

Production and Performance Evaluation of Pedal Operated Pressed Briquettes

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ABSTRACT

This paper treats the production and performance tests of pedal operated pressed briquettes of about 220 mm x 80 mm x 67 mm using agricultural and wood wastes. The densification was achieved by using some mechanical pressure to reduce the volume of vegetable matter and its conversion to a solid form within a pedal operated briquette press designed and constructed for that purpose. The characteristics values of the briquettes such as the effects of the binder proportion in the briquette and its effects on the combustion properties were investigated using ASTM methods. The calorific value of the briquettes ranged between 11.50 MJkg⁻¹ and 14.02 MJkg⁻¹, making them suitable for use as supplementary fuel in small scale industries such as bakeries. It was observed that the percentage composition of the binder greatly affects the friability index of the briquette. The resistance to humidity also played an important role in the briquette combustion abilities. This briquetting technique of agro-residues is one sure way of fighting climate change and provides a sustainable energy source due to the fact that it reduces dependence on fossil fuels and converts waste materials to wealth.

Keywords: agro-residues, biomass, briquette, combustion characteristics, sustainable energy.

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I. INTRODUCTION

Throughout the world, the cost of energy sources, their availability and impact on the environment are major causes for concern. Briquetting can be used as an alternative to fuel-wood as the demand and adverse environmental effects of the latter, especially in the developing country continue to rise as a result of increasing population. According to the World Health Organisation (WHO) [1], more than two billion people use biomass for cooking food, while the smoke from burning biomass is one of the fourth leading causes of disease and death in the world's poorest countries. Although the importance of biomass briquettes as substitute fuel for wood, coal and lignite is well recognized, the numerous failures of briquetting machines in Thailand, Sri-Lanka, Kenya, Sudan, Brazil and almost all developing countries have inhibited their extensive exploitation [2]. Inegbenebor [3] compressed fibrous agricultural and wood waste materials with suitable adhesive into solid fuel briquettes in a compressing machine. Nine samples of fibrous waste materials were prepared into different categories: category A (100% sawdust, 100% rice-husk, 50-50% rice-husk/saw-dust using starch as adhesive). Category B (100% saw-dust, 100% rice-husk, 50-50% rice-husk/saw-dust using gum Arabic as adhesive) and Category C (100% saw-dust, 100% rice-husk, 50-50% rice-husk/saw-dust using bentonite as adhesive). Results from a water boiling test (WBT), involving comparison of the burning abilities of the solid fuel briquettes and fire wood of the same quantity (200 grams) in boiling 1.5 litres of water showed that the solid fuel briquettes bound with each of the three adhesives; bentonite, gum-Arabic and starch; boiled water to 100°C (373 K) within a period of 14 to 22 minutes, while firewood did so within a period of 22 to 27 minutes. Aris *et al.* [4] focused on the development of briquettes from oil palm waste to enhance its utilization as fuel. Several aspects of improvement to the physical properties as well as energy content were taken into account in the study. A total of eight tests were conducted for different ratios of shell, fibre and binder mixtures as well as varying the type of binder material used. Varying briquettes pressing pressure were also considered in these tests. Results showed good physical properties in terms of durability, impact and compressive strength for a 36:54:10 ratio by mass of fibre, shell and waste paper briquette with 5.7% ash 5.24% moisture content. The gross calorific value of 22.4MJkg⁻¹ indicated good energy content of the briquette. The briquette pressing pressure of 159 MPa was used after discovering that it had an outright positive effect on almost all physical and energy components for all combinations and proportions tested. Several aspects of agro-residues and other wastes materials briquetting has received increasing research attention by scholars worldwide [5, 6, 7, 8, 9, 10].

Therefore the objective of this study is the production and performance evaluation of agricultural and wood wastes based briquettes of about 220 mm length, using a small pedal operated press designed for that purpose. The physical, chemical, thermal properties and the binder proportions effects of the briquettes were investigated.

II. MATERIALS AND METHODS

2.1. Equipment

A pedal operated briquette press [10], 2 stoves: a local “tripod” stove [11] and a sawdust stove [12]; aluminium pots. A Metler Toledo AB54 weighting machine with limitations of 10 mg minimum and a maximum of 51 grams, a Casio databank stop watch and a tape rule. 100kg of sawdust and rice husk (i.e.: 50kg of sawdust and 50kg of rice husk) was obtained from a saw mill and from a local paddy rice boiler in Maiduguri, Nigeria.

