Evaluating Groundnut Shell Briquettes as High Grade Fuels for Domestic Cooking; Part 1: Modeling the Effect of Processing Parameters on the Physio-Mechanical Characteristics of the Briquettes

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Abstract

The paper investigated and modelled the effect of some processing parameters namely; particle size, binder ratio and compaction pressure on the physio-mechanical characteristics (maximum density, relaxed density, density ratio, compaction ratio, durability and compressive strength) of groundnut shell briquettes. Multiple regression analysis was used for the development of these models using SPSS 20 version. It was discovered that the results of the physio-mechanical characteristics of the groundnut shell briquettes obtained compared favourably well with those obtained by previous researchers. However, none of the processing parameters had significant effect on the physio-mechanical characteristics of the groundnut shell briquettes. This implied the models are not very strong (the processing parameters were not linearly related to the response variables). Thus, the need to investigate the effect of the interaction and quadratic effects of the processing parameters on the physio-mechanical characteristics of the groundnut shells briquettes. Hence, the need to resort to higher order techniques such as response surface methods to study the effects of the interaction and quadratic variables of the independent variables on the response variables of the briquettes.

Keywords: *Briquettes, model, durability, particle size, binder ratio, compaction pressure*

1. Introduction

The decreasing availability of domestic fuel like wood, charcoal and the ever-rising prices of kerosene and cooking gas in Nigeria, has drawn attention to the need to consider alternative sources of energy for domestic and cottage level industrial use in the country (Kwadzah and Ogbeh, 2013). Traditionally, wood in the form of fuel wood, twigs and charcoal had been the major sources of renewable energy in Nigeria, accounting for about 51% of the total annual energy consumption (Kwadzah and Ogbeh, 2013).

One of the principal sources of energy is fossil fuels. According to El-Saeidy 2004 and Kaliyan and Morey, 2009, 86% of energy being consumed all over the world is from fossil fuels. It must be admitted that, the use of fossil fuels is very convenient. However, many problems are associated with their applications. One of such problems is the issue of global warming, the seriousness of which was underscored by United Nation sponsored conference on climate change held at Copenhagen in Sweden in early December, 2009, where notable world leaders rubbed mind on how best to reduce global warming (Oladeji, 2011). Therefore, there is the need to gradually shift attention from fossil fuels and in this regard agricultural residues can play a significant role in alternative energy generation on a renewable basis.

Fuel briquettes under different conditions have been reported to have different handling characteristics. These characteristic are also found to be strongly affected by the raw material properties. If biomass or agro-waste briquettes are to be used efficiently and rationally as fuel, they must be characterized to determine parameters such as the moisture content, ash content, density, volatile matter, and heating values among others. The result of these determinations indicates the positive and negative attributes of agro-waste briquettes (Oladeji, 2010).

One of the processes through which these residues could be converted to biomass energy is briquetting. Olorunnisola, 2007, Wilaipon, 2007 described briquetting as a process of compaction of residues into a product of higher density than the original material, while Kaliyan and Morey 2009 defined briquetting as a densification process.

Controlling densification system variables can be important to achieving the desired density, durability and quality. The quality of pellets or briquettes can be managed by proper control of manufacturing conditions, such as control of the manufacturing process, change of formulation and the use of additives (Tumurulu et. al, 2011). Shaw (2008), in his studies on densification of biomass, demonstrates how process variables (die temperature, pressure, and die geometry) feedstock variables (moisture content, particle size, and shape) and biomass composition (protein, fat, cellulose, hemi cellulose, and lignin) play a major role in the quality of the densified biomass.

The aim of this research was to model the effect of some processing parameters (binding ratio, compaction pressure and particle size) on the physio-mechanical characteristics (maximum density, relaxed density, density ratio, compaction ratio, briquette durability and compressive strength) of groundnut shell briquettes.

