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Modelling the effect of compaction pressure on the densification of agricultural waste briquettes

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An empirical model for predicting the required compaction pressure of heterogeneous briquettes was developed in this study. The study was based on low-pressure compaction, where the used of binders is paramount. Three agricultural wastes: sawdust, rice husk, and palm kernel shell were used in the study. The material type was a key factor of influence on the briquette samples produced. The optimum compaction pressures of the homogeneous briquettes were 686.5, 981, and 981 N/cm^2, for sawdust, rice husk, 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 sawdust/palm kernel shell briquettes, 710 N/cm^2 to 906 N/cm^2 for sawdust/rice husk briquettes, and 936 N/cm^2 to 975 N/cm^2 for palm kernel shell/rice husk briquettes. The heterogeneous briquette samples compacted at the predicted required compaction pressures offered better quality briquettes in terms of density and calorific value than those compacted at a fixed compaction pressure of 1177 N/cm^2. It was established that the developed model offered ease of compaction and effective utilization of materials and will be of great use in the design of variable pressure briquetting machines.

Keywords: briquettes, compaction pressure, densification, homogeneous, heterogeneous

Introduction

Energy challenges remain the bane of development in developing nations. The over-dependence on fossil fuel by our nation, Nigeria, and the continuous exploitation of wood for fuel by rural dwellers are getting much more challenging by the day and, therefore, demand a paradigm shift to some alternative sustainable energy forms that can fit both the rural and the urban populace. As small and medium-scale industries keep springing up in different areas, demand for sustainable energy remains a challenge to our nation that is so blessed with abundant human and natural resources (Essien 2017).

Biomass (agricultural waste) has been known to offer great energy potential that needs to be tapped for energy generation. Briquetting has been one of the technologies developed to tap this great energy potential. Briquetting encompasses 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). Based on compaction pressure, briquetting processes can be classified into 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).

Various factors greatly influence the final briquettes produced; therefore, a careful consideration of these factors is very important in adapting briquetting technology as an alternative energy source (Essien 2017). Menind et al. (2012) reported that briquette quality can be influenced by many parameters. Five of these have the most significant effect on briquette properties. These parameters are material type, pressing temperature, compacting pressure, fraction largeness and material moisture content.

According to Križan, Šooš, and Vukelić (2009), compacting pressure, pressing temperature, fraction largeness, material humidity, etc. are the technological parameters while length of the pressing chamber, conicalness of the pressing chamber, impact of the friction coefficient, impact of the cooling chamber, final shape of the pressing chamber, etc. are the constructional parameters that have great impact on the final briquette density. Among these parameters, compaction pressure is the most important factor that influences briquettes strength. Maninder, Rupinderjit and Sonia (2012) reported that fraction largeness has a very high impact on the briquetting process: the bigger the fractions, the more compression is needed for briquetting.

Davies, Davies, and Augustina (2017) reported that one of the major factors used to determine the quality of fuel briquettes is density and burning rate, while Križan, Šooš, and Vukelić (2009) opined that briquette quality is evaluated mainly by briquette density since it is very important from the viewpoint of manipulation, burning speed, briquette stability, etc. Quoting Akintunde (2012),

> Standard O-Norm M7135 defines briquettes density value for group Hp (wood briquettes) and for group Rp (crust briquettes) more than 1.12 kg/dm^3 (g/cm^3), and for other briquettes this value must be more that 1 kg/dm^3 (g/cm^3). Standard DIN 51731 defines interval of briquettes density values from 1 to 1.4 g/cm^3. As reported by Plíštil et al. (2005), the basic standards for the solid biofuels developed Technical Committee-CEN/TC 335 Solid Biofuels. Standard EN 149561: Solid Biofuels- fuel specification and classes determine the briquettes density ρ = 0.8–1.2 g/cm^3. The density of $\rho > 1.0$ g/cm^3 is recommendable for high quality wood briquettes.

