Evaluation of briquettes produced from maize cob and stalk

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Abstract. This study seeks to investigate the performance of maize cob and maize cob with stalk (with a mix ratio 2:1; 200 g shelled maize cob: 100 g of maize stalk) briquettes as fuel source for domestic cooking. The two residues were individually chopped into small pieces using a hammer mill and a 0.6 mm particle size was utilized for the purpose of this work. Cassava starch was used as binder with mix ratio of 2:1 (Residue to Binder). A briquetting mold was used and residues were compressed into briquettes using a manual hydraulic press. Performance tests showed maize cob with stalk briquettes performed better with a higher cooking efficiency (17.3 %), fuel efficiency (19.78 %) and low fuel consumption (0.97 kg/hr) and boiling time of 20 mins. These results were significant at 5 % level of significance. Maize cob briquettes had higher calorific value (17.8 MJ/Kg) and higher fuel consumption rate (1.3 kg/hr), but had lower cooking efficiency (10.28 %) and fuel efficiency (12.8 %) with a boiling time of 15 minutes. The smoke emission using the briquettes was highly reduced. The crop residues used significantly affect the performance of the developed briquettes. Maize cob with stalk briquette was preferred due to its high cooking efficiency, fuel efficiency and low fuel consumption.

1. Introduction

The consistently growing population, high price and unavailability of some sources of energy have triggered the need for renewable sources of energy. The burning of forest woods as a replacement to fossil fuel and electricity for domestic and industrial uses has led to a drastic reduction in the land mass of Nigeria’s forest [1]. In year 2013, 3.7% was the estimated rate of deforestation in Nigeria, which according to the United Nation Collaborating Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries, is one of the highest in the world [1]. The direct burning of loose biomass to generate power in place of fossil fuel and electricity results in widespread air pollution and low thermal efficiency. To address these issues the use of briquettes as fuel was developed, it’s a technology that has been adopted in several countries, especially in developing nations [2]. Briquettes are blocks of solid materials that are highly flammable and are used as fuel to generate energy [3]. Briquetting is a densification process that is carried out to improve biomass and handling characteristics of raw materials, thereby enhancing the volumetric calorific value of the biomass [4]. Briquettes have gross calorific value of up to 4200Kcal/kg, and about 2.2 Kg of briquettes are equivalent to 1 litre of furnace fuel. Briquettes are good substitute for wood, because of their consistent quality which can enable a price premium to be obtained over wood [5]. Briquettes as an alternative source of fuel are developed through the use of biomass which is mostly waste materials like agricultural waste and industrial waste. Waste is a great resource if properly managed and this can be done by recycling waste materials [5]. The breakdown of waste generation in Nigeria has been
quantified as follows: municipal solid waste \((4075 \times 10^6 \text{ tonnes})\), fuel wood \((38.1 \times 10^6 \text{ tonnes})\), agro waste \((11.24 \times 10^6 \text{ tonnes})\), and sawdust \((1.8 \times 10^6 \text{ tonnes})\). [6] reported that maize waste constitutes about 3,423 tonnes of the total agro waste, about 80% of maize produced ends up as waste (maize cobs and stalks) [7]. These claims motivated the use of maize residues as the raw material for briquette production. Some other agro waste have been used by several researchers; [4] used banana peel for production of briquette; [8] compared two briquette source (corn cob and rice husk); [9] evaluated briquette produced from two species of corncob; [10] did a comparative assessment of energy values from some agricultural wastes (maize cob, rice husk, groundnut shell, and sugarcane bagasse); [11] studied the combustion properties of briquette produced from maize cob with different particle sizes; [1] produced briquette from elephant and spear grass; [2] produced briquette from low grade coal. A comparative usage of maize cob and maize stalk has not yet been reported. The objectives of this study are; (i) production of briquette from maize cob, and a combination of maize cob and stalk (ii) evaluation of the produced briquettes as fuel source.

2. Materials and Methods

2.1 Materials

Maize stalks and cobs were harvested from Landmark Un iversity Teaching and Research Farm, latitude \((8.1239^\circ \text{N})\) and longitude \((5.0834^\circ \text{E})\). Cassava starch used as binder was sourced from a local market in Omu-Aran, Kwara State, Nigeria. Water, Oven, Moisture analyzer, Weighing balance, Thermometer, Measuring cylinder and Beaker, Lighter, Stop watch, Mixing bowl and Sieve were the materials also used during the research.