2. Materials and Methods

Groundnut shell residues were obtained from the premises of Federal Polytechnic Bauchi opposite Gwallameji village in Bauchi town. The groundnut shell residues were sun-dried until stable moisture content was obtained, thereafter subjected to size reduction process through the use of mortar and pestle. Three different particle sizes 0.8mm, 2.4mm and 4.0mm representing fine, medium and coarse respectively were selected for this work. Cassava starch was bought from Gwallameji market in Bauchi and mixed with hot water and stirred properly in order to form a starch gel. Thereafter the residues were thoroughly mixed with the starch gel at the ratio of 10, 20 and 30% by weight of residues and formed into briquettes with the aid of a fabricated briquetting machine at compaction pressures of 2.0, 3.5 and 4.5 Mpa respectively. A dwell time of 120 seconds was observed for the briquettes during formation. The initial, maximum and relaxed densities were obtained using ASAE standard methods for determining densities.

The compaction ratio was determined as the ratio of the maximum density (the compressed density of the briquette immediately after ejection from the briquetting machine) to the initial density (density of the residue before compressing in the briquetting machine). It can be expressed mathematically as:

$$CompactionRatio = \frac{MaximumDensity}{InitialDensity} \qquad (1)$$

(Oladeji, 2012).

The density ratio of the briquettes was determined as the ratio of the relaxed density to the maximum density. The relaxed density which is also known as the spring back density can be defined as the density of the briquette obtained after the briquette has remained stable and is simply calculated as the ratio of the briquette's mass to the new volume. Mathematically,

$$DensityRatio = \frac{RelaxedDensty}{MaximumDensity} \qquad (2)$$

(Oladeji, 2012).

The shattering index is a measure of the durability of the briquettes. The durability of the briquettes as defined by Kakitis et al, (2011) is the measure of the resistance of densified fuels towards shocks and/or abrasions as a consequence of handling and transportation processes. The briquettes shattering index was measured according to ASTM D44086 (2002) of drop shatter developed for coal (Davies and Abolude, 2013). The test was conducted after two weeks of briquettes sample formation. A test sample of five briquettes of Known weight (W_1) was placed in a plastic polythene bag. The bag was thrown onto concrete flow three times. After the dropping, the briquettes and fractions was placed on top of a 35cm square mesh screen and sieved. The experiment was replicated three times. The durability rating for each type of briquette was expressed as the ratio of weight of material retained on the screen (W_2) to weight of the briquette before the dropping. The handling durability of the briquette was computed as:

$$Shattering\ index = \frac{Weight\ of\ briquettes\ retained\ on\ the\ screen\ after\ dropping}{Weight\ of\ briquettes\ before\ dropping} \qquad (3)$$

2.1 Model Development

Let the functional relationship between the dependent and independent variables be as follows:

(i) MD = f (PS, BR, CP) + constant

(ii) RD = f (PS, BR, CP) + constant

(iii) DR = f (PS, BR, CP) + constant

(iv) CR = f (PS, BR, CP) + constant

(v) BD = f (PS, BR, CP) + constant

(vi) CS = f (PS, BR, CP) + constant

Where P.S, B.R, C.P, M.D, R.D, D.R, C.R, BD and CS stand for particle size, binder ratio, compaction pressure, maximum density, relaxed density, density ratio compaction ratio, briquette durability and compressive strength respectively.

After establishing the relationship between the dependent and independent variables, multiple regression analysis was used to estimate the coefficient of the models.

3. Results and Discussion

The effect of the processing parameters (binding ratio, compaction pressure and particle size) on the physio-mechanical characteristics (maximum density, relaxed density, density ratio, compaction ratio, briquette durability and compressive strength of groundnut shell briquettes is shown in Table 1.