The parameters that influence briquette quality are interwoven. Briquette density and compressive strength are influenced by material composition and the type of briquetting machine used (Križan et al. 2011). Briquette density is dependent on density of the raw material, compaction pressure, binder ratio and particle size (Davies and Abolude 2013). This calls for the need for a standardized model for selecting the compaction pressure for good quality briquettes to be produced.

Literature review

Considering agricultural waste briquettes for burning as fuel, briquette calorific value, density and resistance to humidity are the factors that directly influence briquettes burning. However, there are many factors such as compaction pressure, moisture content, etc., that greatly influence the quality and other properties of briquettes. Various research studies have been carried out to determine the effects of these factors on homogeneous and composite briquettes as well as on other factors (Essien 2017).

Akintunde (2012) reported on the effects of paper and palm kernel shells on mechanical properties of sawdust briquettes.

Wakchaure and Sharma (2007) studied the effect of material and concentration of binders on the physical quality of biomass briquettes. Two binding materials, molasses and sodium silicate, at varying concentrations of 10, 15, 20 and 25% were used in the preparation of briquettes. The study revealed that among all types of briquettes, saw dust briquettes with sodium silicate at 25% concentration were better in terms of compressive strength, shattering resistance, bulk density and calorific value and hence better for transportation, storage and for burning purposes.

Chirchir, Nyaanga, and Githeko (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 was varied at 10%, 15% and 25%. It was reported that the binder types and ratios had an effect on the density, calorific values, ignition and burning time which was also reported to increase with the increased amount of binder. Also on binder type, Adegoke and Mohammed (2002) reported that cassava starch is a better bonding agent than cassava glue while Idah and Mopah (2013) used banana peel and cassava peel gel.

Ismaila et al. (2013) worked on 14 selected types of biomass (agricultural waste) and reported that the investigation of the effect of particle size on the High Heating Values (HHVs) indicated that finely ground particles (about 125 µm) had low calorific values as the grinding resulted in a loss of some heat and made the sample vulnerable to air oxidation.

Abdulrasheed, Aroke, and Ibrahim (2015) investigated the effects of changing the compression pressure used in moulding of briquettes on its combustion and mechanical properties. Briquettes were produced from sawdust at different compression pressures using Styrofoam (Polystyrene foam) adhesive as binding material. The combustion properties investigated were afterglow time, burning rate, specific fuel consumption, power output, percentage heat utilized, flame propagation rate and percentage ash content; and the mechanical properties investigated included density, compressive strength, impact resistance, water resistance and abrasion resistance.

Plate 1: Ground sawdust (Essien 2017).

Other parameters like particle sizes, mixing ratio, etc. also influenced the quality and calorific value of briquettes. In the work of Olugbade and Mohammed (2015), calorific value was found to increase with a decrease in palm kernel shell grain size.

The objective of this study was to develop an empirical model for predicting the required compaction pressure of heterogeneous briquettes, based on their known mixing ratios.

Materials and method

Materials selection

Three agricultural wastes, rice husk, sawdust and palm kernel shell were selected for this study. 'These agricultural wastes offer good prospects as biomass fuel and are readily available in Akure and its surroundings' (Essien 2017). The palm kernel shell was ground and sieved to a particle size of ≤2 mm, based on the report of Olugbade and Mohammed (2015). To restrict the effect of particle sizes, the sawdust and rice husk were also sieved to a particle size of ≤2 mm. The binding material used in this research was locally made cassava starch. The ratio of the binder was chosen at 25% the mass of the briquette (Wakchaure and Sharma 2007; Chirchir, Nyaanga, and Githeko 2013). Plates 1, 2 and 3 show the three selected agricultural wastes after being sieved.

Plate 2: Ground palm kernel shell (Essien 2017).

Plate 3: Rice Husk (Essien 2017).

Production of the homogeneous briquettes

Five samples of homogeneous briquettes from each of the agricultural wastes were made and compacted at varying pressures of 98, 294, 686, 981 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). The briquetting machine used was a hydraulic piston press with sixteen mould chambers, 40 mm diameter by 140 mm height; with a chamber volume of 1.76×10^{-4} m.