2.2 Method

2.2.1 Sample Preparation. The samples were milled with a hammer mill and further sieved to the required particle size of 1.2 mm. The sieved residue was mixed with measured quantities of starch (selected binder for the agglomeration) at a specific ratio 2:1 (Binder to Residue) and thoroughly mixed in separate bowls labeled A and B. Sample A consists of shelled maize cob and sample B contains maize stalk + cobs in the ratio 1:2 (that is, 100g of maize stalk to 200g of shelled maize cobs). A briquetting mold in Figure 1 \((240 \times 160 \times 5 \text{ mm})\) was used for molding the briquettes. The mold was filled with the prepared samples and smoothed at the surface to obtain a leveled top. Pressure was exerted manually by the hydraulic press as in Figure 2 through the mold cover press. The already formed briquette was ejected from the mold onto a flat surface for drying to reduce existing moisture content to a minimum of 8% and a maximum of 10%.
Figure 1. Isometric view of the briquette mold

Figure 2. Briquette undergoing compression

2.2.2 Laboratory analysis. The following laboratory analysis was carried out using the produced briquettes to evaluate the burning characteristics;

Fuel efficiency

The fuel efficiency of the briquette was determined by the ratio of heat transferred to the cooking medium to the heat supplied by the briquettes. This was determined by using Equation 1 as suggested by [12].

$$\eta_f = \frac{M_{w,i} \times c_{p,w} \times (t_e - t_i) + M_{w,exp} \times H_l}{M_f \times H_f}$$

(1)

Where; $\eta_f$ = fuel efficiency (%), $m_{w,i}$ = initial amount of water in the pot (kg), $c_{p,w}$ = specific heat of water (4.2 KJ/kg°C), $t_e$ = temperature of boiling water (°C), $t_i$ = initial temperature of water (°C), $m_{w,exp}$ = amount of water evaporated during experiment (kg), $H_l$ = heat of water evaporation of water at atmospheric pressure at 100°C (2,260KJ/kg), $M_f$ = amount of fuel burnt (kg), $H_f$ = combustion value of fuel used (MJ/kg).

Cooking efficiency
Cooking efficiency is the ratio of useful heat output to the heat input into the stove. This was evaluated by using Equation 2 as given below:

\[ \eta_c = \frac{M_w \times h_l}{M_f \times C_f} \]  

(2)

Where; \( \eta_c \) = cooking efficiency (%), \( M_w \) = mass of water evaporated (Kg/hr), \( h_l \) = heat evaporation of water at atmospheric pressure at 100°C, \( M_f \) = fuel consumption rate (kg/hr), \( C_f \) = heat value of fuel (MJ/kg)

Fuel consumption rate

This is the rate at which briquettes of various fuel samples were burnt and was determined by Equation 4 below:

\[ M_f = \frac{W_i - W_f}{t} \]  

(3)

Where; \( M_f \) = fuel consumption rate (kg/hr), \( W_i \) = initial weight of fuel before combustion (kg), \( W_f \) = final weight of fuel after combustion (kg), \( t \) = total boiling/cooking time (hour)

Calorific value

The calorific values of the samples was calculated using the Equation 4

\[ HCV = 20 \times (1 - A - M) \]  

(4)

Where HCV= Gross (or Higher) Calorific Value (MJ/Kg), \( A \) = Ash content (%), \( M \) = Moisture content of the actual fuel (%).

The lower (or net) calorific value, which takes into account unrecovered energy of the water vapor from inherent moisture and from the oxidation of the hydrogen content, is sometimes used for reference purposes, especially in industrial applications:

\[ LCV = 18.7 \times ((1 - A - M) - (2.5 \times M)) \]  

(5)

Where LCV= Lower Calorific Value (MJ/Kg), \( A \) = Ash content (%), \( M \) = Moisture content of the actual fuel (%).

2.2.3 Statistical Analysis. The statistical tool used in the analysis of this work is the independent sample T-test and all result interpreted at 5% level of significance. This tool was used to compare the sample means of fuel efficiency, cooking efficiency, boiling time and fuel consumption rate for briquette samples in order to determine whether there is any significant difference between the two fuel samples.

