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A Comparative Study of the Thermo-Physical Properties of Fuel Briquettes of Sawdust and Rice Husk

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***ABSTRACT*: *Fuel briquettes were produced using rice husk and sawdust with cow dung and waste paper pulp as binders respectively with the aid of a manually – operated hydraulic press. These two categories of briquette were subjected to proximate and ultimate analyses in the laboratory and their thermo-physical properties were determined. The results of the experiment showed an average calorific value for the sawdust briquettes as (4,844Kcal/kg), while that of the rice husk was (3347Kcal/kg); the most durable briquettes of sawdust were of moisture content range of (5.7 – 7.1% wet basis) as compared to (4.3 – 5.2%, wet basis) recorded for the rice husk briquette; an average density of (1.04g/cm^3) was recorded for the sawdust briquette, while that of rice husk briquette was found to be (1.06g/cm^3); an average percentage ash content of (2.5%) was recorded for the sawdust briquette, whereas a value of (2.8%) was noted for the rice husk briquette; an average percentage fixed carbon of (20.6%) was recorded for the sawdust briquette, while a value of (23.2%) was noted for the rice husk; also an average percentage volatile matter of (71%) was recorded for the sawdust briquette as compared to (69.4%) value for the rice husk briquette. From the result of these analyses, it was concluded that sawdust possesses better qualities that would ensure good stability for storage, yield high heat content, and better combustibility than rice husk when use for fuel briquettes under the same production conditions.*

Keywords: Volatile matter, Calorific value, Ash content, fixed Carbon, Rice husk, Sawdust, Briquette.
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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 (Lucas and Akinoso, 2001). Traditionally, wood in form of fuel wood, twigs and charcoal had been the major source of renewable energy in Nigeria, accounting for about 51% of the total annual energy consumption (Olorunnisola, 2004). The over-reliance on forest wood in Nigeria mainly for charcoal production, firewood and furniture making had resulted in the depletion of forest reserves at a faster rate. A similar scenario, according to (Emerhi, 2011), in other sub-Saharan countries had resulted in shortage of fuel wood which led to the depletion of over 75% of the total forest cover and thus leading to environmental crises. As rightly noted by (Stout and Best, 2001), a transition to a sustainable energy system is urgently needed for developing countries.

Fuel briquettes showed great promise in solving this problem. Fuel briquetting is a viable technology that generates energy from municipal and biomass wastes, through the application of high pressure by briquetting presses or machines with or without a binding agent. It involves drying, shredding, grinding and pressing biomass wastes into various briquette sizes and shapes with or without a binder (Ramesh, 2005). This study was carried out to compare and analyze the thermo-physical properties of sawdust and rice husk briquettes under similar condition, with a view to finding out the most reliable of these waste products as raw material for briquette making that would serve as energy source for domestic cooking, heating and lighting.

MATERIALS AND METHODS

The main feedstock used as raw materials for this research work included: sun-dried sawdust and rice husk with waste paper pulp and cow-dung as binding materials. The equipment included: A manually operated hydraulic press; a set of BS sieves with mesh sizes of 2.36mm, 1.70mm, and 1.18mm, a mixing pan; a measuring cylinder; steel tape; vernier caliper; a stop watch; a rectangular metallic moulds of dimension 100x 80x300mm and two cylindrical moulds with diameter 100mm and height 250mm, and diameter 80mm and height 300mm; lubricants; brush; weighing balance; oven; and a standard Gallenkamp Ballistic Bomb Calorimeter.

Experimental Methods

Raw Materials Preparation

The sawdust and rice husk were acquired from saw and rice mills and they were pretreated by open-air drying in order to achieve the inherent moisture contents range of 10 to 18% (dry basis) suitable for briquettes making as recommended by (Olorunnisola, 2004), to ease the contribution of the natural binder of the raw materials to the briquetting process. The sawdust and rice husk particles were sieved into different grades to obtain different textural classes. The sawdust particle grades were sieved and designated as D_1 (1.18mm), D_2 (1.70mm), and D_3 (2.36mm) and rice husk was also sieved and designated as R_1 (1.18mm), R_2 (1.70mm), and R_3 (2,36mm).