Cylindrical briquettes with centre 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 ± 30C and $75 \pm 5\%$ respectively (Olorunnisola 2007; Sotannde, Oluyege, and Abah 2010), after which their mass, height, external diameter and internal diameter were again taken. The masses of the briquettes were taken using a digital weighing balance. The calorific value and the density of the different sample briquettes were determined using an e2 K Bomb Calorimeter. Plate 4 shows the briquette samples while Plate 5 shows a briquette sample on a digital weighing balance.

Plate 4: Briquettes samples (Essien 2017).

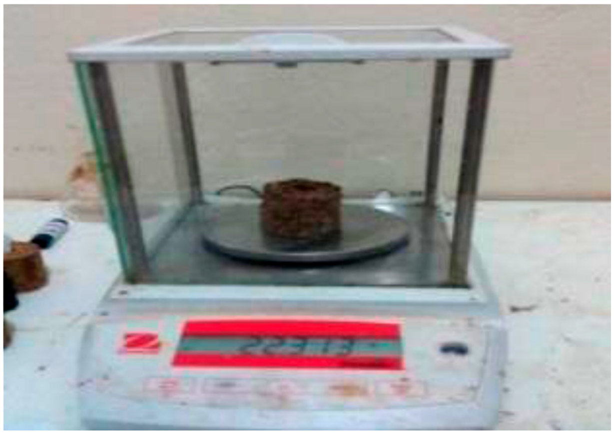

Plate 5: Sample on digital weighing balance (Essien 2017).

Determination of the calorific values of the homogeneous briquettes

The calorific value test was carried out at the Central Research Laboratory, Federal University of Technology Akure. An e2 K Bomb Calorimeter was used for the test. Fifty (50) g of the material was placed in the combustion chamber, oxygen gas was added at a pressure of 1500 kPa and the whole setup was left in the Bomb Calorimeter for 10 minutes, after which the calorific values were read directly from the display unit of the Bomb Calorimeter. Plates 6 and 7 show the e2k Bomb Calorimeter and its setup.

Determination of the density the homogeneous briquettes

The density of the briquettes was calculated from the ratio of the mass to the volume of the briquette.

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

The relaxed density or spring back density, which is the density of a briquette obtained after the briquette has remained stable, was calculated as the ratio of the briquette's weight to the new volume. The relaxed density of the briquettes was determined after drying for 19 days (Olorunnisola 2007; Sotannde, Oluyege, and Abah 2010).

Plate 6: The e2k combustion calorimeter (Essien 2017).

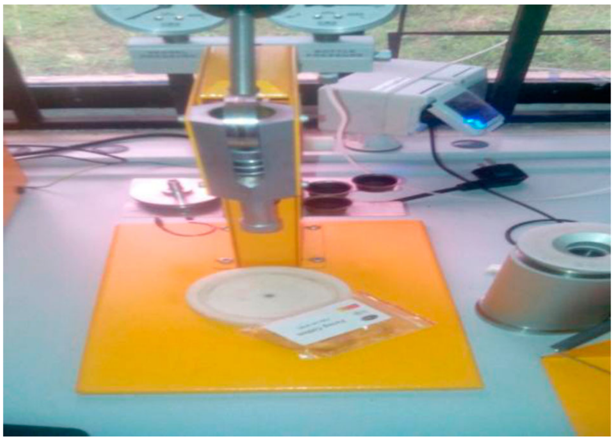

Plate 7: Firing cotton (Essien 2017).

The density ratio was calculated as the ratio of relaxed density to maximum density (Olugbade and Mohammed 2015).

$$DensityRatio = \frac{Relax\ Density}{Maximun\ Density} \quad (2)$$

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).

Model development

Based on the calorific values obtained, the determined density values and observations made in the course of the first stage of 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
(ii) the expected mixing ratios of the different materials of the composite briquettes to be produced.

Assumptions of the model

The model was developed based on the following assumptions:

(i) The model is a deterministic model (i.e. random variations are ignored and the same outcome from a given starting point is always predicted).
(ii) Other factors that affect calorific value as well as the briquette quality, based on density, are kept constant.
(iii) The compaction pressure of a composite or heterogeneous briquette is a function of the percentage composition of the constituent agricultural wastes.

