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Effect of Particle Size and Binder Level on the Physical and Combustion Properties of Briquettes Produced from Wheat Offal

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ABSTRACT

This study focused on the production of fuel briquettes from wheat offal. The variables investigated are particle size and blending ratio. The wheat offal used was sourced from Maiduguri Flour Mill. The material was sieved into fine, medium and coarse particle sizes using 1mm and 2mm wire mesh. Each particle size was thoroughly mixed with gelatinous cassava starch in ratios; 90:10, 85:15, 80:20 and 75:25 by weight. The blended material was then hand-fed into a 3.11cm x 40.50cm cylindrical mould and compressed at a pressure of $10.76kg.cm^{-2}$. In order to have enough briquettes for material testing, each production was replicated 10 times. The physical properties; stability of the briquettes was evaluated as a function of compressed and relaxed density, relaxation ratio, moisture content while the combustion properties; %volatile matter, %ash content, %fixed carbon and heat value were evaluated for each production. The result shows that all the physical properties of the briquette were greatly influenced by particle size ($p<0.001$). In density, there is no significant effect of the binder level on the briquette produced but gives the highest result when medium particles size was used with the valued of $1.06g/cm^3$ and lowest in coarse particle $0.46g/cm^3$, binder level had no significant effect on briquette produced ($p= 0.281$).The EMC was best in medium particle size with the value 131.25% at 25% binder level with the value 135.63%, EMC was significantly affected by binder level. Volatile matter was not influenced by particle size and binder level at ($p=0.581$) and ($p=0.980$) respectively but has better performance in medium particle size of 4.30% at 15% with the value of 4.14%. Ash content was not significantly influenced by particle size at ($p=0.0069$) but significantly influenced by binder level at ($p<0.002$) and was preferable in medium particles of 2.40% at 10% binder level with the value 2.08%. Fixed carbon was not influenced by particle size at ($p=0.150$), also better in medium particle of 93.84% at 20% binder level with value 94.01%, while Heat value was influenced by particle size and binder level at($p=0.005$)and ($p=0.0021$) respectively, highest with medium particles of 33.52mj/kg at 20% level of binder with the value 33.59mj/kg. It was observed that better and combustible briquette can be obtained from medium particles of wheat offal at low binder ratio.

Introduction

Deforestation is a singular reason for most of the world's ecological imbalances. Worldwide, the effect of global warming which is caused by the emission of carbon dioxide, and other green house gases can be felt. This has posed serious challenges to the protection of forest resources. The problem of forest resource protection brings to mind the need for increased deforestation control and use of cutting wood for fuel thereby making it necessary to seek alternative fuel production.

According to the world's energy topics, it is widely accepted that fossil fuel shortage, increasing price of gas and global warming are critical issues (Wilaipon, 2007). With respect to this, briquetting; a technology that deals with densification process of improving biomass fuel characteristics has been attracting attention as an energy source, since little or no carbon dioxide is emitted into the atmosphere from the time of production to utilization. Briquettes are a processed fuel that can serve as an alternative to wood or charcoal for heat energy (Wikipon, 2007). This energy according to Kaygusaz and Turker (2002) accounts for approximately 14% of total energy consumption in the world.

Although briquetting have been practiced for many years, it is very disappointing to know that it is yet to get a strong foothold in many developing countries including Nigeria. This is as a result of technical constraint and lack of knowledge to adapt the technology to suit local conditions (Grover and Mishra, 1996). It is in this regard that Wamukanya and Jenkins (1995) observed that for briquetting technology to be a success in developing and less industrialized countries of the world, the equipments should consist of locally designed simple low-cost materials. These materials should be available and less expensive.

Briquetting presses are inexpensive and easy to produce compared to alternative technological investments. It is estimated that one micro entrepreneur group of six persons working in response to real market demand can meet the need of up to 75 families, reducing fuel wood consumption by up to 200 tons per year (Mary et al., 2009). Briquetting can either be of low or high density technologies. The low density briquettes

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require pyrolysis of the biomass followed by briquetting using a binder in order to maintain the structure. On the other hand, high density briquetting technology compact biomass and holds the structure together with a binder.

Recent studies have shown that agricultural residues are promising choices for briquetting or biomass energy production. These agricultural residues are readily available from farms. They are environmentally friendly and can serve as an abundant energy source. Briquettes from agro-residues simply involve collection and compaction of combustible waste material which are not directly useable because of their low density and processing them into a solid fuel product of any convenient shape that can supply heat energy like wood or charcoal (Mary et al., 2009).

