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Investigations into Physical and Fuel Characteristics of Briquettes Produced from Cassava and Yam Peels

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Abstract
Globally, 140 billion metric tons of biomass is generated every year from agriculture. This volume of biomass can be converted to an enormous amount of energy and raw materials. These residues are usually dumped and flared on the farms, where they constitute health risk to both human and ecology. Densification of these residues would improve their bulk handling, transportation and storage properties. Therefore, this work investigated densification characteristics of cassava and yam peels using an experimental briquetting machine.

The ASAE standard methods were used to determine the moisture contents (dry basis) and densities of the milled residues and briquettes, while ASTM standard methods were used to determine the proximate and ultimate analyses of the residues. The initial, maximum and relaxed densities were also determined using ASAE standard methods. Also evaluated were compaction, density and relaxation ratios of the briquettes. The mechanical properties were determined using universal testing machine, while the heating value was determined using Ballistic Bomb calorimeter. The mean moisture contents of cassava and yam peels residues were 10.19% and 9.27% respectively, while those of relaxed briquettes were 8.76% and 7.95% respectively. The initial, maximum and relaxed densities were 251.50 kg/m^3; 741.13 kg/m^3 and 386.4 kg/m^3 respectively for briquettes produced from cassava peel, while the corresponding values for briquettes produced from yam peel were 283.40 kg/m^3; 911.45 kg/m^3 and 512.54 kg/m^3 respectively. The compaction ratio of 2.94 and 3.21 were obtained for briquettes produced from cassava and yam peels respectively. The compressive strength of briquette from cassava peel was 1.53kN/m^2 (SD 0.05), while that of yam peel was 1.76kN/m^2 (SD 0.04). The higher heating value of briquettes from cassava peel was found to be 12,765kJ/kg (SD 30), while the corresponding value for yam peel was 17,348kJ/kg (SD 20). The results of this work indicate that briquettes produced from the two biomass residues would make good biomass fuels. However, findings show that yam peel briquette has more positive attributes of biomass fuel than its cassava peel counterpart. It has a moderate moisture content of 10.95 %, higher density of 911.45 kg/m^3 and lower relaxation ratio of 1.78. Other positive attributes of yam peel briquette over cassava peel are long after glow time of 375 secs and slow propagation rate of 0.16 cm/s. It also has higher heating value of 17,348 kJ/kg and compressive strength of 1.76 kN/m^2 compared to cassava peel, which are 12,765 kJ/kg and 1.53 kN/m^2 respectively.

Keywords: agricultural wastes, briquette, briquetting machine, cassava peel, yam peel,

1. Introduction

The importance of energy for a nation's development cannot be overemphasized. This is because; energy is the cornerstone of economic and social development (El-Saeidy, 2004). Globally, 140 billion metric tons of biomass is generated every year from agriculture (Jekayinfa and Scholz, 2009). This volume of biomass can be converted to an enormous amount of energy and raw materials equivalent to approximately 50 billion tons of oil. Agricultural biomass waste, if converted to energy can substantially displace fossil fuel, reduce emissions of greenhouse gases and provide renewable energy to some 1.6 billion people in developing countries, which still lack access to electricity (El-Saeidy, 2004). Biomass takes the form of residual stalks, straws, leaves, roots, husks, nut or seed shells, waste wood and animal husbandry wastes (Oladeji, et. al., 2009). Widely available, renewable, and virtually free, waste biomass is an important resource.

Although, there is an emerging trend in the utilization of biomass energy conversion technologies from combustion of rice husk and sugarcane bagasse to gasification of other agricultural residues, biomass is still largely under-utilized and left to rot or openly burnt in the fields, especially in developing countries (Jekayinfa and Omisakin, 2005). As commonly practiced, direct combustion of agricultural residue results in air pollution, thereby posing health risk to both human and ecology (Wilaipon, 2008).

One of the principal sources of energy is fossil fuels and according to Wilaipon (2007) and Kaliyan and Morey (2009), 86 % of all the energy consumed all over the world come from fossil fuels. Although, the use of fossil fuels is very convenient, there are a lot of problems associated with their application. One of such problems is environmental degradation as a result of green house emissions. The seriousness of global warming was underscored by the United Nation sponsored conference on climate change held at Copenhagen in Sweden in early December, 2009, where notable world leaders rubbed minds on how best to reduce global warming.