Implicit assumption of the model

(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) 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 the different agricultural wastes at this respective percentage by mass could be compacted separately. (Essien 2017).

Parameter definition

For a composite briquette made from two different agricultural wastes, say A and B, the following parameters were given:

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 of 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 of agricultural waste B

For a composite or heterogeneous briquette produced from three different agricultural wastes A, B and C, the following parameters were given:

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 of agricultural waste B
M_3 = compaction pressure of 100% by mass of agricultural waste C
Y_3 = percentage composition of agricultural waste C in the composite briquette (the expected mixing ratio of C in the composite)
X_3 = compaction pressure Y_3% by mass of agricultural waste C

Derivation of the model

From the assumptions, if 100% by mass of agricultural waste 'A' is compacted at M_1 (N/cm^2), by mathematical proportionality, Y_1% by mass of agricultural waste 'A' will be compacted at X_1 (N/cm^2). Therefore, for heterogeneous briquettes produced from two agricultural wastes, 'A' and 'B', the model was derived as shown in Table 1 to be:

$$\hat{Y} = X_1 + X_2 = 0.01M_1Y_1 + 0.01M_2Y_2 \ (\mathrm{kg/cm^2}) \quad (3)$$

where $\hat{Y}$ is the predicted required compaction pressure.

Table 1: Model for heterogeneous briquettes produced from two agricultural wastes.

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
$X_1 = \frac{M_1 \times Y_1}{100}$		$X_2 = \frac{M_2 \times \mathbf{Y}_2}{100}$	
$X_1 = 0.01M_1\ Y_1\ (N/cm^2)$		$X_2 = 0.01M_2 Y_2\ (N/cm^2)$	
The required compaction pressure for the heterogeneous briquette, (A + B) = $X_1 + X_2$ (N/cm²)			

Source: Essien 2017

Also, for heterogeneous briquettes produced from three agricultural wastes, 'A', 'B' and 'C', the model was derived as stated in Table 2 to be:

$$\hat{Y} = X_1 + X_2 + X_3$$
$$= 0.01M_1Y_1 + 0.01M_2Y_2 + 0.01M_3Y_3\ (N/cm^2) \quad (4)$$

where $\hat{Y}$ is the predicted required compaction pressure.

Verification of the developed model

To verify the model, the heterogeneous briquettes were compacted at a particular fixed compaction pressure, 1177 N/cm^2, 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/cm^2, were compared to their respective results obtained when compacted at their respective predicted required compaction pressures.

Result and discussion

Calorific value and density of the homogeneous briquettes

The result of the calorific values and densities of the homogenous briquette samples are depicted in Table 3.

From the result in Table 3, sawdust offered a better quality briquette with a calorific value of 16.82 MJ/kg, a density of 661.08 kg/m^3 and a density ratio of 0.8356, at a compaction pressure of 686 N/cm^2; rice husk offered a better quality briquette with a calorific value of 13.72 MJ/kg, a density of 744.07 kg/m^3 and a density ratio of 0.8348, at a compaction pressure of 981 N/cm^2; while palm kernel shell offered a better quality briquette with a calorific value of 18.34 MJ/kg, a density of 1633.26 kg/m^3 and a density ratio of 0.8083, at a compaction pressure of 981 N/cm^2. The main influence on the compaction pressure was observed to be the material type. 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

Table 2: Model for heterogeneous briquettes produced from three agricultural wastes.

Agricultural Waste A		Agricultural Waste B		Agricultural Waste C	
% Composition	Pressure (N/cm²)	% Composition	Pressure (N/cm²)	% Composition	Pressure (N/cm²)
100	M_1	100	M_2	100	M_3
Y_1	X_1	Y_2	X_2	Y_3	X_3
$X_1 = \frac{M_1 \times Y_1}{100}$		$X_2 = \frac{M_2 \times \mathbf{Y}_2}{100}$		$X_3 = \frac{M_3 \times \mathbf{Y}_3}{100}$	
$X_1 = 0.01M_1Y_1(N/cm^2)$		$X_2 = 0.01M_2Y_2\left(\frac{N}{cm^2}\right)$		$X_3 = 0.01M_3Y_3\ (N/cm^2)$	
The required compaction pressure for the heterogeneous briquette (A + B) = $X_1 + X_2$ (N/cm²)					

Source: Essien 2017

Table 3: Calorific values and densities of the homogeneous briquette samples.