2.2. Methods

To carry out these tests, the sawdust and rice husk were prepared for densification by dividing them into three categories as reported by Inegbenebor [3]. Category A is 100% sawdust, category B is 100% rice husk and category C is 50% sawdust 50%rice husk. Each category was prepared by mixing them with industrial starch as binder as reported by Olorunisola [7]. For each category, six (6) briquettes were produced using the pedal operated briquette press. Physical characteristics of the briquettes, like density, length before and after drying were evaluated. The premixed fibrous waste and binder of mass (m) was weighted by means of a weighting balance and the fed into the mould through the space between the compactors and the mould until the mould is completely filled up to an initial height(H). The machine was then operated to compress the fibrous waste in the mould. After the compression, briquettes were ejected and the final height (h) was measured and recorded. Also the time (t) taken for the operation is recorded using a Casio databank stop watch. The performance of the machine was then determined using the following formulae:

$$\text{True density } (\rho_t) = \frac{M}{V} \text{ --- (1)}$$

$$\text{Apparent density } (\rho_a) = \frac{M}{V_o} \text{ --- (2)}$$

Percentage increase in density of compressed briquette; η_d

$$\eta_d = \frac{\rho_t - \rho_a}{\rho_a} \times 100\% \text{ --- (3)}$$

Machine capacity, c

$$c = \frac{N \times 60}{t} \text{ per hour --- (4)}$$

$$\% \text{ Shrinkage} = \frac{V - V_f}{V} \text{ ----- (5)}$$

where:

M= mass of mixed fibrous waste, kg;

H=height of mould,

h=height of compressed briquette, mm;

t = time taken to complete one operation, minutes;

A_o =area of mould, m^2 ;

V_o =volume of mould, m^3 ;

V= volume of compressed briquette, m^3 .

V_f = volume of briquette after drying, m^3 .

ρ_t =true density of briquette, kgm^{-3}

ρ_a =apparent density of briquette, kgm^{-3}

N = number of briquette per operation.

2.3. Proximate analysis.

The proximate analysis determines the moisture content (M_o , in weight percent (w/o)) by driving off the free moisture at $\sim 107^\circ C$ for approximately one hour. The volatile matter content (V' , (w/o) is determined by driving off volatile hydrocarbons CO, CO_2 and combined H_2O at $\sim 950^\circ C$. The briquette sample is then burned and the inorganic residue is the ash content (A' (w/o). The fixed carbon ($C_f(\frac{w}{o})$) is then calculated by difference [13].

$$C_f(\frac{w}{o}) = 100 - \left[M'(\frac{w}{o}) + V'(\frac{w}{o}) + A'(\frac{w}{o}) \right] \text{ ----- (6)}$$

2.4. Heating or calorific value.

The ash free lower calorific value (LCV) can be calculated to within 2% accuracy by using the Barnard [14] equation:

$$LCV = 18.7 \times (1 - A' - M') - 2.5 \times M' \text{ ----- (7)}$$

LCV----- MJ/ kg while elements are in weight %

Furthermore, open burning tests were conducted using two types of stoves; the local “tripod” fuel wood stove and the sawdust stove under two different conditions:

- a.) In a confined not well aerated space and;
- b.) In an open space.

2.5. Friability and humidity tests.

Friability and humidity tests were carried out on the samples based on their binder content and not the nature of their constituents, using the Centre des Recherches Agronomiques (CRA) [5] method. The friability test was done by repeatedly dropping the samples from a specified height, while the humidity test was done by wrapping the samples in an aerated grains storage bag for 21 days and placed in a damp environment. The wrapping was to avoid direct contact with water. The disintegration level due to impact with respect to the whole sample size is the characteristic of importance. In the humidity test too, disintegration (due to humidity) and percentage elongation are the most important parameters.

III. RESULTS AND DISCUSSION

The machine was able to produce 120 briquettes per hour. Figure 1 shows the three (3) categories of briquettes based on composition.

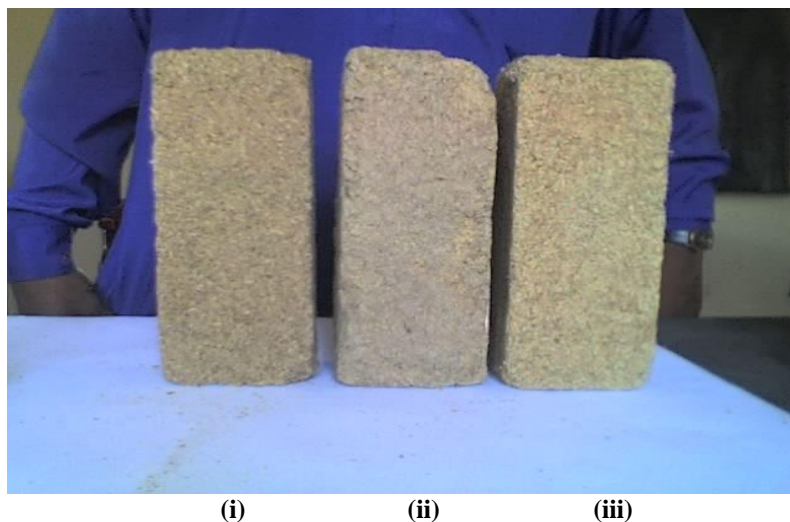


Figure 1: produced briquette samples: (i) 100% sawdust (ii) 50% sawdust-50% rice husk (iii) 100% rice husk.

The results of the unbroken and broken briquette combustion tests are respectively as follows:

1a.in a confined space; a heavy smoke was observed to be accompanying the flame.

1b.in an open space; less smoke was produced than the previous tests.

2a.in a confined space; broken into 20 pieces; a slightly reduced smoke was observed to be accompanying the flame.

2b.in an open space; broken into 20 pieces; it was almost smokeless.