Agricultural residues in their natural forms will not bring a desired result because, they are mostly loose, low density materials in addition to the fact that their combustion cannot be effectively controlled (Enweremadu, et al., 2004; Wilaipon, 2009). Although, there are many conversion routes through which these residues can be converted into biomass energy, one of such promising technologies is that of the briquetting process. Wilaipon (2008) described briquetting as a process of compaction of residues into a product of higher density than the original material, while Kaliyan and Morey (2009), Gilbert, et al. (2009) defined briquetting as a densification process. The use of briquettes can reduce drastically the demand for wood and therefore decrease deforestation (Oladeji, et al., 2009). Among the agro-residues and forestry wastes that can be subjected to the process of briquetting are residues from maize, wood, guinea corn, beans, groundnut, rice, cotton and sugar cane. Many of these residues that have been subjected to process of briquetting are those of wood, cotton, rice straw, and banana peel (Granada et al., 2002; El-Saeidy, 2004; Wilaipon, 2008). Others are waste paper + admixture of coconut husks, rattan furniture waste and maize cob (Olorunnisola, 2004, 2007; Wilaipon, 2007). Generally, techniques of briquetting are grouped into two major classes: namely high-pressure technique and low-pressure technique (Bhattacharya et al., 2002). There are also two ways in which briquettes can be formed and these are briquettes with binders and briquettes without binders. Both techniques mentioned above can produce any shape, be it rectangular, spherical, pellet form and so on (Garriot, 2004). The broad aim of this work was to investigate the physical and combustion characteristics of briquettes produced from cassava and yam peels with blend of cassava starch gel. This would go a long way to reduce garbage in our cities, towns and villages.

2. Materials and Methods

Cassava and yam peels that were utilized in this work were obtained from waste dumps at Odo-Oba, a suburb of Ogbomoso. The residues were sun-dried until stable moisture content was obtained. The two residues were individually subjected to size reduction process through the use of hammer mill equipped with a 2.0 mm screen in compliance with procedure described in ASAE424.1. (2003)

A simple prototype briquetting machine was fabricated to facilitate the process of conversion of the two biomass feed stocks into briquettes (Plate 1). The design and operation was based on the hydraulic principle. The briquetting machine consists of a rectangular frame, which supports all other components of the machines. Other major components of the machines are the four cylindrical moulds (which are welded together), where the compaction of the biomass feed stocks was effected. Five percent (5 %) by weight of cassava starch was used as binding agent in line with the work of Wilaipon, (2008) and Musa, (2007).

The cassava starch, which is in form of gel, was added to a measured quantity (1kg) of the cassava and yam peels. In each trial, the biomass feedstock was fed into the moulds of the briquetting machine and compressed by a 5-ton hydraulic jack at a pressure of 2.4 MPa. According to the design of the mould, three briquettes were produced per batch as shown in Plates 2 and 3 and were later ejected after five minutes as specified in Wilaipon, (2008). The experiment was replicated three times.

2.1 Determination of physical and combustion characteristics of the briquettes produced

The density of briquette from each specimen was determined immediately after ejection from the mould by computing the quotient obtained by dividing the mass by the volume of the compressed briquette. The mass was obtained by using a digital weighing scale, while the volume was estimated by taking the linear dimensions (length, breadth and thickness) of the briquette by a standard vernier calliper.

The relaxed density of the briquettes obtained from the two specimens was determined in the dry condition after nineteen days. It was calculated simply as the ratio of the briquette's mass to the new volume. Put in equation form:-

$$Relaxed\ Density = \frac{Briquette`s\ Mass}{Briquette`New\ Volume} \quad (1)$$

Relaxed density also known as the spring-back density can be defined as the density of the briquette obtained after the briquette has remained stable.

Equilibrium moisture contents of the briquettes produced were determined in line with ASAE Standard S 269-4 (2003), while the percentage carbon, hydrogen, oxygen, nitrogen and sulphur were determined as highlighted in ASTM standard D5373-02 (2003).

Proximate and ultimate analyses of the briquette samples were carried out to determine the percentage volatile matter content, ash content and content of fixed carbon using the procedure of ASTM standard D5373-02 (2003).