Agricultural waste	Compaction pressure (N/cm^2)	Calorific value (MJ/kg)	Density (kg/m^3) Max density	Density (kg/m^3) Relaxed density	Density ratio
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
Rice husk	1177	13.70	737.34	594.14	0.8058
	981	13.72	744.07	621.17	0.8348
	686	13.51	725.89	542.81	0.7478
	294	13.55	738.46	610.12	0.8262
	98	13.52	742.6	588.34	0.7922
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

Source: Essien 2017

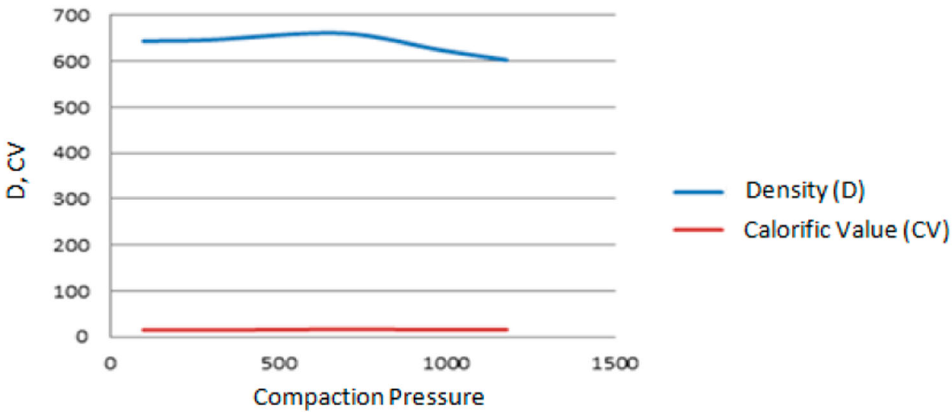

Figure 1. Relationship between compaction pressure, density and calorific value for homogeneous briquette of sawdust (Essien 2017).

pressure. However, the variation of density could be directly linked to the effect of compaction pressure, as can be seen in the graphs in Figures 1, 2 and 3 for sawdust, rice husk, and palm kernel shell, respectively.

> The response of the density to compaction pressure for the three 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 due 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)

Quoting Ismaila et al. (2013) on the widely acceptable range of calorific value of '17–21 MJ/kg' for high quality briquettes, only the calorific value of rice husk briquettes was far below the range while that of sawdust fell approximately within the range and that of palm kernel shell fell clearly 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 showed a high quality briquette with a value well above the stipulated range. However, the observed drop in density values of

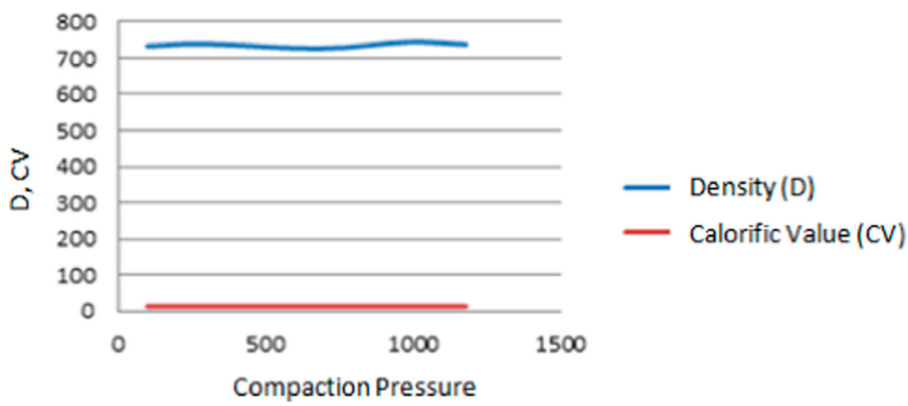

Figure 2: Relationship between compaction pressure, density and calorific value for homogeneous briquette of rice husk (Essien 2017).

