8083, at a compaction pressure of 981 N/cm².

The variations in calorific value could not be directly linked to the compaction pressure, but the fact that the amount of binder present in a briquette can affect the calorific value of the briquette could explain the variations in the calorific value in terms of the effect of compaction pressure. However, the variation of density could be directly linked to the effect of compaction.

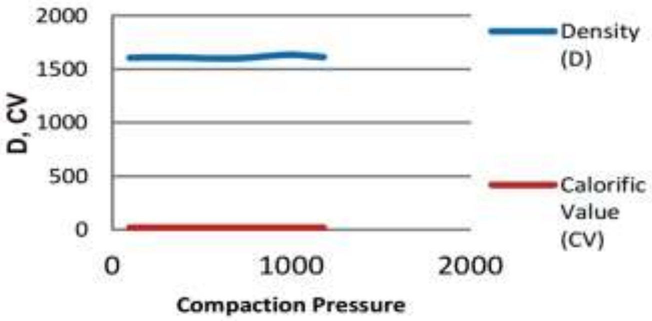

Figure 1: Compaction Pressure, Density and Calorific Value Relationship for Homogeneous Briquette of Palm Kernel Shell.

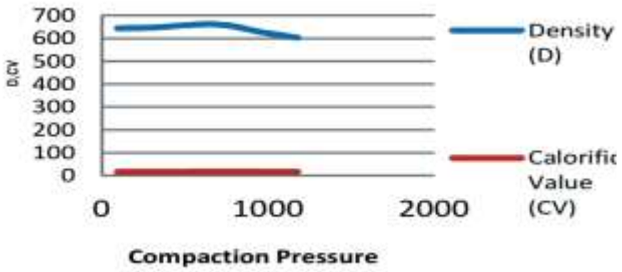

Figure 2: Compaction Pressure, Density and Calorific Value Relationship for Homogeneous Briquette of sawdust.

pressure (Essien 2017), as could be seen on the graphs of Figure 1 and Figure 2.

The response of the density to compaction pressure for the two materials showed that briquettes density drop with increase in compaction pressure, after a certain optimum value has been reached. This could be due to spring back effect owning to the squeezing out of the binder at certain high compaction pressure. “The graph of sawdust briquettes clearly depicted this drop in density as compaction pressure increased beyond the optimum compaction pressure” (Essien, 2017); which could be mainly due to the fact that sawdust material tends to exhibit spring back effect more than palm kernel shell.

Quoting Ismaila *et al.* (2013) on the widely acceptable range of calorific value of “17 – 21 MJ/kg” for high quality briquettes, the calorific value of sawdust approximately fall within the range and that of palm kernel shell clearly fall within the acceptable range. Also, comparing the density values for the optimum compaction pressure of the materials to the "Standard EN 149561" quoted by Akintunde (2012) which specifies density value of "0.8 - 1.2 g/cm^3" for high quality briquettes, only the density value for palm kernel shell could show a high quality briquette with a value well above the stipulated range. However, the observed drop in density values of the different materials above the optimum compaction pressure and the agreement of the data from palm kernel shell material to standard values qualified the acceptance of the optimum compaction pressure of sawdust for furthering the study.

The optimum compaction pressures along with the expected mixing ratios were used in the developed model in equation (3) to predict the required compaction pressures of the heterogeneous briquettes. The density ratios showed an indication of the briquettes stability and were taken as a percentage stability of the briquettes after drying. Considering the results of the relaxed density on Table 2 and as posited by Oyelaran *et al. (2015)* that relaxed density offers a better and single quantitative index of stability, it can be asserted that the higher the density ratio, the higher the briquette stability after drying. Therefore, the values of the density ratios further justified the selection of the optimum compaction pressures for the prediction of the required compaction pressures of the heterogeneous briquettes.

3.2 Analysis of the model parameters

The hypothesis tested with the F-test was that all the coefficients of the regression model are equal to 0. If all the coefficients are equal to 0, then none of the independent variables in the model is helpful in predicting the dependent variable (Barry *et al*., 2012). From the multiple regression analysis, the coefficient of determination, R^2 was 0.9999. This means that 99.99% of the variability in the compaction pressures predicted could be explained by the regression model. The significance F value was 1.36 x 10^{16}. A low F value of 1.36 x 10^{16}, compared to the level of significance of the model (0.5), suggested that the overall model was statistically significant. The Excel output provided the regression coefficients as: $\hat{Y}$ = 685.6, X_1 = 0 and X_2 = 2.94. However, there was not enough evidence to accept the null hypothesis since at least one of the coefficients of the variables was not zero. The result of the regression analysis further confirmed the validity of the developed model.