The aim of this study, therefore, is to determine the physical and combustion properties of briquettes produced from wheat offal using cassava starch as binder.

Materials and Method

Materials

The materials used for the study includes:

i Wheat offal at three different particle sizes (fine, medium and coarse).

ii. Starch as binding agent at different levels

iii. Fabricated briquette press (Appendix 1).

iv. Veneers caliper for measuring length and diameter.

v. Weighing balance for measuring weight.

vi. Jack press for exertion of pressure.

vii. Masking tape for labelling.

viii. Oven for drying

Sample Collection

The wheat offal used for the study was purchased from the market. It was sieved to three different sizes using a 1mm and 2mm wire mesh into fine, medium and coarse particle sizes. The cassava starch was also purchased from the market and prepared into paste using boiled water.

Sample Preparation

The collected wheat offal was sieved to 3 different particle sizes in order to test the effect of particle size on the compaction properties of briquettes. A mould with an inner diameter of 3.11cm and length of 40.50cm was used. A small metal disc was used at the top and base of the mould with a hole at the middle through which a small iron rod was passed through, so as to increase the surface area and aid combustibility of briquettes. Starch was then measured at four different levels 10,15,20, and 25% and prepared separately into paste using hot water.

Production Process

A 100g of the material was weighed at the ratios 90:10, 85:15, 80:20 and 75:25 to binder. Starch was then prepared thick to make binding more effective. The starch is then mixed thoroughly with the different particle sizes. No water was added during mixing as boiled water has already been used in preparing the starch. The mould was greased with engine oil to ease removal, avoid sticking and subsequent disintegration of the briquettes. This is then set at the centre of the press with a metal disc at the base and iron rod at the centre through the hole of the disc. The prepared mixture was then poured into the mould and covered at the top with another metal disc. The jack press was placed on a metal pipe and pressure was exerted for compression and samples were allowed to stay in the mould for 10 minutes before removing briquette. To each particle size and at all binder levels, 5 replicates were produced following the above procedure. However, the Samples obtained were $FB_1r_1\text{-}_5$, $FB_2r_1\text{-}_5$, $FB_3r_1\text{-}_5$, $FB_4r_1\text{-}_5$, $MB_1r_1\text{-}_5$, $MB_2r_1\text{-}_5$, $MB_3r_1\text{-}_5$, $MB_4r_1\text{-}_5$, $CB_1r_1\text{-}_5$, $CB_2r_1\text{-}_5$, $CB_3r_1\text{-}_5$, $CB_4r_1\text{-}_5$ for fine, medium and coarse particle and 4 binder levels respectively.

The diameter and height of briquette was taken using mituotogo digital caliper; weight of the briquettes were equally recorded immediately after removal from mould. The briquette were first subjected to drying under atmospheric condition and weight, diameter and height are recorded on a daily basis until constant value was obtained. The total samples produced for all particles sizes were 60.

Test and Analysis

The following tests were carried out on the briquettes produced;

Density

This is simply described as mass per unit volume of a given sample (g/cm^3) of each sample. The weight of each sample in gram was recorded using a weighing balance while the volume in cm^3 was obtained by measuring the height and diameter of the briquettes. The density is thus calculated as

$$D = \frac{M}{V}$$

Where D = Density of sample

M = Mass of sample (g)

V = Volume of sample (cm^3)

Equilibrium Moisture Content

This is a function of the movement of temperature and relative humidity. The briquettes were subjected to drying for 15 days under atmospheric conditions. The weight, height and diameter of the briquettes were taken until they became stable.

Proximate Analysis

Proximate analysis carried out include

Percentage Volatile Matter

Specified gram (4g) of pulverized briquette sample in a crucible was placed in oven to obtain constant weight, first for ten minutes. Thus

$$\%\ volatile\ matter = \frac{B - C}{B}\ X\ 100$$

Where B = Weight of oven dried sample (g)

C = Weight of sample after 10 minutes in oven (g)

Percentage Ash Content

This involves heating oven dried samples (4g) for a long period of time until it turns ash. Therefore

$$\%\ Ash\ Content = \frac{D}{B}\ X\ 100$$

Where;

D = Weight of Ash (g)

B = Weight of oven dried sample (g)

Percentage Fixed Carbon

This is obtained by subtracting the value of addition of percentage volatile matter and percentage ash content from 100%

$$\%\ \text{fixed carbon} = 100 - (\%\ V + \%A)$$

Where;

V = Percentage volatile matter

A = Percentage ash content.