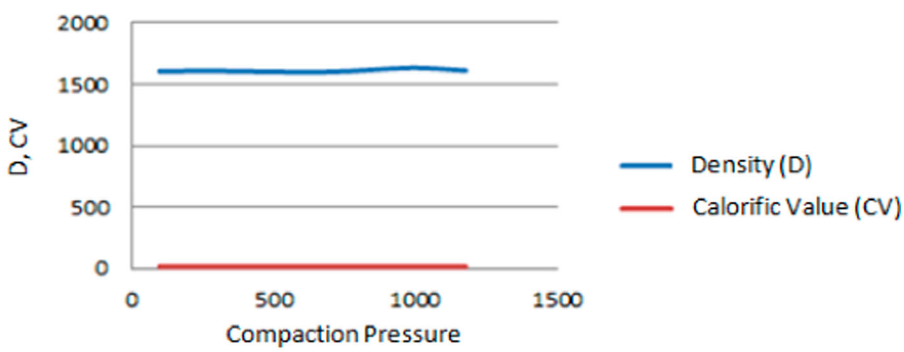

Figure 3: Relationship between compaction pressure, density and calorific value for homogeneous briquette of palm kernel shell (Essien 2017).

Table 4: Required compaction pressures, calorific value and density of heterogeneous briquette of sawdust/palm kernel shell.

S/N	Mixing ratio: Sawdust	Mixing ratio: Palm kernel shell	Required compaction pressure (N/cm^2)	Calorific value (MJ/kg)	Density (kg/m^3)
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

Source: Essien 2017

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 and rice husk for this study.

The optimum compaction pressures along with the expected mixing ratios were used in the developed model 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 in Table 3,

> 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. (Essien 2017)

Compaction of the heterogeneous briquettes

Table 4 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 predicted required compaction pressure of the briquettes increased with an increase in percentage composition of palm kernel shell material in the briquettes, clearly explaining the effect of the material nature of palm kernel shell particles. The calorific value of the briquettes also increased with an increase in percentage composition of palm kernel shell in the briquette samples, as depicted in Table 4. The presence of palm kernel shell material in sawdust briquettes improved the quality of the briquettes while the presence of the sawdust material reduced the required compaction pressures of palm kernel shell briquettes. The result is in line with the report of Akintunde and Seriki (2013) and Adegoke and Mohammed (1999) that composite briquettes with palm kernel shell as additive give higher calorific values than those of pure sawdust briquettes. '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' (Essien 2017).

Table 5 depicts the required compaction pressures, the calorific values and the densities of the heterogeneous briquettes of sawdust/rice husk at their respective mixing ratios. The result in Table 5 show that the predicted required compaction pressure of the briquettes increased with an increase in percentage composition of rice husk in the briquette samples while the calorific value increased with an increase in percentage composition of sawdust material in the briquette samples. Compared to the homogeneous briquette of rice husk, the presence of sawdust material in the briquette, at any percentage, improved the quality and calorific value of rice husk material and also reduced the required compaction pressure of rice husk briquettes. The result in Table 5 also shows that the variation of the briquettes' density with compaction pressure was not well defined, as random variation could be seen.

> This random variation in the densities of sawdust/rice husk briquette explains the effect of material type on other factors that influence briquette quality. This effect is more pronounced in sawdust/rice husk briquette due to the elastic nature of rice husk material, which causes

Table 5: Required compaction pressures, calorific value and density of heterogeneous briquette of sawdust/rice husk.

