Evaluating Groundnut Shell Briquettes as High Grade Fuels for Domestic Cooking; Part 2: Modeling the Effect of Processing Parameters on the Combustion 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 combustion characteristics (volatile matter, VM, fixed carbon, FC, ash content, AC, moisture content, MC and calorific value, CV) of the 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 combustion characteristics of the groundnut shell briquettes obtained compared favourably well with those obtained by previous researchers. However, apart from particle size on some occasions, none of the processing parameters had significant effect on the combustion characteristics of the groundnut shell briquettes. This implied 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 processing parameters on the combustion 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.

Keywords: *briquettes, combustion, fixed carbon, volatile matter, heating value*

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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). However, increased use of fuel wood is not encouraged as it causes soil erosion and desertification. Also, kerosene and gas though viable and much more convenient, are expensive, fast depleting and scarce as they are no longer easily available. These, therefore, have necessitated the need to search for other alternative sources of fuel for domestic cooking. On this basis, the quest for agricultural residues as alternative sources of energy becomes imperative. This is due to the fact that, they are environmentally friendly, renewable (i.e. can be replenish after usage) and readily available.

One of the processes through which these residues could be converted to biomass energy is briquetting. Olorunnisola (2007) and 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.

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).

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.

Combustion or burning is the sequence of exothermic chemical reactions between a fuel and an oxidant accompanied by the production of heat and conversion of chemical species. The release of heat can produce light in the form of either glowing or a flame. The combustion characteristics considered in this paper were fixed carbon, volatile matter, ash content and heating values of the briquettes. Compaction pressure is the stress exerted uniformly in all directions on the biomass residues in order to increase the dry density of the briquettes by means such as impact or by rolling their surface layers. The aim of this work was to model the effect of processing parameters (particle size, binder ratio and compaction pressure) on the combustion characteristics (fixed carbon, volatile matter, ash content and heating value) 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. The 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.

Volatile matters are the methane, hydrocarbons, hydrogen and carbon monoxide, and incombustible gases like carbon dioxide and nitrogen found in coal/briquettes. Thus the volatile matter is an index of the gaseous fuels present. A typical range of volatile matter is 20 to 35%.

Percentage volatile matter was determined in accordance to ASTM D5373-02, (2003).About 2g of ground residue was selected. The sample was placed in crucible and heated in a muffle furnace at 250^0C for 7 minutes. The crucible was retrieved and kept to cool in desiccators to room temperature. The final weight was determined. The loss in weight was expressed as a percentage of the original weight to obtain the percentage volatile matter as in Equation (1).

$$\%Vm = \frac{100(W_1 - W_2)}{W_1} \qquad \text{.....................} \ (1)$$

Where W_1 is the initial weight of the oven-dried sample and W_2 is the final weight of the sample after being subjected to 250^0C for 7 minutes.

Ash is an impurity that will not burn. Typical range is 5% to 40%. Ash reduces handling and burning capacity, increases handling costs, affects combustion efficiency and boiler efficiency and causes clinkering and slagging.
The ash content was determined according to ASTM Standard D5373-02, (2003). About 2g of finely ground sample of the briquette was placed in a crucible and heated in a muffle furnace at 2500C for 10 minutes. After cooling it in desiccators, the final weight was measured. The ratio of the initial weight to the final weight was expressed as a percentage to obtain percentage ash content of the residue samples using Equation (2).

$$\%Ash = \frac{100W_3}{W_4} \qquad \text{..} \ (2)$$

Where W_3 is the initial weight of the oven-dried residue sample and W_4 is the final weight.

Fixed carbon is the solid fuel left in the furnace after volatile matter is distilled off. It consists mostly of carbon but also contains some hydrogen, oxygen, sulphur and nitrogen not driven off with the gases. Fixed carbon gives a rough estimate of the heating value of coal/briuqettes.
ASTM Standard D5373-02, (2003) was used for determination of the fixed carbon. The fixed carbon was obtained by assuming that, the sulphur content is negligible as found by Emerchi (2011). The amount of fixed carbon in the combusted oven-dried sample was obtained using Equation (3).

$$\%FC = 100\% - \left(\%Ash + \%V_m + \%M_c\right) \qquad \text{..........................} \ (3)$$

Where %FC is the amount of fixed carbon (%), %Ash is the oven-dried residue sample, V_m is the volatile matter content of the oven dried residue sample (%) and $\%M_c$ is the % moisture content (dry-basis).