Heating Value

The heating value of samples was calculated as

$$HV = 2.326\ (147.6C + 144V)\text{MJ/Kg}$$

Where

HV = Heating value

C = Percentage fixed carbon

V = Percentage volatile matter.

Table 1. Analysis of variance showing the influence of particle size and binder level on the physical properties of briquettes produced

SV	Df	SS	MS	F ratio	P value
Compressed density					
Particle size (PS)	2	0.101	0.051	35.926	0.000
Binder level (BL)	3	0.006	0.002	1.313	0.281
PS x BL	6	0.029	0.005	3.411	0.007
Error	48	0.068	0.001		
Total	59	0.204			
Equilibrium moisture content					
Particle size (PS)	2	18768.797	9384.399	34.816	0.000
Binder level(BL)	3	15342.334	5114.111	18.973	0.000
PS x BL	6	2120.644	353.441	1.311	0.270
Error	48	12937.952	269.541		
Total	59	49169.727			

P – Value < 0.05 is significant

Table 2. Physical Properties of the Briquettes

Parameters	Compressed Density (g/cm^3)	Equilibrium Moisture Content (%)
Particle Size		
Fine	1.01 ± 0.03^b	120.00 ± 25.95^b
Medium	1.06 ± 0.05^a	131.25 ± 25.43^a
Coarse	0.96 ± 0.05^c	89.39 ± 16.74^c
Binder Level (%)		
10	1.00 ± 0.09^a	93.61 ± 16.83^c
15	1.02 ± 0.05^a	104.25 ± 21.57^c
20	1.02 ± 0.04^a	120.70 ± 28.88^b
25	1.01 ± 0.04^a	135.63 ± 28.88^a

Each value is an average of 5 – replicates value with the same alphabets in each column are not significantly different from one another when subjected to DMR Test at α = 0.05

Table 3. Analysis of Variance Showing the Effect of Particle Size and Binder Level on the Combustion of the Briquettes

SV	Df	SS	MS	F ratio	P value
Volatile matter					
Particle size (PS)	2	1.783	0.891	0.556	0.581
Binder level (BL)	3	0.294	0.098	0.061	0.980
PS x BL	6	15.459	2.576	1.607	0.189
Error	24	38.428	1.603		
Total	35	56.106			
Ash content					
Particle size (PS)	2	2.239	1.119	2.994	0.069
Binder level (BL)	3	7.455	2.485	6.645	0.002
PS x BL	6	3.764	0.627	1.678	0.170
Error	24	8.975	0.374		
Total	35	22.105			
Fixed carbon					
Particle size (PS)	2	6.727	3.364	1.634	0.216
Binder level (BL)	3	9.942	3.314	1.610	0.213
PS x BL	6	21.762	3.627	1.762	0.150
Error	24	49.400	2.058		
Total	35	87.216			
Heating value					
Particle size (PS)	2	0.352	0.176	3.405	0.050
Binder level (BL)	3	0.671	0.224	4.325	0.014
PS x BL	6	0.526	0.088	1.695	0.166
Error	24	1.241	0.052		
Total	35	2.766			

P – Value < 0.05 is significant

Table 4. Proximate Analysis of the Briquettes

Parameters	Volatile matter (%)	Ash content (%)	Fixed carbon (%)	Heating value (mj/kg)
Particle Size				
Fine	3.76 ± 1.19^a	2.86 ± 0.82^a	92.84 ± 1.71^a	33.32 ± 0.28^a
Medium	4.30 ± 1.19^a	2.40 ± 0.60^a	93.84 ± 1.50^a	33.52 ± 0.24^b
Coarse	4.07 ± 1.32^a	2.98 ± 0.91^a	93.20 ± 1.48^a	33.30 ± 0.30^b
Binder Level (%)				
10	4.11 ± 1.32^a	2.08 ± 0.69^a	92.56 ± 1.75^a	33.21 ± 0.34^b
15	4.14 ± 1.44^a	2.70 ± 0.62^a	93.16 ± 1.70^a	33.37 ± 0.21^b
20	3.93 ± 1.24^a	2.88 ± 0.70^b	94.01 ± 1.34^a	33.59 ± 0.23^a
25	3.99 ± 1.27^a	3.32 ± 0.70^a	93.23 ± 1.70^a	33.35± 0.21^{ab}

Each value is an average of 3-replicates.Value with the same alphabets in each column are not significantly different from one another when subjected to DMR test at X = 0.05.