S/N	Mixing ratio: Sawdust	Mixing ratio: Rice husk	Required compaction pressure (N/cm^2)	Calorific value (MJ/kg)	Density (kg/m^3)
1	90	10	710	17.16	494.2
2	80	20	734	16.64	417.67
3	70	30	759	15.56	424.23
4	60	40	783	16.39	403.57
5	50	50	809	16.30	404.48
6	40	60	833	16.49	422.83
7	30	70	857	16.25	491.24
8	20	80	882	16.03	483.08
9	10	90	906	15.79	478.15

Source: Essien 2017

Table 6: Required compaction pressures, calorific value and density of heterogeneous briquette of palm kernel shell/rice husk.

S/N	Mixing ratio		Required compaction pressure (N/cm^2)	Calorific value (MJ/kg)	Density (kg/m^3)
	Palm kernel shell	Rice husk			
1	10	90	936	14.93	723.53
2	20	80	941	15.40	780.63
3	30	70	946	15.54	884.35
4	40	60	951	15.98	867.28
5	50	50	956	15.93	1067.26
6	60	40	960	15.79	1142.36
7	70	30	965	16.18	1168.19
8	80	20	970	16.04	1288.32
9	90	10	975	16.25	1500.07

Source: Essien 2017

a spring back effect; and due to the lower affinity of rice husk material with the binder used, as observed in the course of the research (Essien 2017).

Table 6 depicts the required compaction pressures, the calorific values and the densities of the heterogeneous briquettes of palm kernel shell/rice husk at their respective mixing ratios. The result in Table 6 shows that the required compaction pressure increased with an increase in percentage composition of palm kernel shell material in the briquette samples. The calorific value was also observed to increase with an increase in the percentage of palm kernel shell material in the briquettes. The presence of palm kernel shell material improved the quality and the calorific value of rice husk briquettes compared to the homogeneous briquettes of rice husk (Essien 2017).

The graph in Figure 4 shows the variation of density with compaction pressure. The graph shows that the density of the briquettes increased with an increase in the compaction pressure of the briquettes. The curve is an irregular curve as there was some randomness in the variation between the two factors. This explains the fact that many other factors like material type, the percentage composition of the material and the effect of binder, as well as other factors as reported by Menind et al. (2012), do influence the quality and properties of heterogeneous briquettes even when some factors have been experimentally controlled. This can be seen clearly in the sawdust/rice husk briquette graph. 'This density variation graph further explains the complex relationship between the different factors that influence the quality of heterogeneous briquettes' (Essien 2017).

Compaction of the heterogeneous briquettes at the fixed compaction pressure

Tables 7–9 depict the result of the calorific values and densities of the heterogeneous briquettes when compacted at the fixed compaction pressure higher than the require compaction pressures obtained from the model.

Comparing the results obtained when the briquettes were compacted at their respective required compaction pressures (compaction pressure predicted from the developed model) to the results obtained when the briquettes were compacted at the fixed compaction pressure showed that better quality briquettes (in terms of densities and calorific values) were obtained when the briquettes were compacted at the predicted 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).

Conclusion

The study developed an empirical model for predicting the required compaction pressure of heterogeneous briquettes. As observed in the course of the study, certain optimum compaction pressures are required to produce good quality briquettes.

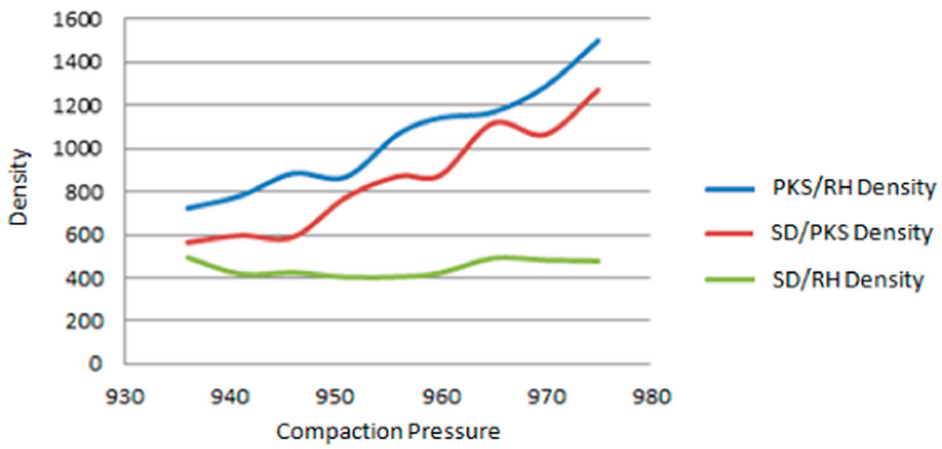

Figure 4: Compaction pressure and density relationship for the three heterogeneous briquettes (Essien 2017).