The flame propagation rates of the briquette samples were determined as described by Musa, (2007). To obtain this, one piece of the oven-dried briquette was graduated in centimetre and ignited over a bunsen burner in laboratory environment until the fire extinguished itself. The flame propagation rate was estimated by dividing the distance burnt by the time taken in seconds.

The afterglow time was also estimated and determined by making use of procedure of Musa, (2007). This became necessary in order to estimate how long the individual briquette would burn before restocking when they are used in cooking and heating. Essentially, this was by way of igniting a piece of oven-dried briquette over a bunsen burner and blowing out of the flame after a consistent flame was established. Thereafter, the time in seconds within which a glow was perceptible was recorded.

Furthermore, the heating value of the two biomass briquettes was also evaluated and the procedure in line with ASTM E 711-87 (2004) was followed. The apparatus used was Parr isoperibol bomb calorimeter.

The compressive strength of the briquettes was determined by using a universal testing machine and in line with ASTM 1037-93 (1995).

Density ratio was calculated as the ratio of relaxed density to maximum density i.e

$$\text{Density ratio} = \frac{\text{Relaxed Density}}{\text{Maximum Density}} \tag{2}$$

In this formula, maximum density is the compressed density of briquette immediately after ejection from briquetting machine.

Relaxation ratio was calculated as the ratio of maximum density to relaxed density i.e

$$\text{Relaxation Ratio } (C_r) = \frac{\text{Maximum Density}}{\text{Relaxed Density}} \tag{3}$$

Finally, compaction ratio which is defined as the density of the in-die briquette divided by the initial density of the residue was determined and calculated as:

$$\text{Compaction Ratio } (C_r) = \frac{\gamma_m}{\gamma_i} \tag{4}$$

Where

γ_m = Density of the material at any point of its circle of the compression,
γ_i = Initial density of the material before compression

3. Results and Discussion

The results of the determination of physical and combustion characteristics of briquettes produced from cassava and yam peels are shown in Tables 1 and 2, while the results of burning characteristics of the briquettes produced from the two residues examined are presented in Table 3.

From the result of ultimate analysis, the moisture content of cassava peel briquette was 10.96%, while the moisture content of yam peel briquette was 10.95%. These results are within the limits of 15% recommended by Wilaipon (2009) and Kaliyan and Morey (2009), for briquetting of agro-residues. Other results of ultimate analysis for cassava peel gave 22.08 %, 13.54%, 37.31%, 2.38% and 1.82% for contents of carbon, hydrogen, oxygen, nitrogen, and sulphur respectively, while the corresponding values for yam peel in the order listed above were 25.29%, 15.19%, 49.79%, 1.48%, and 1.39% respectively. The amount of carbon and hydrogen contents in the two residues examined is very satisfactory as they contribute immensely to the combustibility of any substance in which they are found (Musa, 2007). The low sulphur and nitrogen contents in both specimens are welcomed development, as there will be minimal release of sulphur and nitrogen oxides into the atmosphere and that is an indication that the burning of briquettes from the two specimens examined in this work will not pollute the environment (Enweremadu, et al., 2004).

For the proximate analysis, the fixed carbon, ash and volatile matter contents of cassava peel were 2.57%, 4.40% and 83.06% respectively. The corresponding values for yam peel in the order listed above were 3.29%, 3.86% and 82.87% respectively. The values obtained for volatile matter contents of 83.06% and 82.87% for cassava and yam peels respectively and the corresponding lower ash content of 4.40% and 3.86% are good and acceptable. This is because; higher percentage of the briquettes from the two residues would be made available for combustion.

The higher heating value calculated for briquette produced from cassava peel was 12,765 KJ/kg, while that of yam peel was 17,348 KJ/kg. These energy values are sufficient enough to produce heat required for household cooking and small scale industrial cottage applications. They also compare well with most published values of biomass energy content as exemplified by cowpea briquette-14,372.93KJ/kg, soy-beans briquette-12,953 KJ/kg and groundnut shell briquette-12,600 KJ/kg (Enweremadu, et al. 2004; Musa, 2007).