Results and Discussions

Physical Properties of the Briquettes

The physical properties investigated include compressed density, relaxed density, relaxation ratio, moisture content and equilibrium moisture content. Their results are presented in Tables 1, 2, 3 and 4.

Density of Briquettes

The results of the analysis of variance presented in Table 1 shows that variations in particle size had a marked effect on the compressed density of the briquettes produced (P < 0.01). The briquettes produced with medium sized particles had the highest compressed density with an average value of 1.06g/cm^3 closely followed by those produced using fine particles (1.01g/cm^3) while the briquettes made from coarse particles had the least average compressed density of 0.46g/cm^3.

However, unlike particle size, the percentage of the binder used had no significant effect on the briquettes produced (P = 0.281). Nevertheless, briquettes produced using 15% and 20% of binder had the highest average compressed density of 1.00 g/cm^3. But it is worthy of note that the interaction between particle size and binder level had significantly influence on the compressed density of the briquettes (Fig. 1). The compressed density (density obtained after drying) is a basis for the determination of various properties of briquettes just as listed above. From the results, it was evident that differences in particle size had a significant effect on both the compressed densities of the briquettes. This could be as a result of variations in densities of the particles and material used. The values obtained were close to those obtained for groundnut and melon shell (Oladeji et al., 2009). This implies that better compressed densities can be obtained using medium sized particles at binder level of 15% and 20%.

Moisture Content and Equilibrium Moisture Content of the Briquettes

The results of analysis of variance presented in Table 3 shows that differences in particle size greatly influenced the equilibrium moisture content of briquettes (P < 0.001). But the briquettes produced using medium sized particles had the highest average equilibrium moisture content of 131.25% which was followed by those of coarse and fine with an average equilibrium moisture content of 120.00% and 89.39% respectively.

However, it is also important to note that the equilibrium moisture content of the briquettes was significantly influenced by the percentage of binder used (P < 0.001). Briquettes produced with 25% of binder attained the highest mean value of 135.63%. This was followed by those produced using 20% of binder with a mean value of 120.70%. The least equilibrium moisture content was recorded at the binder level of 10% (93.61%).

Thus the interaction between particle size and binder levels does not significantly influenced both the equilibrium moisture content of briquettes produced where P = 0.943 and P = 0.270 for and equilibrium moisture content respectively. The variation in equilibrium moisture content could be attributed to difference in temperature and climatic conditions, as equilibrium moisture content is a function of relative humidity and temperature of surrounding air. However, equilibrium moisture content of 15% is recommended for good storability and combustibility of briquetting of agro residue (Wilaipon, 2008).

Combustion Properties of Briquettes

Percentage of Volatile Matter

The result of the analysis of variance presented in Table 6 shows that variation in particle size had no significant effect on the volatile matter of the briquettes (P = 0.581). The briquettes produced using medium particles had the highest mean value of 4.30%. This was followed by coarse particle size with a mean value of 4.07% while the least mean value of 3.76% was obtained when fine particles was used. Similarly, the percentage of binder used does not influence the percentage volatile matter of the briquettes (P = 0.980). Nevertheless, briquettes produced at binder level of 15% had the highest volatile content of 4.14% which was followed by those produced with 10% binder level which had an average value of 4.11% the least volatile matter of 3.93% was attained when 20% of binder was used. The influence of the interaction between binder level and particle size on the volatile matter of the briquettes is illustrated in Figure 3. The values obtained in this study, fell within the smokeless fuel grade similar to briquettes from sawdust and charcoal dust of Azadiracta indica (Sotannde et al., 2010b) and briquettes from lignite with biobinders (Ivanov et al., 2003) and thus can be described as smokeless fuel.