Waste paper in form of discarded typing sheets, photocopying and printing paper (excluding cardboard papers were collected from a printing press). This waste paper was then manually shredded into small bits, mixed together and then soaked in cold water for seven days. The water was drained off and the paper was then transformed to pulp by manually pounding it with the aid of the mortar and pestle. Cow-dung was collected from cattle houses and pretreated by sun-drying and pulverization. Finer particles of the cow dung were obtained by sieving the pulverized waste in a 1.18mm sieve.

Briquetting Production and Quality Evaluation

The fuel briquettes from the sawdust and rice husk were produced based on the designated particle grades with a variation on the percentage of waste paper pulp and cow dung. In making the briquettes, 20, 40, and 50% of the waste paper pulp were mixed with the sawdust particle grades to produce sawdust briquettes and 20, 40, and 50% of the cow dung were mixed with the rice husk particle grades to produce rice husks briquettes. Through the aid of the pressure gauge mounted on the hydraulic press, the maximum applied pressure was determined during each process of briquette production. Measuring tape was used to determine the compressed and relaxed height of the briquettes. A detention time of 10 minutes was observed during compression in order to release lignin from the cellular walls of the waste particles to facilitate effective binding of the particles. At the end of the expiration of the detention time, the compressed briquettes were extruded from the mould by pushing the piston die upon the compressive plate.

Data Collection

Upon extrusion of each briquette from the metallic mould, the mass, length, width and inner and outer diameters were determined. The densities of the briquettes and the degrees of expansion, after 30 minutes of extrusion from the mould were calculated. The ultimate analysis which indicates the various elemental chemical constituents in the waste material (carbon, hydrogen, oxygen, sulphur,) was carried out for each category of briquette. This analysis is useful in determining the quantity of air required for combustion and the volume and composition of the combustion gases. Data were collected on the thermo-physical properties of the sawdust and rice husk briquettes produced. The methods used for the data collection were as given below.

a. **Percentage Moisture Content:** 5g of the sample was weighed into a previously weighed crucible. The crucible plus sample taken was then transferred into the oven set at 100^{o}C to dry to a constant weight for 24 hours overnight. At the end of the 24 hours, the crucible plus sample was removed from the oven and transferred to a desiccator, cooled for ten minutes and weighed.

The formula used was:

$$\text{Percentage Moisture Content, (PM)} = \frac{W_3 - W_0}{W_1 - W_0} \times 100\% \ldots (1)$$

Where; W_0 = Mass of empty crucible
W_1 = Mass of crucible plus waste sample
W_3 = Mass of crucible plus oven-dried waste sample

The moisture content (MC) of the briquettes after twenty one days of drying at ambient temperature and relative humidity of 35^{o}C and 50% were then determined.

b. **Density:** The mass of briquettes were determined on the balanced in the laboratory. Then, the volumes of briquettes were determined by a simple calculation based on the direct measurement of length, width, and thickness of the briquettes.

Formula:

$$\text{Density of briquette} = \frac{M}{V} \ldots\ldots\ldots (2)$$

Where; D = Density
M = Mass
V = Volume

c. **Heat Value:** The heat value of both samples was determined using a standard Gallenkamp Ballistic Bomb calorimeter. 0.50g of each sample of briquette was weighed into the steel capsule. A 10cm cotton thread was attached to the thermocouple to touch the capsule. The bomb was closed and charged in with oxygen up to 30 atm. The bomb was fired up by depressing the ignite switch to burn the sample in an excess of oxygen.