3.3 Result for the heterogeneous briquettes

Table 3 depicts the required compaction pressures, the calorific values and the densities of the heterogeneous briquettes of sawdust/palm kernel shell, at their respective mixing ratios. The variation of the compaction pressure with the density is as depicted in Figure 3. The required compaction pressure increased with increase in percentage of palm kernel shell in the briquette, and the calorific value of the briquettes also increased with increase in percentage of palm kernel shell in the briquette samples. This explains that the presence of palm kernel shell material in saw dust briquettes improved the briquettes quality while the presence of the saw dust material reduced the required compaction pressures of palm kernel shell briquettes. The result is in line with the report of Akintunde and Seriki (2013); Adegoke and Mohammed (1999).

A better quality briquette of sawdust/palm kernel shell (with a calorific value of 17.20 MJ/kg and density of 1271 kg/m^3) was obtained at a mixing ratio of 10:90 percent sawdust to palm kernel shell, and at a compaction pressure of 950 N/cm^2, as shown on Table 3.

Table 3: Heterogeneous Briquette of Sawdust/Palm kernel shell (Essien, 2017)

S/N	Mixing Ratio		Required Compaction Pressure (N/cm^2)	Calorific Value (MJ/kg)	Density (kg/m^3)
	Sawdust	Palm Kernel Shell			
1	90	10	715	15.34	563.83
2	80	20	744	15.55	596.58
3	70	30	774	15.31	588.87
4	60	40	803	16.25	772.68
5	50	50	833	15.80	871.21
6	40	60	862	16.00	876.04
7	30	70	891	16.40	1117.6
8	20	80	921	17.04	1064.74
9	10	90	950	17.20	1271.44

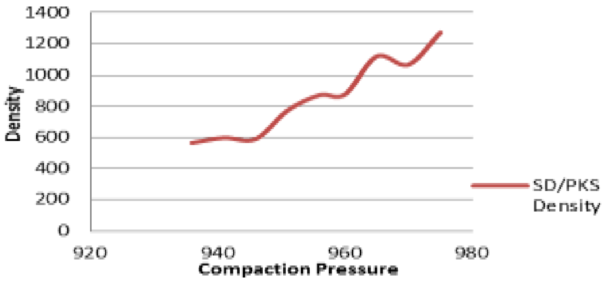

Figure 3: Compaction Pressure and Density Relationship for the Heterogeneous Briquettes Sawdust/Palm kernel shell

3.4 Result for the heterogeneous briquettes compacted at the fixed compaction pressure

Tables 4 depicts the result of the calorific values and densities of the heterogeneous briquettes when compacted at the fixed compaction pressure (1177 N/cm^2) chosen to be higher than the required compaction pressures obtained from the model.

Comparing the results obtained when the briquettes were compacted at their respective required compaction pressures, predicted from the developed model, to the results obtained when the briquettes were compacted at the fixed compaction pressure, the results showed that better quality briquettes (in terms of densities and calorific values) were obtained when the briquettes were compacted at their required compaction pressures. "The differences in the result could be attributed to the effect of compaction pressure owing to the squeezing out of binders from the briquettes thereby leading to excessive spring back effect and to poor quality briquettes" (Essien, 2017).

Table 4: Result for Sawdust/Palm kernel shell Briquettes Compact at a Fixed Pressure of 1177 (N/cm^2) (Essien, 2017)

S/N	Mixing Ratio		Compaction Pressure (N/cm^2)	Calorific Value (MJ/kg)	Density kg/m^3
	Sawdust	Palm Kernel Shell			
1	90	10	1177	15.00	486.14
2	80	20	1177	15.13	483.74
3	70	30	1177	15.12	561.63
4	60	40	1177	15.25	733.32
5	50	50	1177	15.30	816.88
6	40	60	1177	16.00	904.28
7	30	70	1177	16.54	982.05
8	20	80	1177	16.75	1079.78
9	10	90	1177	16.89	1156.2

CONCLUSION

The study was set out to develop a model for predicting the required compaction pressure of heterogeneous briquettes of Sawdust/Palm kernel shell. “As observed in the course of the study, certain optimum compaction pressures are required to produce good quality briquettes. In the case of homogeneous briquettes, the required compaction pressure depended largely on the material nature of the agricultural waste compacted while in the case of heterogeneous briquettes, it depend on the percentage composition (the mixing ratio) of the constituent agricultural wastes in the heterogeneous briquette, as well as the materials type” (Essien, 2017). A better quality briquette of sawdust/palm kernel shell (with a calorific value of 17.20 MJ/kg and density of 1271 kg/m^3) was obtain at mixing ratio of 10:90 percent composition of sawdust to palm kernel shell, and at a compaction pressure of 950 N/cm^2.