Percentage of Ash

The amount of ash produced after dry ashing at 300^{0}C was not significantly influenced by the size of particles used (P = 0.069) (Table 5). Nevertheless, highest average ash content of 2.98% was recorded when coarse particle was used. The briquettes produced with fine particles was next with an average value of 2.86% while those produced with medium sized particles was the least (2.40%) (Table 6). However, unlike particle size, the percentage of binder used significantly influenced the ash content of the briquettes (P < 0.002). There were variations at different levels of binder the highest mean value of 3.32% was obtained using 25% binder. At 20% binder level, a mean value of 2.88% was attained, closely followed by 2.70% obtained using 15% binder level while the least value of 2.08% was obtained when the binder level was 10%. Lastly, despite the influence of the level of binder used on the ash content of the briquettes, the interaction between particle size and binder level had no remarkable effect on the ash content of the briquettes (Fig. 4). Relatively low ash content was recorded using medium sized particle (2.40%). This is relatively close to that of corn cob with mean value of 1.40% and lowers when compared with 18.62 for rice husk (Oladeji, 2010). The lower the ash content, the higher the heating and thus, the more the heating effect of briquettes. Similar low percentage ash content has been reported by Nasrin et al., (2008) for briquettes from oil palm biomass and Ivonov et al., (2003) for briquettes from lignite biobinders.

Percentage of Fixed Carbon

With regards to percentage of fixed carbon, particle size, binder level and interaction between them does not significantly influenced the percentage of fixed carbon of the briquettes with P = 0.216, 0.213 and 0.150 for particle size, binder level and their interactions, respectively (Table 5). Nevertheless, the highest mean value of 93.84% was obtained when medium sized particles was used, followed by 93.20% and 92.84% obtained when coarse and fine particles were used respectively. Similarly, when the binder level was varied, the percentage fixed carbon of the briquettes produced increased and reached the peak at 20% binder level after which further increase in binder level resulted in reduction in percentage fixed carbon of the briquettes produced. Thus the averages percentage fixed carbon of 93.16%, 94.01% and 93.23% were obtained when 15%, 20% and 25% binder level were used (Table 6). The influence of the interaction between binder level and particle size on the percentage fixed carbon of the briquettes is illustrated in Figure 5. The highest average percentage fixed carbon of 93.84% was obtained using medium sized particles. This is higher than 85.23%-85.20% range for charcoal briquettes from Azadiracta indica (Sotannde et al., 2010b) and 84.7%-96.9% range obtained in carbonisate produced from velenje lignite at varying temperature as well as 13.40% and 12.07% for rice husk and corn cob briquettes (Oladeji 2010).

Heating Value

From the results presented in table 5, the particle sizes were found to significantly influenced the heating value of the briquettes (PL 0-05). The highest mean value of 33.52 MJ/kg was obtained when medium sized particles was used followed by 33.32MJ/kg and 33.30MJ/kg obtained when fine coarse particles are used (Table 6).

The level of binder used was also found to significantly influenced the heating value of the briquettes (p = 0.021) (Table 5).

Similarly, it was observed that the heating values of the briquettes increased with increase in the level of binder used and reached the peak when the binder level was increased to 20% after which further increase in binder level resulted in decrease in heating value (Table 6). Thus, the highest mean value was 20% closely followed by 33.37mj/kg and 33.35mj/kg obtained when 15% and 25% binder levels were used respectively (Table 6).

The influence of the interaction between binder level and particle size on the heating value of the briquettes is illustrated in Figure 6. The values obtained were found to be higher when compared with 14.1MJ/Kg in maize cob briquettes (Wilaipon, 2007) and 18.89MJ/Kg obtained in banana peel briquettes (Wilaipon, 2008). The heating value is an indication of the quantity of fuel required to generate a specific amount of energy.

Conclusion

From the results of this study, it is evident that briquettes can be satisfactorily produced from low density agricultural residue like wheat offal. Thus based on the findings from this study, the following conclusion can be drawn;

1. The density, relaxed density and relaxation ratio of the briquettes were significantly affected by particle size. Also both particle size and binder levels influenced the Moisture content and equilibrium moisture content of the briquettes.
2. The result of the combustion properties shows that particle size, binder level and their interaction had no significant effect on the following: i. Volatile matter with better performance in medium particle and at 15% binder level. ii. Ash content was preferable in medium particles at 10% binder level. iii. Fixed carbon was also better with medium particles at 20% binder level, while iv. Heat value was influence by particle size and binder level with medium particles at 20% level of binder.It is observed that better and combustible briquette can be obtained from medium particle of wheat offal at low quantity of binder.

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