The maximum densities (column iv in Table 1.) varied from 247.14 to 854.7 Kg/m^3. These values are within the range of 600 Kg/m^3 recommended by Gilbert et. al (2009) and Mani et. al (2006) for efficient transportation and storage. The value of the relaxed densities (column v in Table 1.) varied from 286.86 to 452.31 Kg/m3. These values are lower than 194.64 to 927.81 Kg/m^3 obtained for maximum densities in this work implying that the briquettes can be easily handled and transported. The values of the compaction ratio which varied from 0.833 to 2.882 (Table 1.) compare and compete favourably well with notable biomass residues like melon shells and rice husks with 3.5 and 3.8 respectively (Oladeji et. al 2009 and Oladeji 2010).

Furthermore, the values of the density ratio which varied from 0.499 to 1.433 (Table 1.) compared well with notable biomass residues like coconut fibres, palm fibre and peanut shells with density ratio vales of 0.71, 0.41 and 0.25 respectively (Chin and Siddique, 2000). The values of the compaction and density ratios obtained in this research are sufficient enough implying that the briquettes would not crumble during transportation and storage. The values of the briquette durability (Table 1.) varied from 40 to 85% compared well with notable biomass briquettes like barley (42 - 92%), canola (72 – 95%), oat (43 – 91%) and wheat (45 – 95%) (Tumuluru et al, 2011).

Table 1. The Effect of Some Processing Parameters on the Physio-Mechanical Characteristics of Groundnut Shell Briquettes

S/No	Particle Size (mm)	Binder Ratio (%)	Compaction Pressure (MPa)	Maximum Density (Kg/m^3)	Relaxed Density (Kg/m^3)	Density Ratio	Compaction Ratio	Durability (%)	Compressive Strength (KN/m^2)
1	0.8	30	35	2.8490	1.4250	0.500	2.882	70	8.961475
2	0.8	20	35	1.4637	1.1709	0.800	1.481	45	7.541003
3	0.8	10	45	1.6122	0.9673	0.599	1.631	40	8.407349
4	2.2	30	35	1.4336	1.1465	0.799	1.450	65	9.863016
5	2.2	20	35	1.9771	0.9885	0.499	1.999	40	9.426254
6	2.2	10	25	2.0047	1.0024	0.500	2.028	80	9.174898
7	3.6	30	45	0.8238	1.0984	1.333	0.833	85	8.7396
8	3.6	20	45	1.6122	0.9673	0.599	1.631	70	8.60024
9	3.6	10	35	0.9238	1.1185	1.433	0.933	45	6.741994
10	0.8	30	25	1.5143	0.9562	1.333	0.862	60	7.883554
11	0.8	20	25	0.8518	1.1357	0.700	1.501	40	7.367329
12	2.2	20	45	2.2616	1.5077	0.667	2.288	70	12.12211
13	2.2	10	45	1.8847	1.1307	0.599	1.906	50	11.11194
14	3.6	10	25	0.9238	1.1185	1.433	0.933	55	6.277029
15	3.6	30	25	0.8238	1.0984	1.333	0.862	70	7.305347

(Source: Author, 2016)

Where P.S, B.R, C.P, M.D, R.D, D.R, C.R, BD and CS stand for particle size, binder ratio, compaction pressure, maximum density, relaxed density, density ratio compaction ratio, briquette durability and compressive strength respectively.

The values of the compressive strength (Table 1.) varied from 6.277029 to 12.12211KN/m^2 which compared well with the value of 4.545 KN/m^2 obtained by Supatata et al, (2013) for fuel briquettes made from sewage sludge mixed with water hyacinth. These values of durability and compressive strength are reasonable enough implying that the briquettes will suffer less damage during transportation and storage.

The estimated coefficients of the fitted model for the response variables obtained from the regression analysis of the experimental data using SPSS 20 Version were presented in Table 2. The empirical models obtained using the regression analyses were presented in equations 4-9 below.