Table 7: Calorific values and densities of sawdust/palm kernel shell briquette when compacted at a fix pressure of 1177 (N/cm^2).

	Mixing ratio				
S/N	Sawdust	Palm kernel shell	Compaction pressure (N/cm^2)	Calorific value (MJ/kg)	Density kg/m^3
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

Source: Essien 2017

Table 8: Calorific values and densities of the heterogeneous sawdust/rice husk.

	Mixing ratio				
S/N	Sawdust	Rice husk	Compaction pressure (N/cm^2)	Calorific value (MJ/kg)	Density kg/m^3
1	90	10	1177	16.50	400.53
2	80	20	1177	16.31	358.01
3	70	30	1177	15.93	346.15
4	60	40	1177	16.11	344.51
5	50	50	1177	15.30	350.03
6	40	60	1177	15.42	371.81
7	30	70	1177	15.25	419.97
8	20	80	1177	15.03	424.69
9	10	90	1177	15.11	425.02

Note: Briquette when compacted at a fix pressure of 1177 (N/cm^2) (Essien 2017).

Table 9: Calorific values and densities of the heterogeneous.

	Mixing ratio				
S/N	Palm kernel shell	Rice husk	Compaction pressure (N/cm^2)	Calorific value (MJ/kg)	Density kg/m^3
1	10	90	1177	14.03	583.33
2	20	80	1177	14.91	623.29
3	30	70	1177	15.04	789.49
4	40	60	1177	14.98	779.03
5	50	50	1177	15.43	906.88
6	60	40	1177	15.46	938.58
7	70	30	1177	15.52	965.92
8	80	20	1177	15.67	1157.56
9	90	10	1177	16.01	1240.36

Note: Briquette palm kernel shell/rice husk when compacted at a fix pressure of 1177 (N/cm^2) (Essien 2017).

> In the case of homogeneous briquettes, the required compaction pressures depend largely on the material nature of the agricultural waste compacted while in the case of heterogeneous briquettes, it also depends on the percentage composition (the mixing ratio) of the constituent agricultural wastes in the heterogeneous briquette. (Essien 2017)

Three composite or heterogeneous briquettes, sawdust/palm kernel shell, sawdust/rice husk, and palm kernel shell/rice husk, were produced in course of this research. The required compaction pressures of the briquettes, as predicted from the model, ranged from 715 N/cm^2 to 950 N/cm^2 for sawdust/palm kernel shell briquettes, 710 N/cm^2 to 906 N/cm^2 for sawdust/rice husk briquettes, and 936 N/cm^2 to 975 N/cm^2 for palm kernel shell/rice husk briquettes.

This study has provided a useful 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. The briquettes produced at the required compaction pressure predicted from the developed model possess density or calorific value or both in the range of the generally accepted standard quoted by Akintunde (2012).

The results obtained in this study have shown that compaction pressure greatly influences the quality of briquettes; therefore, it can be concluded that compacting briquettes with inappropriate compaction pressures will often result in poor quality briquettes. ‘This is owing to the fact that the binding materials are often squeezed out of the briquettes thereby leading to excessive spring back and to poor quality briquettes’ (Essien 2017). To check these anomalies, designers of variable pressure briquetting machines should focus attention on the regulation of compaction pressure to ensure good quality briquette production.

This research work has further validated the energy potential in biomass as can be harnessed through briquetting technology and therein highlights the need for the Renewable Electricity Policy Guidelines (REPG), 2006 (Iwayemi et al. 2014), and National Renewable Energy Efficiency Policy (NREEEP) (2014) to co-opt the tapping of electricity from biomass which is a viable renewable energy source.

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