The maximum temperature rise in the bomb was measured with the thermocouple and galvanometer system. Equation 3 was used to calculate the heat content.

$$Heat\ Value\ (Kcal/g) = \frac{\text{G. meter deflection x Calibration}}{Mass\ of\ Sample} \ldots\ldots (3)$$

In determining the calorific value (heat content) of the two categories of briquettes, three replicates of the same mass, but different particle grades of the briquettes were carried out and the average of the values was taken.

d. Percentage Ash Content: 5g of the briquette sample was weighed into a porcelain crucible. This was transferred into the muffle furnace set at 550^{o}C and left for about 4 hours. At the expiration of this regulated time, the entire sample had turned to white ash. The crucible and the content were cooled to about 100^{o}C in air, then room temperature in a desiccator and weighed.

The formula for determining the ash content was as stated below:

$$\text{Percentage Ash Content, (PAC)} = \frac{\text{Weight of ash}}{Original\ Mass\ of\ sample} \times 100\% \ldots (4)$$

e. Percentage volatile matter: The percentage volatile matter (PVM) was determined by pulverizing 2g of the briquette sample in a crucible and placing it in an oven until a constant weight was obtained. The briquettes were then kept in a furnace at a temperature of 550 °C for 10 min and weighed after cooling in a dessicator.

$$Percentage\ Volatile\ Matter(PVM) = \frac{M_a - M_b}{M_a} \times 100\% \ldots (5)$$

Where;
M_a = Mass of Oven-dried sample
M_b = Mass of sample after 10minutes in a furnace at 550 ^{0}C.

f. Percentage fixed carbon: The percentage fixed carbon (PFC) was computed by subtracting the sum of PVM, PAC and PMC from 100 as shown in Equation 6:

$$\text{Percentage fixed carbon, (PFC)} = [100 - (PMC + PVM + PAC)] \ldots (6)$$

RESULTS AND DISCUSSION

Physico-chemical Characteristics of the Briquettes

The result of the physico-chemical characteristics of the sawdust and rice husk briquette were presented as shown in Table 1 and discussed in this section. The average weight of the sawdust briquette was approximately 537.5g, while the rice husk briquette had an average weight of 548.2g. The average length and diameter of the sawdust and rice husk briquettes were 13.0cm and 5.1cm respectively and that of the rice husk briquette were 16.4cm and 5.4cm respectively. The average volume of the sawdust and rice husk briquette was 521.1cm^3. The sawdust briquettes assumed a brown coloration while the rice husk briquettes take on a greenish-brown coloration, mainly as a result of the cow dung used as binding material.

(a) **Moisture Content:** It was observed, as shown in Table 1, that the sawdust briquette has higher moisture content than the rice husk briquette produced. The quality of briquettes assessed on the basis of specific external features and certain physical parameter was very good. Their external surface was smooth and the structure of their cross-section was compact and homogenous. One of the main parameters determining briquette quality was the moisture content of the sawdust used as the input material. The most durable briquettes of sawdust are of the moisture content range of (5.7 – 7.1%, wet basis), whereas those of rice husk were of the moisture content range of (3.2 – 5.4%, wet basis). These observed values do not vary appreciably from such work carried out by (Wamukonya and Jenkins, 1995), whose value was in the range of (7.7 – 15.1%, wet basis) for briquettes produced from sawdust and wheat-straw, and the range of values of (12 – 20%, wet basis) as recommended for good storability and combustibility of briquettes. This lower moisture content of briquettes implies higher calorific value. Moisture content in excess of 20% would result in considerable loss of energy required for water evaporation during combustion at the expense of the calorific value of the fuel. Such a fuel may not also be stable in storage.