The values of 741.13 kg/m^3, 386.40 kg/m^3 and 1.92 were obtained for maximum density, relaxed density and relaxation ratio for the cassava peel briquette respectively, while the corresponding values for yam peel briquette were 911.45 kg/m^3, 512.10 kg/m^3 and 1.78 respectively. The two densities obtained in this work compare well with density of notable biomass fuels such as coconut husk briquette-630 kg/m^3, banana peel-600 kg/m^3, groundnut shell briquette-524 kg/m^3, and melon shell briquette-561 kg/m^3 (Olorunnisola, 2007; Wilaipon, 2008; Oladeji et al., 2009). The relaxation ratios of 1.92 and 1.78 obtained for cassava and yam peels respectively are also good enough and they are close to the values obtained by Olorunnisola (2007), which gave the relaxation ratio raging between 1.80 and 2.25 for coconut husk briquette and Oladeji, et al., (2009), which gave values 1.97 and 1.45 for groundnut and melon shell briquettes respectively.

The compressive strengths for the two feed stocks investigated were found to be reasonable with the briquette from yam peel having the higher value of 1.76kN/m^2. The implication of this is that, briquette from yam peel will suffer less damage during transportation and storage than the cassava peel briquette.

The afterglow times of 367 and 375 second were recorded for cassava and yam peels briquettes respectively, while the propagation rates of 0.13 cm/s and 0.16 cm/s were obtained for briquettes produced from cassava and yam peels respectively. The longer afterglow time and slow propagation rate for yam peel briquette imply that yam peel briquette will ignite more easily and burn with intensity for a long time than its cassava peel counterpart.

4. Conclusion

The present work examined the physical and combustion characteristics of briquettes produced from cassava and yam peels using briquetting machine as compactor and based on the various results obtained and the findings of this study, the following conclusions can be drawn:

- The briquettes produced from both cassava and yam peels would make good biomass fuels.
- Briquettes from both residues will not crumble during transportation and storage because the values obtained for their relaxed densities are sufficient enough.
- Cassava and yam peels would make a good biomass fuel with minimum environmental pollution and emission of greenhouse gases. This is not unconnected with low values of sulphur and nitrogen contents which are 1.82 % and 2.38 % for sulphur and nitrogen respectively for cassava peel. The corresponding values for yam peel are 1.39 % and 1.41 %.
- The relaxed densities of the relaxed briquettes which are 386.4 kg/m^3 for cassava peel and 512.54 kg/m^3 are higher than the initial densities of the residue materials which are 251.5 kg/m^3 and 283.4 kg/m^3 for cassava and yam peels respectively. This translated into a volume reduction, which provides technological benefits and a desirable situation for material storage, packaging and transportation.
- The average energy values of 12,765kJ/kg (SD 30) and 17,348kJ/kg (SD 20) obtained for briquettes from cassava and yam peels respectively are sufficient enough to produce heat required for household cooking and small scale industrial cottage application.
- In the similar manner, the average values of compressive strengths of 1.53kN/m^2 (SD 0.05) and 1.76kN/m^2 (SD 0.04) obtained for briquettes from cassava and yam peels respectively were sufficient and found to be reasonable. The implication of this is that, briquettes from these residues will suffer less damage during transportation and storage.
- Briquettes produced from yam peels have more positive attributes of biomass fuel than briquettes produced from cassava peels.