The model for predicting the required compaction pressures of heterogeneous briquettes of agricultural wastes, once the respective mixing ratios of the constituent agricultural wastes are selected, will offer ease of compaction, effective utilization of materials, and good quality briquettes.

ACKNOWLEDGMENT

The thanks goes to Mrs. Francisca Udonkang for her financial support to the research work.

REFERENCES

Adegoke C. O. and Mohammed T. I. (2002). Investigation of Sawdust Briquettes as High-Grade Fuel. *West Indian Journal of Engineering, Technical Paper,* Vol.25 No. 1, pp.4-5.

Akintunde M. A. (2012). Effect of Paper and Palm Kernel Shell and Mechanical Properties of Sawdust Briquettes. *Journal of Mechanical and Civil Engineering*, Vol.4 No.4, pp.11-16.

Akintunde M. A. and Seriki M. E. (2013). Effect of paper paste on the calorific value of sawdust briquette. *International Journal of Advanced Research and Technology,* Vol.2 No.1, Available online at www.ijoart.org. Retrieved November 26 2018.

Barry R., Ralph M. S. Jr., and Michael E. H. (2012). Quantitative Analysis For Management. *Pearson Education, Inc., publishing as Prentice Hall, One Lake Street, Upper Saddle River, New Jersey* 122-130

Chirchir D. K., Nyaanga D. M. and Githeko J. M. (2013). Effect of Binder Types and Amount on Physical and Combustion Characteristics. *International Journal of Engineering and Technology,* Vol.2 No.1, pp.1-13.

Essien U. A. (2017). Effect of Pressure on the Densification of Agricultural Waste Briquettes. *Master’s Thesis, Federal University of Technology, Akure, Nigeria*

FAO (Food and Agriculture Organization of the United Nations) Corporate Document Repository (2017). The Briquetting of Agricultural Wastes for Fuel. Website: www.fao.org. Accessed 22 May 2017.

Ismaila A., Zakari I. Y., Nasiru R., Tijjani B. I., Abdullahi I. and Garba N. N. (2013). Investigation on biomass briquettes as an energy source in relation to their calorific values and measurement of their total carbon and elemental contents for efficient biofuel utilization. *Advances in Applied Science Research,* Vol.4 No.4, pp.303-309.

Križan P., Šooš L. and Vukelić D. (2009). A Study of Impact of Technological Parameters on the Briquetting Process. *Working and Living Environmental Protection,* Vol.6 No.1, pp.39 – 47.

Martin J., Mae R. and Manaay A. (2008). Design and Development of Charcoal Briquettes Machines. *Journal on Mechanical Engineering,* Vol. 16, pp. 85-90.

Olorunnisola A. (2007). Production of Fuel Briquetting from Waste Paper and Coconut Husk Admixtures. *Agricultural Engineering International: the CIGR Ejournal*, No.9, pp.1-15.

Olugbade T. O. and Mohammed T. I. (2015). Fuel Developed from Rice Bran Briquettes and Palm Kernel Shells. *International Journal of Energy Engineering*, Vol.5 No.2, pp.9-15.

Oyelaran O. A., Bolaji B. O., Waheed M. A. and Adekunle M. F. (2015). Characterization of Briquettes Produced from Groundnut Shell and Waste Paper Admixture. *Iranica Journal of Energy and Environment,* Vol.6 No.1, pp.34-38.

Sotannde O., Oluyege G. and Abah B. (2010). Physical and Combustion Properties of Briquettes from Sawdust of Azadirachta indica. *Journal of Forestry Research*, Vol.21, pp.63-67.

Wakchaure G. C. and Sharma P. K. (2007). Physical Quality of Some Biomass Briquettes. *Journal of Agricultural Engineering*, Vol.44 No.1, pp.47-52.

Essien U. A. (2017). Effect of Pressure on the Densification of Agricultural Waste Briquettes. *Master’s Thesis, Federal University of Technology, Akure, Nigeria.*