(b) **Density of the Briquettes:** During the briquetting of both categories of waste, it was found that higher pressing temperature and compacting pressure were necessary in order to achieve good and stable briquettes. Density was an important parameter, which characterized the briquetting process. If the density was higher, the energy/volume ratio would be higher too. Hence, high density products were desirable in order to ease their transportation, storage and handling. The density of briquettes depended on the density of the original biomass, the briquetting pressure and, to a certain extent, on the briquetting temperature and time. The briquette density was higher at higher compacting pressures. The densities recorded for the briquettes of sawdust for the different particle grades (D_1, D_2, and D_3) varied from 1.0 – 1.8g/cm^3; whereas that of rice husk varied from 1.3 – 2.1g/cm^3 as shown in table 2 below. These values were much higher than the initial densities of the uncompressed waste. Thus the process has achieved increased density which is a valuable factor in briquette production. These values did not differ much from the values of 1.20 – 1.40g/cm^3 recorded by (Eriksson and Prior, 1990) for briquettes of agricultural wastes. It was noticed however, that the densities of the briquette increase proportionately with increase pressure, but decrease as binder ratio increases.

Upon extrusion of the briquette from the metallic mould, it was noticed that its stability and compression strength depend to a large extent on the magnitude of the applied pressure and temperature, the duration of the detention, and the generic moisture content of the briquetting materials. The composition of the sawdust and rice husk briquette analyzed on an 'as-received basis' during this experiment showed 53.01% and 52.09% carbon, 4.10% and 3.90% hydrogen, 39.6% and 34.80% oxygen, 0.28% and 0.31% nitrogen and 0.302% and 0.200% sulphur for the sawdust and rice husk briquettes respectively. These results do not vary much significantly from such observations made by (Chaney, 2010), who reported that analysis of biomass using the gas analysis procedures revealed the principal constituent as carbon, which comprises between 30% and 60% of the dry matter and typically 30% to 40% oxygen. Hydrogen, being the third main constituent, makes up between about 5% and 6%, and nitrogen and sulphur (and chlorine) normally make up less than 1% of dry biomass. The amount of carbon and hydrogen content in the sample examined was an indication that they would contribute immensely to the combustibility of the briquettes as suggested by (Musa, 2007). According to (Grover et al., 1994) the resulting composition of biomass affects its combustion characteristics as the total overall mass of the fuel decreases during the volatile combustion phase of the combustion process, as the hydrogen to carbon ratio of the fuel increases and, to a lesser extent, as the oxygen to carbon ratio increases. Nitrogen, sulphur and chlorine are significant in the formation of harmful emissions and have an effect on reactions. The sulphur and nitrogen contents reported were both below 1%. This was a desired development as there would be minimal release of sulphur and nitrogen oxides into the atmosphere, thereby limiting the polluting effect of the briquettes.

Thermal Properties of the Briquettes

(a) Heat Value: Heat value or calorific value determined the energy content of a fuel. It is the property of biomass fuel that depends on its chemical composition and moisture content. The most important fuel property is its calorific or heat value. Table 1 revealed that, briquettes made from sawdust have a higher heat value than the briquettes made from rice husk of the same mass and particle grades. The briquettes generated more energy or heat per gram as compared to the same amount of the loose waste products.

(b) Percentage Ash Content (PAC): Ash, which is the non-combustible component of biomass, was found to be 2.4% for the sawdust briquettes and 2.8% for the rice husk briquettes. According to (Kim *et al.,* 2001) ash has a significant influence on the heat transfer to the surface of a fuel as well as the diffusion of oxygen to the fuel surface during char combustion. As ash is an impurity that will not burn, fuels with low ash content are better suited for thermal utilization than fuels with high ash content. Higher ash content in a fuel usually leads to higher dust emissions and affects the combustion volume and efficiency. According to (Loo and Koppejan, 2008), the higher the fuel's percentage ash content, the lower is its calorific value.

(c) Percentage Volatile Matter, (PVM): Biomass generally contains a high volatile matter content of around 70% to 86% and low char content. This makes biomass a highly reactive fuel giving a faster combustion rate during the devolatisation phase than other fuels such as coal (Loo and Koppejan, 2008). As reported by (Chaney, 2010), low-grade fuels, such as dung, tend to have low volatile content that results in smouldering which (De Souza and Sandberg, 2004) described as an incomplete combustion which leads to a significant amount of smoke and release of toxic gases. However, for the sawdust and rice husk briquettes under investigation, Percentage volatile content of 71% and 68.3% were recorded respectively. These values were high and indicated the relative ease of ignition of the briquettes and the proportionate increase in flame length as supported by (Loo and Koppejan, 2008) research work. The high volatile matter content indicated that during combustion, most of the sawdust and rice husk briquettes would volatilise and burn.