3. Results and discussions

3.1 Physical properties of produced briquette

Results of the determination of physical properties of maize cob and maize cob plus stalk briquettes are shown in table 1, while the result of performance evaluation of the two fuel types examined is presented in table 2. From the result of properties of briquettes, the moisture content of maize cob briquette was 9.71%, while the moisture content of maize cob plus stalk briquette was 9.89%. [13] and [14] recommended limits of 15 % for briquetting of agro-residues. Thus, this result is within the limit.

Table1. Properties of the briquettes produced

| Parameters | Sample A (maize cob) | SampleB (maize cob + stalk) |
|------------|----------------------|----------------------------|
|            |                      |                            |
The physical properties of the briquettes produced are distinguished by the colour or outward appearance. The briquette sample A is light brown while sample B had a deep brown colour (Figure 3). The deep brown colour of sample B is as a result of the presence of maize stalk.

![Figure 3. Samples A and B briquettes](image)

### 3.2 Performance evaluation of the fuel samples

As stated in methodology, all results were subjected to independent sample T-test at 5%. Results in Table 2 clearly indicate significant difference for Cooking efficiency, Fuel consumption and Fuel efficiency. Briquettes from maize cob plus stalk performed better on overall scale. However, there was no significant difference between both fuel types for LCV and HCV.

| Fuel Sample | Cooking Efficiency (%) | Fuel Consumption (kg/hr) | Fuel efficiency (%) | Boiling Time (mins) | LCV (MJ/Kg) | HCV (MJ/Kg) |
|-------------|------------------------|--------------------------|---------------------|---------------------|-------------|-------------|
| A           | 10.28 ±0.10            | 1.30 ±0.05               | 12.76 ±0.13         | 15 ±0.02            | 16.4 ±0.09  | 17.8±0.05   |
3.3 Effect of fuel samples on boiling time

Boiling time for sample A took an average of 15 minutes while sample B took an average of 20 minutes to boil 1.9 Kg water at 100°C. The variation of the boiling time had a significant difference (P-value<0.0001) at a significant level of 5%. This indicates that corn cob briquette had a higher heating value as compared to when in composite with corn stalk. [15] reported that as the percentage of the spear grass in composite with the coal briquette increased, lower boiling time was recorded but it got to a point when fluctuating boiling time was observed.

3.4 Effect of fuel samples on fuel consumption rate

The fuel consumption rate of sample A and B was 1.3kg/hr and 0.93kg/hr respectively. This was defined by the rate of amount of fuel burnt to the time taken to boil water at 100°C. There was a significant difference in the fuel consumption rate with P-value less than 0.0001. This result indicates that corn cob briquette is being consumed faster than corn cob/stalk briquette during usage. This result was in agreement with that reported by [15]. It was reported that as the percentage of the spear grass in the coal briquette increased the consumption rate reduced.

3.5 Calorific value

There was no significant difference in calorific values of both briquette types. Sample A had a maximum calorific value of 17.8 MJ/Kg and sample B had a maximum calorific value of 17.4 MJ/Kg. These values were slightly lower than the maximum calorific value (33.703MJ/Kg) recorded by [10] for groundnut shell and cassava peels.

3.6 Smoke/flame emission

It was observed that the briquette samples produced very little amount of smoke during combustion (Figure 4) with a controllable level of flame for heating unlike firewood that produces high level of smoke. The briquettes undergo combustion with little amount of wind speed while firewood requires a high amount of wind speed for flame production resulting to high flame production. No stain was observed on the pot with the use of briquette samples unlike firewood.
4. Conclusion

Findings of this study have shown that, the briquettes produced from maize cob and maize cob + stalk would make good biomass fuels as these briquettes showed extremely low level of smoke emission with no form of irritation unlike firewood which produces high level of smoke emission thereby posing a threat to the health and safety to users. Maize cob+ stalk briquettes had a higher cooking and fuel efficiency; fuel consumption was also lower than maize cob briquettes. There was no significant difference in calorific values of both briquette samples. Boiling time was 15 and 20 minutes for maize cob and maize cob + stalk respectively. With emission highly reduced, the potentials of this alternative energy resource should be fully explored especially for rural domestic cooking.

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