$MD = 2.098 - 0.232PS - 0.00BR + 0.010CP$ [R^2 = .242] .... (4)

$RD = 1.163 - 0.018PS$ [R^2 = .019] .... (5)

$DR = 0.368 + 0.164PS - 0.009BR - 0.027CP$ [R^2 = .334] .... (6)

$$CR = 2.251 - 0.236PS - 0.012BR + 0.010CP \qquad [R^2 = .260] \ldots \quad (7)$$

$$DB = 34.786 + 5.498PS + 0.675BR - 0.219CP \qquad [R^2 = .318] \ldots \quad (8)$$

$$CS = 8.642 - 0.183PS - 0.002BR + .069CP \qquad [R^2 = .236] \ldots \quad (9)$$

Table 2. Output Variables of the Regression Analysis of the Effects of Some Processing Parameters on the Physio-Mechanical Characteristics of Groundnut Shell Briquettes Using SPSS 20 Version

	Model Factors	Coefficients	t-vales	Sig.
Maximum Density (Kg/m^3)	Constant	2.098	3.958	.002
	PS	-.232	-1.736	.110
	BR	-.006	-.318	.756
	CP	-.010	.702	.497
	R^2=.242, R^2_{Adj}=.035			
Relaxed Density (Kg/m^3)	Constant	1.163	7.298	.000
	PS	-.018	-.454	.658
	BR	.000	-.027	.979
	CP	.000	.102	.920
	R^2=.019, R^2_{Adj}=-.218			
Density Ratio	Constant	.386	1.238	.242
	PS	.164	2.082	.062
	BR	.009	.805	.438
	CP	-.008	-.918	.378
	R^2=.334, R^2_{Adj}=.152			
Compaction Ratio	Constant	2.251	4.236	.001
	PS	-.236	-1.767	.105
	BR	-.012	-.666	.519
	CP	.010	.710	.492
	R^2=.260, R^2_{Adj}=.058			
Briquette Durabilty (%)	Constant	34.768	2.743	.019
	PS	5.498	1.717	.114
	BR	.675	1.505	.160
	CP	-.219	-.626	.544
	R^2=.318, R^2_{Adj}=.132			
Compressive Strength (KN/m^2)	Constant	8.642	6.154	.000
	PS	-.183	-.516	.616
	BR	-.002	-.031	.976
	CP	.069	1.772	.104
	R^2=.236, R^2_{Adj}=.027			

From the regression test results Table 2, the processing parameters (particle size, PS, binder ratio, BR, and compaction pressure, CP) were found to have no significant effect ($p>0.05$) on the physio-mechanical characteristics (maximum density, MD, relaxed density, RD, density ratio, DR, compaction ratio, CR, briquette durability, BD and compressive strength, CS) of the groundnut shell briquettes. Moreover, the correlation coefficients, R^2 and R^2_{Adj} values were less than 44.5%. The implications of these were that the models are not very strong (the processing parameters were not linearly related to the response variables). Thus, the need to investigate the effect of the interaction and quadratic effects of the of the processing parameters on the physio-mechanical characteristics of the groundnut shell briquettes. Hence, the need to resort to higher order techniques such as response surface methods to study the effects of the interaction and quadratic variables of the independent variables on the response variables of the briquettes.

4.0 Conclusion

The effect of some processing parameters namely; particle size, binder ratio and compaction pressure on the physio-mechanical characteristics (maximum density, relaxed density, density ratio, compaction ratio, durability and compressive strength) of groundnut shell briquettes has been investigated and modelled in this research. Multiple regression analysis was used for the development of these models using SPSS 20 version.

It was discovered that the results of the physio-mechanical characteristics of the groundnut shell briquettes obtained compared favourably well with those obtained by previous researchers as mentioned in section 3 above.

However, none of the processing parameters had significant effect on the physio-mechanical characteristics of the groundnut shell briquettes. This implied the models are not very strong (the processing parameters were not linearly related to the response variables). Thus, the need to investigate the effect of the interaction and quadratic effects of the processing parameters on the physio-mechanical characteristics of the groundnut shells briquettes. Hence, the need to resort to higher order techniques such as response surface methods to study the effects of the interaction and quadratic variables of the independent variables on the response variables of the briquettes.

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