(d) Percentage Fixed Carbon, (PFC): The fixed carbon of the briquettes, which is the percentage of carbon available for char combustion after volatile matter is distilled off, was determined to be 20.6% for the saw dust briquettes while the rice husk briquette had a value of 20.2%. Fixed carbon gives a rough estimate of the heating value of a fuel and acts as the main heat generator during burning.

The results of combustion of the briquettes showed that the higher the particle size, the faster the briquette burned. The briquette of particle grade D_3 burned faster than D_1 for the sawdust briquettes; and R_3 burned much faster than R_1 for the rice husk briquettes, hence the combustion efficiency of the two category of briquettes decreased as the pore spaces between the particles decrease. The briquette with higher particle grade (D_2 and D_3) and (R_2 and R_3) recorded quick ignition (quick lighting) and relatively low burning time calorific value. Low ash and moisture content as well as absence of objectionable odour were noticed during the burning process of the briquettes. It was observed that the compaction pressure increased with increasing binder ratio addition. This was as a result of the extra pressure required to remove the excess moisture content of the binding materials. Upon extrusion of the briquettes from the metallic mould, it was noticed that their stability and strength depend to a large extent on the magnitude of the applied pressure, the duration of the detention, and the generic moisture content of the mixture.

Although the particle grades of rice husk expand much more than sawdust, mainly because of the inherent properties, the degree of expansion depends on these aforementioned properties. The degree of expansion of the briquettes decreases with the particle grades. During the drying of the briquettes, it was observed that briquette made from larger particle size cracked and sometimes shattered while drying, whereas those made of fine particle size are stable. It was observed that the type of material briquetted is one of the major factors that have appreciable effects on product expansion. The first thirty minutes after the extrusion of the briquettes showed the most crucial axial expansion. This observation is supported by the works of (Moshenin and Zaske, 1976), and (Olorunnisola, 2004), who all concluded that nearly all the expansion of briquettes takes place within 30 minutes of its extrusion. The material rebounds according to its viscoelastic properties, which may continue for several days naturally with slight increments with a considerable portion of this rebound taking place within a short time after unloading. Table 3 below shows the average degree of expansion of the different categories of fuel briquettes produced.

CONCLUSION

From the results of this research, it was concluded that briquettes from sawdust and rice husk are good source of energy for rural energy requirements. However, those produced from sawdust have greater advantages over briquettes from rice husk waste. These advantages could constitute considerable hindrances in the utilization of rice husk as raw material for large scale briquette production except where the densification mechanism is highly sophisticated to increase the bulk density of such rice husk briquettes. The thermo-physical characteristics of the briquette assessed in this study showed that briquettes manufactured from sawdust had low moisture content (5.7%) higher than that from rice husk (4.3%), but generated high calorific value (4,844Kcal/kg) higher than rice husk (3377Kcal/kg). This high heat content of sawdust over rice husk despite its higher moisture content may be attributed to its better viscoelastic property.

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Fig.1: Picture of the Sawdust and Rice Husk Briquettes Samples

Table 1: Calorific Value, Moisture Content and Density of Sawdust and Rice Husk Briquettes

Briquette category	Mass based on particle grades (g)	Calibration Constant	G. meter Deflection	GE (Kcal/kg)	Moisture Content (%)	Density (Kg/m^3)
Sawdust	0.50	0.7872	3.05	4802	5.82	1040
	0.50	0.7872	3.08	4849	5.88	1070
	0.50	0.7872	3.10	4881	5.91	1080
Rice husk	0.50	0.7872	2.15	3385	5.08	1050
	0.50	0.7872	2.08	3270	4.38	1030
	0.50	0.7872	2.15	3385	5.08	1050