The calorific value is the measurement of heat or energy produced, and is measured either as gross calorific value or net calorific value. The difference is determined by the latent heat of condensation of the water vapour produced during the combustion process. Gross calorific value (GCV) assumes all vapour produced during the combustion process is fully condensed. Net calorific value (NCV) assumes the water leaves with the combustion products without fully being condensed. Fuels should be compared based on the net calorific value.
Heating value also known as the potential energy value of the produced briquettes was determined by the use of Gallen-Kamp Bomb calorimeter and the procedure as highlighted in accordance with ASTM Standard E711-87 (2004) was adopted. The heating value was determined in the following sequence.

1g of the sample was placed in a crucible located inside the bomb calorimeter. Ensuring that there was no weight loss, the sample was carefully pressed down with a spatula to form it into a smooth level layer suitable for combustion. The bomb closing ring was screwed such that the metal to metal contact is achieved between the bomb body and the base. The bomb was filled with oxygen from the steel gas cylinder to a pressure of about 25 bars. The time-firing button was pressed. The reading of the maximum deflection of the galvanometer was closely monitored.

The heating value of the biomass residue was computed based on the following expression given by Emerchi (2011).

$$Cv = \frac{(M_w - M_c)C\Delta T}{M_F} \tag{4}$$

Where; C_v is the higher heating value of the fuel (residue), M_w is the mass of water, M_c is mass of water equivalent of calorimeter, C specific heat capacity of water, M_F is the mass of fuel (residue) tested and ΔT is the corrected temperature rise of water.

2.1 Model Development

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

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

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

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

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

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

Where P.S, B.R, C.P, V.M, F.C, A.C, M.C and C.V stand for particle size, binder ratio, compaction pressure, volatile matter, fixed carbon, ash content, moisture content and calorific value 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 combustion characteristics (volatile matter, fixed carbon, ash content, moisture content and calorific value) of groundnut shell briquettes is shown in Table 1.

The values of the (%) fixed carbon (Table 1.) varied from 3 to 17% which is in line with the work of Garivait et al (2006) that obtained 15.54, 16.03 and 13.14% for rice straw, maize stalk and sugarcane briquettes respectively. The values of the % volatile matter (Table 1.) varied from 22 to 56%. These values are in accordance with the work of Emerchi (2011) who obtained values of 60.39 to 89.47% for % volatile matter from sawdust of three hardwood species with different organic binders. The values of the % ash content (Table 1.) varied from 26 to 50%. These values are also in conformity with the values of 14.89 to 28.13% obtained by Emerchi (2011) for % ash content from sawdust of three hardwood species with different organic binders. These values of % fixed carbon, ash content and volatile matter are good and acceptable. This is because higher percentage of the briquettes would be made available for combustion.

The values of the calorific value (Table 1.) varied from 13,631.60 to 21,162.59KJ/Kg. These values compare well with the results of the heating value of most biomass briquettes including almond shell briquettes (19,490KJ/Kg), corncob briquettes (20,890KJ/Kg), cowpea (14,372.93KJ/Kg) and soybeans (12,953KJ/Kg) (Emerchi, 2011). These values of energy value are sufficient enough to produce the heat required for household and cottage applications.

The values of the moisture content (%) varied from 2 to 22%. These results are within the limits of 15% recommended by Wilaipon (2008), and Grover and Mishra (1996) for briquetting of agro-residues.