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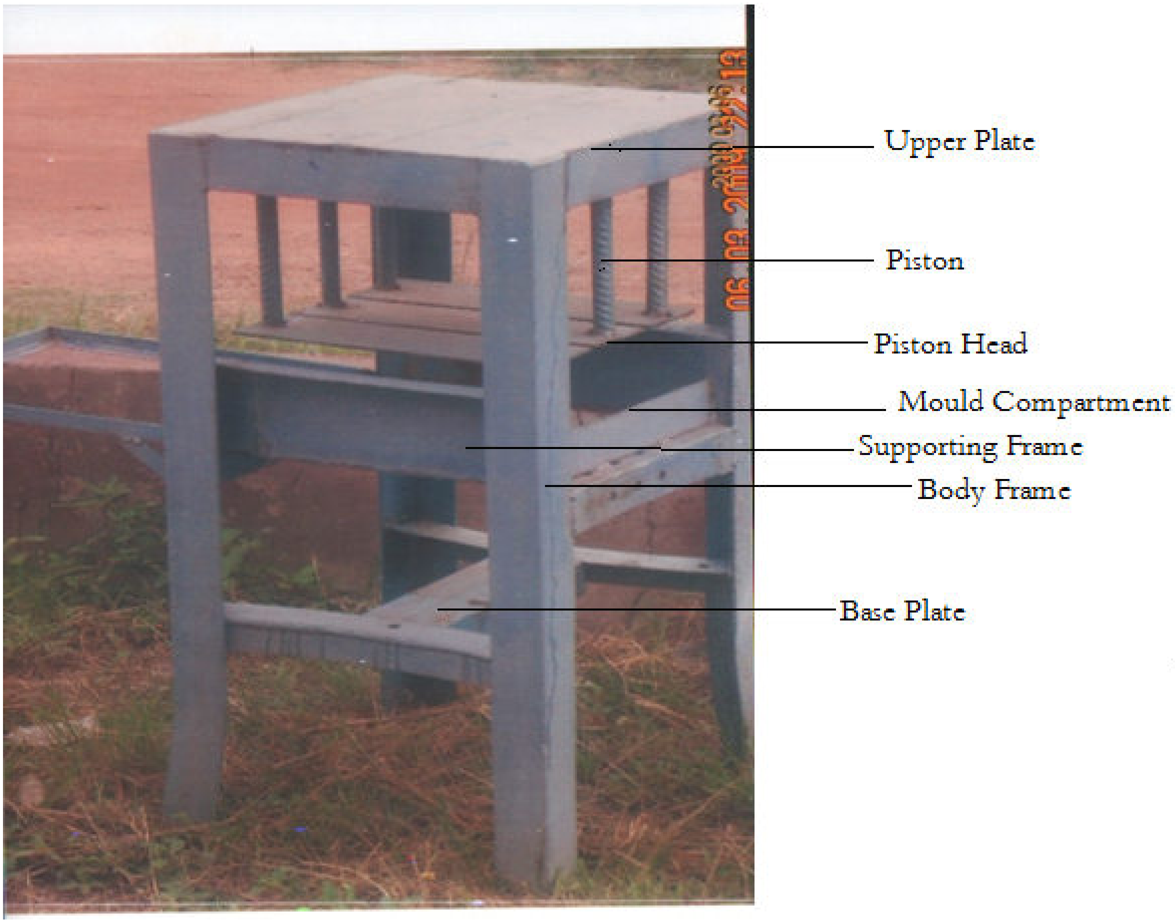

Plate 1. A prototype Briquetting Machine

Plate 2. Briquettes produced from Cassava peels

Plate 3. Briquettes produced from Yam peels

Table 1. Physical and fuel characteristics of briquettes produced from cassava and yam peels (average values)

Parameter	**Unit**	**Briquettes produced from**	
		Cassava peel	**Yam peel**
Length of the briquette	M	0.270	0.270
Breadth of the briquette	m	0.088	0.090
Thickness of the briquette	m	0.008	0.007
Mass	kg	1.02	1.024
Carbon content	%	22.08	25.29
Hydrogen content	%	13.54	15.19
Oxygen content	%	37.31	49.79
Sulphur content	%	1.82	1.39
Ash content	%	4.40	3.86
Nitrogen content	%	2.38	1.41
Volatile matter	%	83.06	82.87
Fixed carbon	%	2.57	3.29

Table 2. Physical and combustion characteristics of briquettes produced from cassava and yam peels (average values)

Parameter	Unit	Briquettes produced from	
		Cassava peel	Yam peel
Moisture content	%	10.76	10.95
Compressive strength	kN/m^2	1.53	1.76
The heating value	kJ/kg	12,765	17,348
Initial density	kg/m^3	251.5	283.4
Maximum density	kg/m^3	741.13	911.45
Relaxed density	kg/m^3	386.4	512.54
Density ratio	-	0.52	0.56
Compaction ratio	-	2.94	3.21
Relaxation ratio	-	1.92	1.78

Table 3. Burning characteristics of briquettes produced from cassava and yam peels (average values)

Parameter	Unit	Briquettes produced from	
		Cassava peel	Yam peel
After glow time	sec.	367	375
Flame propagation rate	cm/s	0.13	0.16

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