Table 2: Thermo-physical Characteristics of Sawdust and Rice Husk Briquettes

Parameter	Sawdust value	Rice husk value
Proximate analysis		
Volatile matter	71.1%	69.4%
Ash content	2.5%	2.8%
Moisture content	5.8 – 7.1%	4.3 -5.2%
Fixed carbon	20.6%	23.5%
Ultimate analysis		
Carbon	53.01%	52.09%
Hydrogen	4.10%	3.90%
Oxygen	39.60%	34.80%
Sulphur	0.302%	0.200%
Nitrogen	0.28%	0.31%
Heating value	4,844 Kcal/kg	3377 Kcal/kg
Volatile matter	71.1%	69.4%
Ash content	2.5%	2.8%
Moisture content	5.8%	5.2%

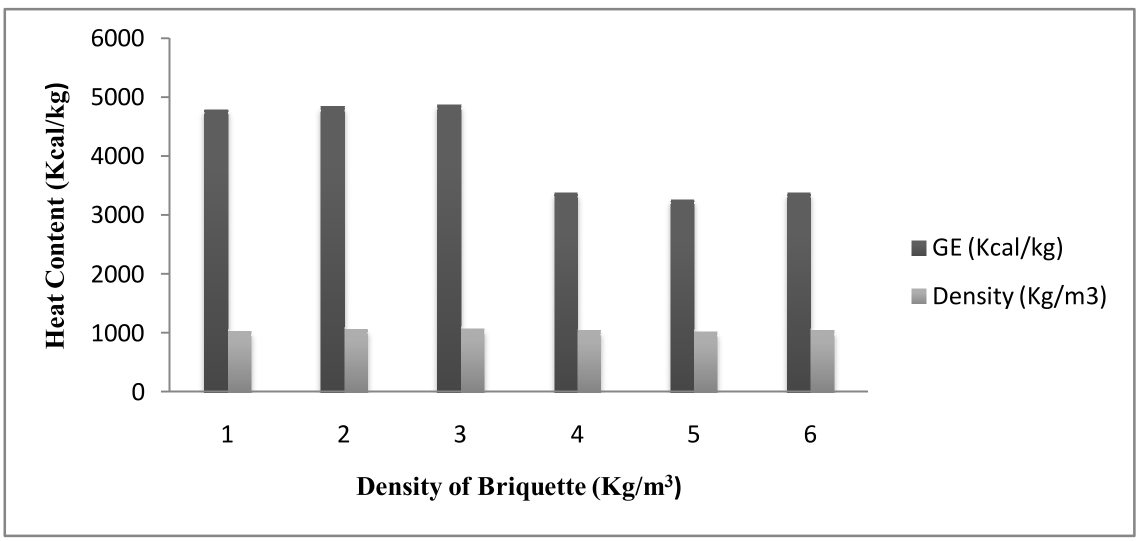

Fig. 2: The Extent of Density Influence on the Heat Content of Briquettes

Table 3: Length, Inner and Outer Diameter, Mass and Volume of 6 Units of Hollow Briquette

SN	Length (cm)	Mass (g)		d_1 (cm)	d_2 (cm)	$D = d_2 - d_1$ (cm)	r=d/2 (cm)	Volume $(d_2 - d_1)h$ Cm^3	Density (m/v) g/cm^3	
		Sawdust	Rice husk						Sawdust	Rice husk
1	13.0	525	524	2.00	7.20	5.20	2.60	552.24	0.95	0.95
2	12.5	550	545	2.00	7.20	5.20	2.60	530.99	1.04	1.03
3	13.0	550	555	2.20	7.30	5.10	2.55	531.20	1.04	1.05
4	14.0	550	565	2.00	7.00	5.00	2.50	510.57	1.08	1.11
5	13.0	525	555	2.10	7.10	5.00	2.50	510.57	1.03	1.09
6	12.5	525	545	2.00	7.00	5.00	2.50	490.93	1.07	1.11

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