Inegbenebor [3] found that the solid fuel briquettes burnt with yellow flame with moderate black smoke, indicating incomplete combustion due to poor air-fuel ratio. He could not ascertain the reason for that. However, our results show that solid briquettes (SB) cannot burn satisfactorily in the combustion appliance of a particular customer; they are indeed unsuitable for some cook stoves and give excessive smoke unless broken into small pieces of 50-60 mm thickness a bit bigger than the 10-20mm thickness suggested by Grover & Mishra [15]. It is difficult to find a situation where consumers are prepared to shift to new appliances to suit a given design. A much more adapted briquetting machine would be needed to suit a particular requirement, need or family; simply showing that briquetting would be a successful family or community affair, which shares common things. A slight rather persistent brownish change in colour was observed with the category C briquette containing more binder (Figure 1). However, it was a little bit smokier than the remaining categories. When broken into pieces a much lower smoke was noticed, which has to do with their shape and sizes as well as areas of utilization. This may even attract the design of a machine to produce readily available small size briquettes (i.e. 50 to 60 mm size). Most of the developing countries in the study area produce sugar cane, millet, sorghum, wheat and groundnut. Shrinkages (table 1) were noticed and the final sizes of the briquettes upon drying were observed to be 215mm x79 mm x 65mm, 215mm x 78mm x 65mm and 210 mm x 80mm x 67 mm for samples A, B and C respectively. This slight change in sizes has to be attributed to the binder content as a function of

porosity and not the composition since sample A is 100% sawdust, sample B 100% rice husk also while sample C is 50/50 sawdust/rice husk. Pressure could have been another reason for the shrinkages if it was not a uniform one applied for all compactions processes. Changes in the sizes were not proportional as shown by the percentage shrinkages in Table 1, with changes in lengths being the most important and easily noticeable.

Table 1: Length variation in briquette samples

	Sample A	Sample B	Sample C
Initial length, L_0 (mm)	220	220	220
After drying length, L_f (mm)	215	215	210
% volume shrinkage	6.37	7.56	4.54

To test the briquettes' resistance to humidity, the briquettes were kept in a relatively damp environment for three (3) weeks. No increase in the friability was noticed but this should not be seen as a conclusive test; there is need to carry out a pressure test on hydraulic pressure ram. The proximate analysis of the briquette sample is as shown (Table 2).

Table 2: proximate analysis tests results

	Sample A	Sample B	Sample C
Moisture (% mass)	15.411	17.110	17.215
Fixed carbon (%)	10.026	13.550	18.853
Volatile matter (%)	66.528	49.099	48.793
Ash (%)	8.035	20.229	15.135

Sample A with lower ash content is better followed by samples C and B respectively (Table 2), thus showing better combustion characteristics. The calorific values (Table 3) of the briquettes are high enough to withstand any given process and even contribute as a supplementary fuel for incineration process in the case of low calorific value fuels.

Table 3: Average Calorific values of the briquette samples

	Sample A	Sample B	Sample C
Calorific value (MJ/kg)	14.024	11.500	12.229

The average true and apparent densities (table 4) were also found to be 338.2 kgm^{-3} and 263.04 kgm^{-3} respectively.

Table 4: Results of performance tests.

S/No.	Mass of Fibrous waste (kg)	H(mm)	h(mm)	$V_o m^3$	vm^3	ρ_t	ρ_a	η_d
1	1.25	90	70	4.752	3.696	338.2	263.0	28.6
2	1.28	90	70	4.752	3.696	346.3	269.4	28.5
3	1.21	90	70	4.752	3.696	327.4	254.63	28.59
4	1.24	90	70	4.752	3.696	335.5	260.9	28.58
5	1.27	90	70	4.752	3.696	343.6	267.26	28.6
average	1.25	90	70	4.752	3.696	338.2	263.04	28.58
	(0.027)*					(7.394)*	(5.779)*	(0.043)*

*standard deviations.

Upon friability tests, partly disintegration was noticed on the sample with low binder content. The remaining samples showed vary little disintegration which was found to be reducing as the higher binder content sample was tested. Inherent binders and most externally added binder are water soluble [2]. This is the reason why the sample could not be subjected to direct water contact but the former method adopted. Disintegration was noticed too on the lower binder content together with a 4 mm elongation, approaching the initial length before densification. The sample with the highest binder content remained unaltered if not for the fungus that started forming on its surface; this analysis has shown that the briquettes could be transported over long distances in Lorries for use not near their production site if produced with the optimum binder content. Furthermore, the percentage elongation appears to be inversely proportional to the binder content in a sample. To these results

should be added the fact the working pressure plays an important role even though its effect has not been thoroughly investigated in this work.

IV. CONCLUSION

The briquetting technology will enable agricultural waste to be removed from the environment, thereby preventing environmental pollution.

The calorific value of the produced briquettes was found to range from 11.50 to 14.02 MJ/kg, making the fuel briquettes suitable to be used as supplementary fuel in small scale industries.

The briquettes were found to have a good resistance to humidity as the binder content increases.

Briquettes size affects the burning of the briquettes i.e.: the smaller the size of the briquettes the more efficient was the burning.

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