S/No	Particle Size (mm)	Binder Ratio (%)	Compaction Pressure (MPa)	Volatile Matter (%)	Ash Content (%)	Moisture Content (%)	Fixed Carbon (%)	Calorific Value (Kcal/Kg)
1	0.8	30	35	15	26	20	39	18415.79
2	0.8	20	35	14	26	16	44	19783.41
3	0.8	10	45	16	40	22	22	12950.26
4	2.2	30	35	17	30	18	35	17729.50
5	2.2	20	35	7	40	10	43	17063.04
6	2.2	10	25	6	50	6	38	15015.74
7	3.6	30	45	17	36	24	23	13631.60
8	3.6	20	45	16	36	14	34	17048.17
9	3.6	10	35	3	50	2	45	16386.66
10	0.8	30	25	15	26	20	39	18415.79
11	0.8	20	25	15	45	16	24	13293.41
12	2.2	10	45	16	30	18	36	17731.15
13	2.2	10	45	16	30	18	36	17731.15
14	3.6	10	25	6	50	2	42	16381.70
15	3.6	30	25	6	36	2	56	21162.59

Table 1. The Effect of Processing Parameters on the Combustion Characteristics of Groundnut Shell Briquettes

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.

$$VM = 11.437 - 1.790PS + 0.206BR + 0.115CP \qquad [R^2 = .380] \ldots. \quad (5)$$

$$FC = 29739 + 2.377PS + 0.123BR - 0.058CP \qquad [R^2 = .107] \ldots. \quad (6)$$

$$AC = 44.285 + 2.783PS - 0.623BR - 196CP \qquad [R^2 = .588] \ldots. \quad (7)$$

$$MC = 14.539 - 3.371PS + 0.294BR + 0.139CP \qquad [R^2 = .456] \ldots. \quad (8)$$

$$CV = 14042.351 + 203.725PS + 111.943BR + 19.342CP \qquad [R^2 = .174] \ldots. \quad (9)$$

Table 2. Output Variables of the Regression Analysis of the Effects of Some Processing Parameters on the Combustion Characteristics of Sawdust Briquettes Using SPSS 20 Version

	Model Factors	Coefficients	t-vales	Sig.
Volatile Matter (%)	Constant	11.437	2.836	.016
	PS	-1.790	-1.757	.107
	BR	.206	1.445	.176
	CP	.115	1.030	.325
	R^2=.380, R^2_{Adj}=.211			
Fixed Carbon (%)	Constant	29.739	3.426	.006
	PS	2.377	1.084	.301
	BR	.123	.400	.697
	CP	-.058	-.240	.815
	R^2=.107, R^2_{Adj}=-.137			
Ash Content (%)	Constant	44.285	7.669	.000
	PS	2.783	1.908	.083
	BR	-.623	-3.051	.011
	CP	-196	-1.228	.245
	R^2=.588, R^2_{Adj}=.475			
Moisture Content (%)	Constant	14.539	2.565	.026
	PS	-3.371	-2.355	.038
	BR	.294	1.468	.170
	CP	.139	.886	.395
	R^2=.456, R^2_{Adj}=.307			
Calorific Value (KJ/Kg)	Constant	14042.351	6.516	0.000
	PS	203.725	.374	.715
	BR	111.943	1.469	.170
	CP	19.342	.325	.751
	R^2=.174, R^2_{Adj}=-.052			

From the regression test results Table 2, the processing parameters with the exception of particle size, PS, (binder ratio, BR, and compaction pressure, CP) were found to have no significant effect ($p>0.05$) on the combustion characteristics (volatile matter, VM, fixed carbon, FC, ash content, AC, moisture content, MC and calorific value, CV) of the groundnut shell briquettes. Moreover, most of 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 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 combustion 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.

4. Conclusion and Recommendations

The effect of some processing parameters namely; particle size, binder ratio and compaction pressure on the combustion characteristics (volatile matter, VM, fixed carbon, FC, ash content, AC, moisture content, MC and calorific value, CV) of the 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 combustion characteristics of the groundnut shell briquettes obtained compared favourably well with those obtained by previous researchers as mentioned in section 3 above.

However, only the particle size among the processing parameters had significant effect ($p<0.05$) on some of the combustion 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 combustion 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.

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